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POTATO BLIGHT EPIDEMICS

Throughout the World

Agriculture Handbook No. 174
UNITED STATES DEPARTMENT OF AGRICULTURE

POTATO BLIGHT EPIDEMICS

Throughout the World

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FOREWORD

Among the important diseases of major food crops the late blight of potato is one of the most difficult for us to understand and combat. Despite the intensive studies that have been devoted to it, the conditions for blight occurrence are still not thoroughly known. Frequently, a severe unexplained outbreak of the disease, or its appearance in a region where it was previously unknown, revives problems that had been considered already solved or raises new questions.

Observations wherever the disease appears throughout the world contribute knowledge for better understanding and solution of these problems. This worldwide account of recent epidemics of potato late blight provides a useful background of epidemiological information. This Handbook is the first review of conditions associated with late blight outbreaks throughout the world. Its length is due to the inclusion of the detailed information that is necessary to permit comparison between regions and correlation with climatic data. The detail cannot be omitted without lessening the precision and therefore the usefulness of the data.

We gladly acknowledge our indebtedness to the authors who undertook this arduous task, and to others of the Plant Pathology Laboratory, Ministry of Agriculture, Fisheries, and Food, Harpenden, England, who made this study possible.

The inception of this collaborative effort was a joint consideration between the Crop Plant Disease Forecasting Project of the Crops Research Division, Agricultural Research Service, United States Department of Agriculture, and the Department of Plant Pathology, University of Wisconsin, Madison. The program was administered by the Wisconsin Alumni Research Foundation with funds for conduct of the work provided by the United States Government.

The results of this extensive study should be useful to plant pathologists throughout the world and especially to the many plant pathologists of the Crop Plant Disease Forecasting Project. It is hoped that the review will provide a basis for additional studies on the impact that plant diseases have on crops and the subsequent economic conditions in various parts of the world.

M. W. Parker

Crops Research Division
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PREFACE

This study was made possible by the Wisconsin Alumni Research Foundation, U.S.A., which administered funds for the purpose. Through the efforts of A. J. Riker, University of Wisconsin, who was especially interested in assembling world data about important epidemic plant diseases, the authors were able to undertake a comprehensive review of recent epidemics of potato blight throughout the world. A. E. Cox, agriculturist, and E. C. Large, plant pathologist, Plant Pathology Laboratory, Ministry of Agriculture, Fisheries, and Food, Harpenden, England, under the direction of W. C. Moore, of that Laboratory, worked jointly in making contacts with specialists, in assembling the data, and in preparing the report. The maps and diagrams were prepared by V. J. Pearson, of the above-mentioned Laboratory.

The material on which this world study of potato blight has been based was derived in part from published literature, but to a far greater extent it has been based upon unpublished information generously provided by leading workers in different countries and from England and Wales, verbally or in correspondence with the authors. The help sought by the authors has always been most readily given and has varied greatly in kind. Special acknowledgments are made to the library of the U. S. Department of Agriculture and to the following specialists:

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INTRODUCTION

Over a century has now passed since the potato late blight fungus, Phytophthora infestans (Mont.) de Bary, found its way from the New World to the Old, and first ravaged the potato crops of Europe. Since 1845 the fungus has been the subject of innumerable studies: The commonly occurring stages of its life history and the phases of its parasitism upon its solanaceous hosts are now well known; but, like the true cryptogam that it is, it still contrives to conceal much from human scrutiny. After more than a century of search its sexual reproduction by means of oospores has only recently been found occurring on potato plants in the field--in Mexico. The means by which it succeeds in producing new races or strains elsewhere in the apparent absence of a sexual phase remains a subject of disputation. The relations between sporulation and spread of the fungus and the microclimatic conditions within potato crops are now under active investigation but are still very imperfectly known; real progress in blight forecasting has been made in recent years, but forecasting is still upon an empirical basis. A vast expense of money and labor goes each year upon control measures, but our debt to the partial blight resistance of some varieties cannot be realized and the rationale of spraying in relation to the frequency and nature of the epidemics is still imperfectly understood.

Of all the mysteries of potato blight that will surely be engaging agriculturalists, plant pathologists, and plant breeders for generations yet to come, perhaps the greatest, and certainly the most economically important, is the real extent and magnitude of the losses that the disease causes among the potato cultivations of the world. There is an intrinsic difficulty in measuring the incidence and the effects of any plant disease over extensive areas, and the branch of plant pathology concerned with such work is still in its infancy. It is only in very few countries of the world that there is sufficient field survey information to define the courses of the blight epidemics or to support even approximately accurate estimates of the losses they cause. At present, very little precise information is available.

The objective of this study is (1) to explore as far as possible the findings in those countries where special surveys have been made; (2) to draw attention to the methods used; and (3) then to apply the results in principle for the interpretation of such scattered information as is available in other countries, to provide the beginnings of a mid-twentieth century conspectus for the world. It cannot be put higher than that; a little has been done, more remains to be done, and it will have to be done in the field.

It would be idle to attempt to describe potato blight epidemics except against the background of the distribution and climatic requirements of the potato cultivations in which they occur. To do this for all countries, and for all the differing regions in countries extending across whole continents, could not be profitably attempted in a couple of years. This study is therefore confined to a limited number of countries, and regions within those countries, which among them probably experience most of the types of epidemic that occur in the world. For each country studied a fairly full section or case study was compiled, after first setting forth some very brief general observations on the potato as a world crop, and on the life history of the fungus, for the assistance of interested readers who may be neither professional agronomists nor plant pathologists.

An indication of the world distribution of potato growing is given in figure 1. In general, principal areas of production were chosen for the closest study. However, in view of the recent introduction of potato blight into a number of countries where it was previously unknown--a second wave of world dispersal related to the speeding-up of communications, expansion of agriculture and commerce, and troop movements of this twentieth century--some countries where relatively few potatoes are grown but where interesting or alarming epidemics have occurred were included. Some countries are also included to exemplify limiting conditions both for the crop and for the occurrence of the disease. A map showing the world distribution of Phytophthora infestans on potatoes is already available (Commmonwealth Mycological Institute (C.M.I.), 1954;[1] the distribution of the fungus is now for all practical purposes coincident with that of the potato itself. Serious losses from the disease on outdoor tomatoes have occurred in recent years in many countries, but the world distribution and present status of tomato blight has already been investigated (Miller and O'Brien, 1955), and the disease on tomatoes is referred to only where it is of particular importance as a link in the chain of infection of potato crops.

In the section on each country the extent and distribution of potato growing, the importance of the potato in the country's food supplies, the principal varieties grown, the nature of the cultivations, and the times of planting and harvesting are given first. Then the cropping periods are related to the long-term average rainfall and average daily mean temperature for each month of the year at

[1] References to Literature Cited (p. 207) are herein indicated by the name of the author (or authors), followed by the year of publication.

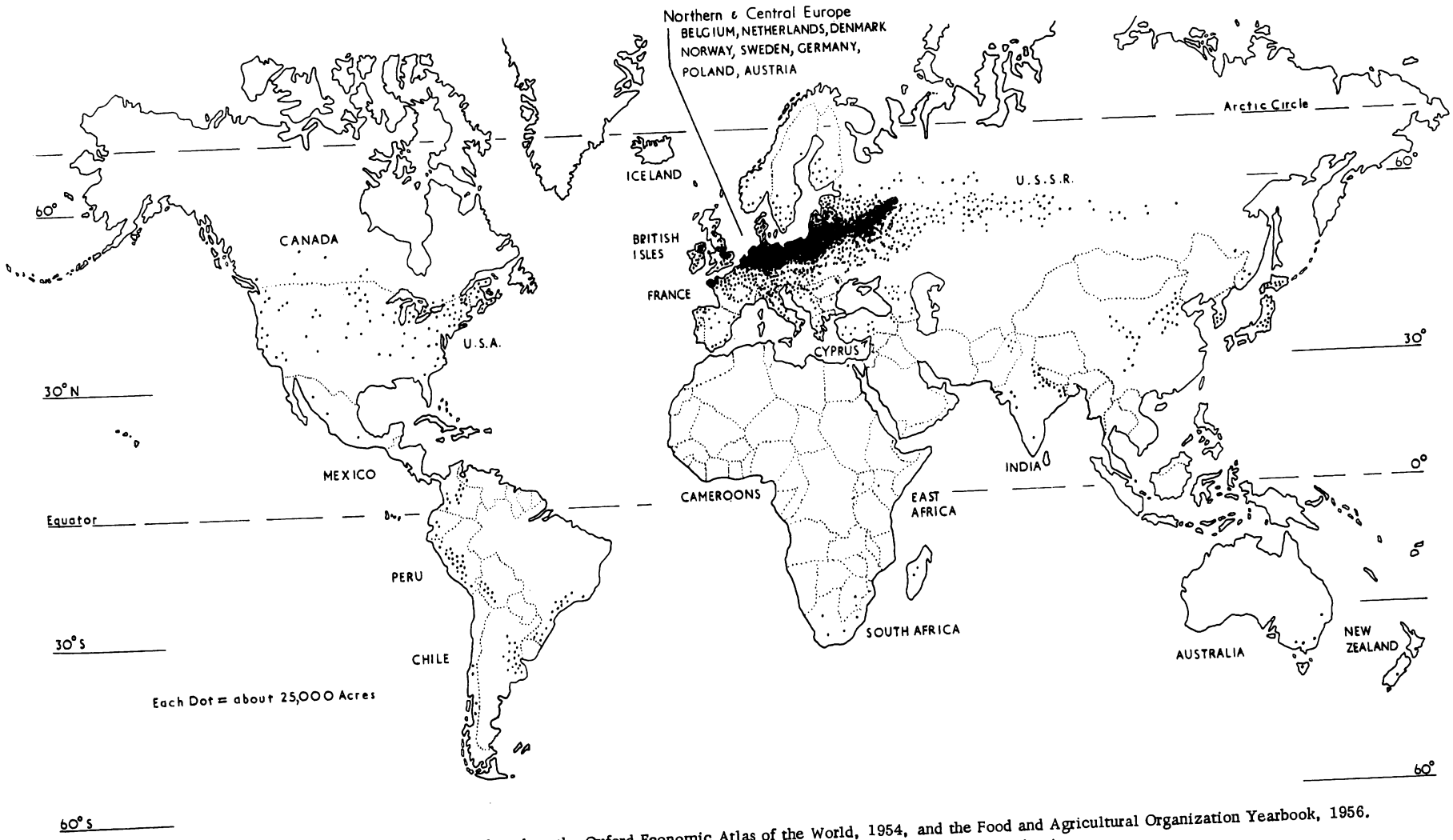


Figure 1.--World distribution of potatoes, based on the Oxford Economic Atlas of the World, 1954, and the Food and Agricultural Organization Yearbook, 1956. Countries named are those included in the present study of potato blight epidemics.

representative weather stations. For this purpose a number of small "climagrams" were constructed to show up as clearly as possible similarities and differences in widely separated parts of the world. The explanatory notes on the climagrams given in figure 2, are important not only in helping to define cropping conditions, but also, later, in revealing the mean temperatures and rainfall associated with the several types of blight epidemic. These climagrams show only the mean temperature line. The diurnal range of temperature also affects cropping and the incidence of blight, but this and other climatic factors are discussed in the text. Fuller relevant information on climate is available in Kendrew (1937).

No attempt is made in the climagrams to portray humidity conditions, although low temperatures in relation to latitude often reflect the modifying effects of cloud and coastal or mountain fog. Very detailed humidity observations at frequent intervals during the day are needed to reveal the actual incidence of "blight weather." For those few countries where such observations have been made, the findings, and the methods used, have been described in detail; but only very cautious inferences can be drawn from humidity data available for the rest of the world. Average humidities are among the most unreliable of climatic parameters.

The incidence of potato blight in each country or region is determined by the frequency with which "blight years" occur and by an account of what constitutes a "blight year" in that particular locality, in terms of the stage in the growing period at which the potato plants are defoliated by the disease, and also in terms of the consequent effect on total yield and on blight infection of the tubers. Some countries had considerable data; in other countries statements were obtained that in such and such years the disease was "severe" on "moderate" or "slight," with little to define such terms, except perhaps the results of a few spraying trials and some clues from scattered observations on the foliage. In some other countries, as in England and Wales, during recent years systematic surveys on hundreds and sometimes thousands of crops were made each year, and these surveys were condensed and summarized. In general, epidemics for the period 1947 to 1956, inclusive, were reviewed; but where important series of trials were made over sequences of years before that, the earlier trials were sometimes included.

Where possible the unrestricted epidemics occurring on unsprayed crops--usually principal maincrop varieties--are described. Then the modifying effects upon the epidemics of any spraying or other control measures adopted in the country, with practical particulars of those measures and the extent to which they are used, are shown. Under control measures not only protective and destructive spraying are considered but also the far more subtle and often almost unconsciously adopted measures that become more apparent from a study of the blight epidemics themselves, such as measures of disease escape, retardation of infection by the avoidance of overlapping cropping, and the like.

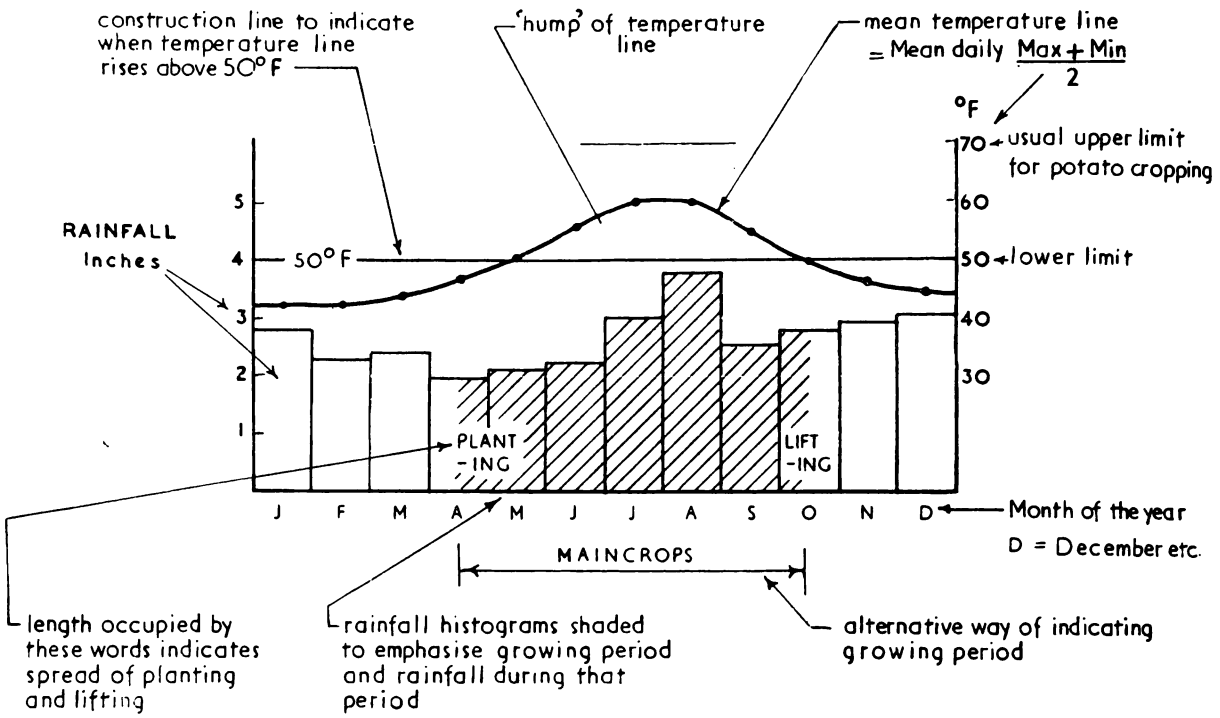
The work of the past quarter of a century on attempts to breed blight-immune varieties by taking advantage of the genes for resistance present in Solanum demissum and other wild potato species; the consequent discovery of new biotypes or races of the blight fungus; and the further stages of attempting to defeat these by search for "field resistance" and other means, are considered briefly in the sections for countries in which the work has been done. The part played by partially resistant varieties, old or new, in modifying the incidence of blight and reducing losses, is a matter most germane to any study of blight epidemics.

Finally, the main findings for each country are summarized briefly at the end of each section. In a final chapter, without attempting a full interpretation of the body of the work, the writers have set out some factors that appear common to blight epidemics in the world as a whole.

POTATOES AS A WORLD CROP

In such a study as this, which by its terms of reference concerns only a single disease, there is a danger of conveying the impression that late blight is the major cause of low yields in potato crops wherever blight occurs and low yields prevail. This is entirely fallacious. Lack of rain, inadequate nutrition, poor cultivation, and virus diseases from poor seed are often far more potent factors. To put matters into perspective, it is necessary to say something of the requirements of the potato crop and its part in world agricultural economy.

Potatoes do best under moist, temperate conditions, where the growing season is long. The greatest concentration of potatoes occurs in northern and central Europe (see fig. 1), and the European continent as a whole contributes about 75 percent of the world's production. The maritime climate of northwestern Europe is almost ideal for potato growing, and it is from this area that the highest average yields (10 tons per acre in the Netherlands and Belgium) are recorded. In many European countries potatoes form a large part of the people's diet. In North America the crop is



NOTES

1. The mean air temperature line is shown. The mean maximum temperature line usually runs 5°–7°F above the mean line, and the mean minimum 5°–7°F below it, in maritime areas. In areas with a continental climate the mean diurnal variation is greater (±9° to ±12°F).

2. The 'hump' of the mean temperature line above 50°F characterises the potato growing season. Its length indicates the period during which there is potato growth above ground. Its height indicates favourability or otherwise of main part of the growing season for tuber production (upper limit about 70°F).

3. In the southern hemisphere December is made to occupy the place of June in the northern hemisphere, so that 'summer' is always in the centre of the diagram.

4. Long-term average figures for each month of the year are generally shown. Portions of the diagram for the cropping season only in individual years of special interest are sometimes shown below.

5. 'Rainfall' includes other forms of precipitation: snow, hail, etc.

Figure 2. --Explanatory notes on the climagrams used in this study.

relatively less important, and the short growing season and high summer temperatures over much of the continent affect yield adversely. Potatoes are a major crop in some South American countries, notably in Peru, parts of Chile, Argentina, and Brazil. In countries on or near the Equator they are grown at high altitudes, as temperatures at low altitudes are too high.

Although the distribution of potato growing is in close accordance with the distribution of population in Europe, North America, and South America, this is clearly not so in the countries of Asia, in many of which rice is the staple food. The largest acreages of potatoes grown in the Far East are in China, India, and Japan, but here it is only in Japan that the crop makes an important contribution to the diet of the people. Potatoes are only a minor crop in Africa, where they are grown principally at high altitudes. The acreage is small in Australasia, but this is chiefly because of a low demand for potatoes due to the small population.

Apart from their use for human food, potatoes are fed to livestock, mainly pigs, and they are used in industry for the production of potato flour (farina) and alcohol. The use of potatoes for livestock is largely confined to those countries where there is a large agricultural labor force. According to the importance of potatoes in the diet of the population, the countries of the world can be divided roughly into four groups. Those with a high human consumption of potatoes (300-400 lb. per head per annum) include a number of European countries--European Russia, Germany, Poland, and France. In each of these countries a large proportion of the total potato crop is fed to livestock and used for industrial purposes. Peru is one of the few countries with a high human consumption of potatoes that has no important alternative outlet for the crop. Countries with a medium consumption rate (200 lb. per person) include Great Britain, Holland, and Sweden. Most of these have alternative uses for potatoes other than the ware market, but in Great Britain surplus potatoes can prove an embarrassment and are only reluctantly taken for livestock feeding. The U.S.A., Canada, and Australia represent countries with a low rate of human consumption (100 lb.). The ware and seed markets are the only outlets for potatoes in such countries, and at the present time the crop is barely holding its ground in the face of competition from other vegetables. Lastly, there are a number of countries where potato consumption is very low (generally less than 20 lb. per head per year). These include India, Pakistan, and Mexico, where potatoes become in effect a luxury crop and their contribution to the national diet is negligible.

The present planting of potatoes throughout the world is about 57 million acres (F. A. O., 1956). This represents only about $12\frac{1}{2}$ percent of the land area devoted to wheat, which is the most important grain crop. There is little international trade in potatoes. This is explained by the bulkiness of the crop, its liability to deterioration during transit, and to stringent important regulations. Nonetheless, some important trade goes on in seed potatoes, notably from Holland, Canada, Ireland, and Scotland. There is also some trade between countries on a small scale in out-of-season potatoes; as, for example, the export of early potatoes to Great Britain from a number of Mediterranean countries.

SOME FACTORS AFFECTING POTATO YIELDS

Climatic conditions, daylength, soil type, cultural treatment, and the incidence of diseases and pests all affect the yield of potatoes. A few of the principal factors have now to be considered individually, as a part of the background of our study, but their interrelationships must also be borne in mind. The optimum water requirement of a potato crop, for example, will depend on temperature and soil conditions, and climate profoundly affects disease and pest attacks.

TEMPERATURE. The work of Bushnell (1925) is usually referred to when considering the optimum temperature conditions for tuber formation in the potato crop (Van der Plank, 1946; Burton, 1948). Bushnell found that maximum tuber production occurred over the temperature range 59°-64° F., but his experiments were conducted with plants grown at constant temperature, a state of affairs very different from that in nature. However, it would seem that if Bushnell's limits are slightly widened, say to 58°-65°, this range represents the usual condition occurring in practice during the latter part of the potato-growing season in those parts of the world, notably northwestern Europe and northeastern North America, where the largest potato yields are produced. The many climagrams given in following sections bring out this point. The temperatures during the last 2 months before lifting are most important, as it is then that the bulk of the crop is formed.

Potatoes are intolerant both of high temperatures and of frost. Bushnell (1925) found that tuber production ceased at 84°F., and Bald (1941) has said that in areas of Australia where mean monthly temperatures exceeded 75° potatoes did not produce a profitable crop. Thus, potatoes are not grown on any large scale in any part of the world where the mean temperatures during the hottest part of the growing season is much in excess of 70°. Again some allowance needs to be made for

differences between continental and maritime climates. To some extent, too, there is an interaction between temperature and daylength (Driver and Hawkes, 1943). Thus, short days, of less than 12 hours, modify the effect of high temperatures.

In most of the principal potato areas of the world frosts mark the beginning and end of the growing season. The mean temperature at which frosts are likely to occur varies according to situation, but in practice planting usually takes place in the month that mean air temperatures approach 50° F., and lifting begins at about the same temperature. (See fig. 2 and other climagrams.) In certain frost-free areas, as in the Ayrshire early potato-growing district of Scotland, potatoes are planted, and a considerable amount of top growth is made before mean temperatures reach 50°; and in the Sierra of Peru the whole growing season occurs at about this temperature; but these areas are exceptional. The importance of temperature is thus seen to lie not only in its effect on tuber production but also in the effect on the length of the growing season, and the length of the growing season is often too short to allow maximum potato production, particularly under continental conditions. Very roughly the potato-growing areas of the world may be divided into two main types: Those such as Aroostock County in Maine, U.S.A., northern Sweden, and the Leningrad district of the U.S.S.R., where the growing season is short (about 120 days) and there is insufficient time for late or maincrop varieties to produce their maximum crop; and those, such as Great Britain, Holland, Australia, and New Zealand, where the growing season is long (160 days or more) and late varieties die down naturally sometime before lifting.

RAINFALL. Although an adequate supply of water is the most important factor affecting yield in the potato, it is impossible to generalize about the plant's actual rainfall requirement. The distribution of the rainfall over the growing season is important. A given amount of rain evenly distributed over the life of the plant may be just what is required, but the same amount coming in a few heavy rainfalls may lead to waterlogging of the soil and actual mechanical damage to the potatoes. The rate of water loss from the soil both by evaporation and drainage is also relevant.

The greater part of the world's potato crop is grown under rainfall without the aid of irrigation. The rainfall may be excessive, as in the high valleys of Mexico, parts of Africa, and the hill crop potatoes in India; under such conditions, often characteristic of high altitudes, yields are generally very low. Rainfall is generally adequate in maritime areas or localities under maritime influence, as in northwestern Europe and the northeastern areas of North America, where the highest potato yields are obtained, and fluctuations in yield from year to year are not usually very great. Rainfall is often insufficient under continental conditions, as over a large part of European Russia and the midwestern states of the U.S.A. The crops then often suffer from drought, and yields fluctuate considerably from year to year.

Potatoes may also be grown wholly or partly under irrigation, as, for example, in the Mediterranean countries, western U.S.A., and parts of South America and India. In these areas it is channel irrigation that is almost universally employed. The use of spray irrigation is confined to supplementing rainfall under more temperate conditions.

DAYLENGTH. Work on the effect of photoperiodism on yield and maturity of the potato has been fully reviewed by Driver (Driver and Hawkes, 1943). Most of the world's potato crop is grown at middle to high latitudes under long-day conditions, and these favor maximum vegetative growth. Under short-day conditions in equatorial regions, top growth is smaller, maturity is speeded up, and yield is decreased. This latter statement has, however, been challenged by Moreau (1944a), working in East Africa. Particular potato varieties have a definite photoperiodic response. Thus, a short-day variety is suited only to short-day conditions, and when grown under long-day conditions it will fail to produce tubers. But many varieties are day-neutral. An example is the American variety Kennebec, which outyielded all others in trials in Florida and Iceland. In Florida a winter crop is grown and the daylength may be as short as 9 hours; in Iceland in June the daylength reaches 21 hours.

SOIL CONDITIONS. Most of the potato crop is grown on sandy or closely allied soils, which can be easily worked and which dry out quickly after rain. This is particularly important where the growing season is short, as under continental conditions, because planting and lifting have then to be done quickly and delays due to waterlogged soils cannot be tolerated. Light soils, however, are generally short of organic matter and their moisture-holding capacity may be so low that the yield suffers. Where the growing season is long, soils of heavier body (medium and heavy silt loams) often make the best potato soils, as in the Netherlands and New Zealand.

HOW THE DISEASE SPREADS

It is not within the scope of this study to review the immense world literature on the biology of Phytophthora infestans. All that is necessary is to explain a few technical terms frequently used in the following pages and the way in which the fungus lives as a parasite on its potato host, with the requirements for its survival and spread. It is in the light of this knowledge that all accounts of late blight epidemics, wherever they may occur in the world, must be seen and interpreted.

The fungus survives the winter as living mycelium in potato tubers. When these infected tubers, planted or remaining in the soil as groundkeepers, produce new growth in the spring, the fungus, still in the form of living mycelium, succeeds in invading a few of the shoots--a very few of them--and comes aboveground within their tissues. When certain necessary temperature and humidity conditions occur, the mycelium of the fungus produces hyphae, known as sporangiophores, which thread out, usually through the stomata of the leaves and stem, and project into the air. On these sporangiophores the microscopic sporangia of the fungus are formed. They become detached and drift off when ripe, and they are also dispersed by rain. Some reach healthy potato leaves and stems nearby and if these remain wet from rain or dew for a sufficient time, the sporangia germinate. At rather high temperatures they may germinate directly, each sporangium putting forth a single germ tube, but generally and under cooler conditions they germinate indirectly, the protoplasm within the sporangium first breaking up into a number of smaller swarm-spores, or zoospores, which swim about in the water on the leaf, and may each produce a small germ tube of its own. After the spore has germinated it may infect the potato leaf or stem on which it is resting, and in this infection process the germ tube of the spore penetrates the leaf cuticle, or, occasionally, enters the leaf by way of a stoma, and then initiates a growth of the fungus mycelium in and among the leaf cells. The invading mycelium debilitates the cells on which it feeds, and as these begin to decay it spreads peripherally into fresh tissue. The period from infection (successful penetration by the germ tube) to the appearance of a visible blight spot, or lesion, on the leaf, is known as the period of incubation.

Given a recurrence of the same favorable temperature and humidity conditions that induced sporulation on the first infected shoots, the new lesions will in turn produce spore-bearing hyphae, and the first generation of the fungus is completed. At this stage, the number of blight spots on the originally infected plant and those nearby is generally quite small, but a primary focus of the disease has been established in the potato field.

From this focus of infection more spores are disseminated; another crop of lesions covers a greater radius; these lesions in turn sporulate with successive spells of favorable weather, and after two or three such generations of the fungus, blight spots may be found here and there, generally but lightly distributed over an entire field, and beginning in other fields in the vicinity. Epidemic spread may then be said to have begun.

At first the damage is negligible, for the crop loses only a few leaves here and there, but if the attack is not checked by protective spraying or dry weather, there will be progressive decay of the foliage as the established lesions increase in area and new ones develop. The course of the epidemic may be rapid or slow, always according to weather conditions, and the crop may be affected in two distinct ways. (1) If the foliage is killed prematurely the yield will be reduced by what is in effect a reduction of the growing period; the earlier the haulm is killed the greater the loss of crop. (2) And if living sporangia from the diseased foliage reach the tubers themselves, these also may be infected, causing a further loss, either in the ground or in storage.

In wet weather, sporangia are washed down from the foliage onto the soil. Normally the soil cover protects the tubers to a great extent, but where the soil cover is inadequate or the soil texture or moisture content render it permeable by the sporangia, some tubers will be infected before lifting. If, at lifting, the tubers are exposed while the fungus is still sporulating on partially diseased foliage or if living sporangia are still present in the surface layers of the soil, further infection of the tubers will occur. This infection will not be apparent at the time, but it will develop in storage.

The infection of the tubers completes the life cycle of the fungus. The vast majority of the blighted tubers rot in the ground or during storage, at least to such extent that there is no living mycelium left in them by the following spring. As far as possible, blighted tubers are removed from seed stocks, and of the few that pass undetected not one in a hundred gives rise to affected shoots aboveground. The first infected shoots among the crops are rare and hard to find, but these, together with occasional infected shoots arising from groundkeepers, and from discards by clamp sites or cull piles, are sufficient to start the blight epidemics each year.

HOW HUMIDITY AND TEMPERATURE CONDITIONS AFFECT THE FUNGUS

The temperature and humidity conditions known or believed to be critical for each

phase of the survival and spread of the fungus may be stated briefly as follows:

SURVIVAL OF MYCELIUM IN THE TUBERS. It may be expected that where seed tubers are subjected to temperatures of 86° F. or over for any considerable time in storage, transit, or in the soil, the fungus will not survive in them (Jensen, 1887). There appears to be no lower limit for the survival of the mycelium; chilling or frosting that does not kill the tubers does not kill the fungus. Van der Zaag (1956) found that the mycelium was killed when seed tubers were immersed for 1 hour in water at 110°. This treatment damaged the tubers themselves when carried out in April, but not in December.

SPORULATION. In experiments under rather artificial constant temperature conditions, i.e., without the diurnal variation of temperature occurring in nature, Crosier (1934) found that sporangia were never formed in an atmosphere at less than 91 percent relative humidity, and that humidity approaching 100 percent was required for their abundant formation. In a saturated atmosphere, temperatures of 62° to 72°F. were optimum both for rapidity and intensity of sporulation. Sporangia commonly appeared within 8 hours and were abundant in 14 hours. At 46° to 59° sporangia were fairly numerous in 24 hours and plentiful in 58 hours. At 37° only a few sporangia were formed in 6 days. Sporangia produced at temperatures over 70° did not germinate well. The sporangia were found to lose their viability in 1 to 2 hours in very dry air (20 to 40 percent relative humidity) and in 3 to 6 hours in air at 50 to 80 percent relative humidity.

Although the main sporulation conditions as defined by Crosier are supported by the findings of the majority of workers, it must be noted that the capacity of the fungus for some restricted sporulation in the field under apparently adverse high temperature and low humidity conditions was reported by Wallin (1953).

LIBERATION OF SPORANGIA. In explorations of the spore content of the air at 6 feet and at 18 inches above the ground in potato fields during the course of potato blight epidemics in England, Hirst (1953) has found that rapid liberation of sporangia starts at about 8 o'clock in the morning (0800 hours) and reaches its peak at about 10 o'clock (1000 hours). This is consistent with De Bary's (1887) suggestion that spore discharge occurs with the hygroscopic twisting movement of the sporangiophores exposed to rapidly changing humidity, and indicates that liberation coincides with rising temperatures and the disappearance of dew and raindrops from the leaves. The ripe sporangia may, however, be dislodged and dispersed by rain at any time of the day or night.

GERMINATION AND INFECTION. Crosier found that free water or dew on the leaves is necessary for the germination of the sporangia. Direct germination, without the production of zoospores, can occur over the temperature range 48° to 79° F., but has a definite optimum at about 75°. Little direct germination occurs in 8 hours, and about 32 hours is necessary for maximum germination in this way. Direct germination therefore probably plays little part in the spread of blight in the field.

Indirect germination, by zoospores, requires free moisture, and a rather low temperature (50° to 59° F., optimum 55°) for a period of only 1/2 to 2 hours. It may also take place at temperatures as low as 37° or as high as 70°, but the time required is considerably longer.

After the zoospores have germinated a further period of at least 2 to $2\frac{1}{2}$ hours at 50° to 77° F. is required for the infection process, or penetration of the term tubes into the host tissue. The whole process of indirect germination and infection thus requires a period of $2\frac{1}{2}$ to $4\frac{1}{2}$ hours with free moisture on the leaves and cool conditions over at least half this time.

INCUBATION. After penetration of the germ tubes into the host tissue the fungus develops most rapidly at 64° to 70° F., i.e., at about the same temperature as that which is also optimum for sporulation. Under such conditions Crosier found that new lesions appeared in 3 to 5 days. Thran (cited by Uhlig, 1955) found that the incubation period could be as much as 13 days at 53°, 6 days at 60°, and 2 to 3 days at 68°. Very varied figures have been given by other workers, but in general the period is 3 to 5 days.

SURVIVAL OF THE FUNGUS IN LEAVES AND STEMS. Crosier found that continuous temperatures of 86° F. checked the growth of the fungus in the field, but that intermittent temperatures of 68° to 86° during the day were not particularly unfavorable to it, and that in potato stems it would tolerate intermittent high temperatures up to 94°. In one trial, one stem lesion out of 197 developed sporangia on plants exposed to bright sunshine and maximum temperatures of 110° to 115° for 6 days. This capacity of the fungus to remain viable in stem lesions during hot dry weather and to start sporulating again when more favorable conditions recur has been noted in England by Clayson and Robertson (1955), and extensively investigated in the U.S.A. by Hoyman and Wallin (1957), who reported survival of the fungus after exposure for short periods to temperatures as high as 114°.

As it is a part of the rhythm of nature for air temperatures to rise during the day and to fall at night, it might be expected that the blight fungus, preferring rather warm conditions for sporulation and rather cool conditions for swarm-spore germination, would produce its sporangia during the day (given the necessary high humidity) and release them in the evening to germinate during the cooler night and in the night dews. Although there may be some sporulation during the day, Hirst has shown, at any rate under English conditions, that the peak liberation of sporangia takes place in the morning. This renders the parasite less efficient than it might otherwise be, and imposes a natural check on distant spread of the disease by airborne sporangia. There is no such restriction, however, on local spread by splash and drip dispersal of the sporangia by rain.

Although high humidity plays an extremely important part in the development of a blight attack, so also does rain. Rain provides water necessary for the germination of the sporangia on the leaves, it raises the humidity within the crop by wetting the soil, and it is responsible for much of the local dispersion of infection. Hänni (1949) and Uhlig (1955) put wet weather very high in their lists of conditions favoring the mass increase of blight, and this is in accord with common observation.

The interplay of diurnal changes of atmospheric humidity and temperature and the differing requirements of the fungus for sporulation, spore discharge, and germination, together with all the divers effects of wind, rain, and varying density of crop growth, render it unwise to attempt to postulate what will or will not constitute "blight weather" from a mere consideration of the optimum conditions for sporulation and germination of the fungus as determined in the laboratory. Very detailed micro-climatic investigations, such as those of Johannes (1953a) in Germany and of Hirst at Rothamsted, are necessary to reveal what constitutes "blight weather" in nature and how it is, in fact, related to any given combination of climatic parameters.

"Blight weather" is a convenient term for weather that permits the increase and spread of the fungus in the field. The problem of what constitutes a "blight weather spell," or "critical period," has arisen in attempts to forecast outbreaks. Progress in this art has come from making intelligent guesses in the formulation of empirical rules, and then trying them out. With successive modifications and limitations, these rules, set out in this study in the sections on the Netherlands, England and Wales, the Irish Republic, the U.S.A., and Western Germany, now embody all we have of real knowledge of blight weather; as a result, "fundamental biological and meteorological research" is laboring to catch up with the practical findings.

In the consideration of blight in relation to weather, there are successive levels on which attention may be focused. First, the microscopic level that is concerned with the behavior of spores in damp chambers; then the close-up of blight lesion distribution in small plots with meteorological instruments among the plants; then the midview of epidemics in limited regions and attempts to forecast them; and finally the long-shot view of the world as a whole. This study is primarily concerned with the world view of blight weather and the broad climatic circumstances in which such weather occurs.

THE BRITISH ISLES

ENGLAND AND WALES

England and Wales, with a population according to the 1951 Census of about 44 millions, now produces 5 to 6 million tons of potatoes each year, most of which are for human consumption within the country. A small tonnage, notably of surpluses, is fed to stock, but very few potatoes are used for industrial purposes. The potato acreage, which reached over a million during the 1939-45 war, stood at about 650,000 acres in 1954, of which 530,000 acres were maincrops (including second-early potatoes), the rest being first-early potatoes (M.A.F.F. [Gr. Brit. Ministry of Agriculture, Fisheries, and Food], 1956). The consumption of potatoes per head is about 200 lb. per annum.

Maincrop production is concentrated in a few districts, with an even and relatively sparse distribution elsewhere, as shown in the distribution map (for 1954) (fig. 3). The principal districts for maincrops are the Fens and the area round the Wash, where the crop is grown on deep organic loams or on silt soils producing very heavy yields; the Vale of York, where the chief soils are sandy loams; Lancashire and the Cheshire plains, mostly on sandy soils of glacial origin. Important potato areas are also in Bedfordshire, Essex, and Kent, with London as their nearest market; near Birmingham; and in Durham, supplying the coal mining districts of the north.

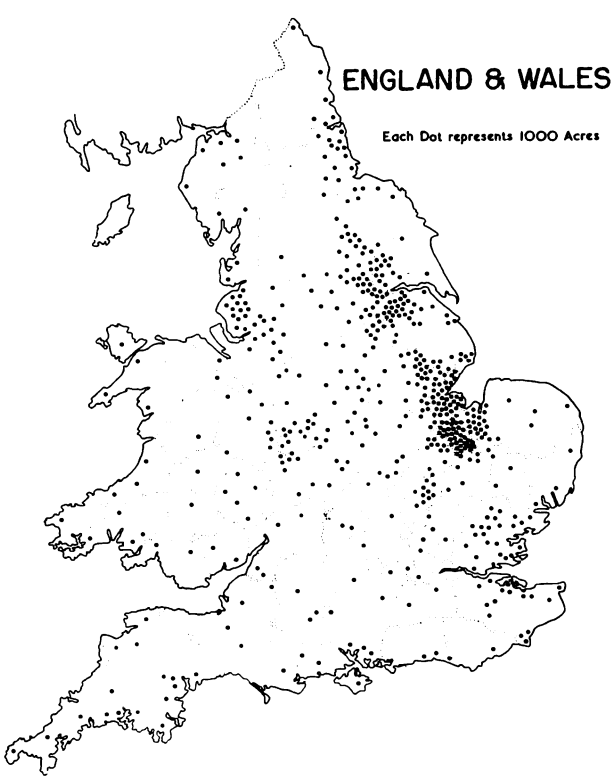


FIGURE 3.--Distribution of maincrop potatoes in England and Wales.

The principal maincrop varieties are Majestic and King Edward. Majestic accounts for about 45 percent of the maincrop acreage, and King Edward (including Red King), which is regarded as the quality potato, for about 35 percent. Other popular varieties are Arran Banner, Arran Peak, Dr. McIntosh, and Redskin, each contributing $3\frac{1}{2}$ percent to the total maincrop acreage. Very few really late varieties are grown.

The planting of maincrops starts at the end of March and continues into early May, according to the season. Whole seed tubers are planted with the sets about 18 in. apart in the rows, and the rows 27 to 30 in. apart (28 in. is the standard width). Lifting usually begins about mid-September, but most of it is done in October. The growing season is therefore rather long--about 160 days. The average yield is about 9 tons per acre. Chitting (sprouting before planting) is practiced fairly extensively in early districts and in the Fens, and this gives the crops a start of about 2 weeks extra growth at the beginning of the season. A newly revised bulletin on "Potatoes" (M.A.F.F. [Gr. Brit.], 1957) provides full information on potato cultivation in England and Wales.

Early varieties are grown in most of the principal maincrop districts; but the first supplies for the early summer market come from Cornwall, Pembrokeshire, the Scillies, and the Channel Islands. The principal first-early varieties are Arran Pilot and Home Guard.

In 1954, Arran Pilot accounted for over 50 percent of the total first-early acreage, and Home Guard for 21 percent. Other popular early varieties include Ulster Chieftain, Ulster Prince, Duke of York, Eclipse, Ninetyfold, and Sharpe's Express. Epicure and May Queen have diminished in popularity since 1945.

In Cornwall and Pembrokeshire the planting of early potatoes starts in early February and continues into March, with lifting toward the end of May or early June. The seed tubers are planted 12 to 15 in. apart in rows 24 to 28 in. apart. Often they are grown on the flat, without earthing up. Yields are from 3 to 5 tons per acre. Early varieties in the other districts, notably parts of Lincolnshire, the Cheshire Plain, Bedfordshire, Essex, and Kent, are planted later and provide the continuation of supplies of "new" potatoes in June and July.

Seed-potato growing in England and Wales is chiefly confined to the production of good "once-grown" stocks--for which there is a

certification scheme. Most of the "new" seed is imported from Scotland and Ireland, although the upland or coastal areas in Devon, Cornwall, Cumberland, and parts of Wales, where climatic conditions are unfavorable for the spread of virus diseases, produce small quantities of the higher grades of certified seed. About 60 percent of the maincrop potato acreage is planted with certified seed, almost all of which is imported from Scotland or Ireland (Boyd and Lessells, 1954).

Key for the assessment of potato blight on the haulm

Blight Percent	
0.0	Not seen on field.
0.1	Only a few plants affected here and there; up to 1 or 2 spots in a 12-yard radius.
1.0	Up to 10 spots per plant, or general light spotting.
5.0	About 50 spots per plant, or up to 1 leaflet in 10 attacked.
25.0	Nearly every leaflet with lesions, plants still retaining normal form; field may smell of blight, but looks green although every plant affected.
50.0	Every plant affected and about half of leaf area destroyed by blight; field looks green flecked with brown.
75.0	About three-quarters of leaf area destroyed by blight; field looks neither predominantly brown nor green. In some varieties the youngest leaves escape infection, so that green is more conspicuous than in varieties like King Edward, which commonly shows severe shoot infection.
95.0	Only a few leaves left green, but stems green.

In the earlier stages of a blight epidemic, parts of the field sometimes show more advanced decay than the rest, and this is often associated with the primary foci of the disease. Records may than be made as, 1 + pf 25, where pf 25 means 25 percent in the area of the primary foci.

Losses by potato blight in England and Wales occur chiefly on the maincrop and second-early varieties. Although the first outbreaks of blight each year are usually on the early varieties, these are lifted before sufficient defoliation occurs to affect the yield, and usually before the tubers are infected. The following study of late blight epidemics in England and Wales therefore refers essentially to the disease on maincrop potatoes (taken throughout as including second-early varieties), although, undoubtedly, blight foci among the early varieties contribute to the sources of infection of the maincrop in the vicinity each year.

DELIMITATION OF "BLIGHT ZONES"

During the second World War the need was found for some precise but practical field method of defining the course of blight on potato crops in different seasons and in different parts of the country. As a result of this, an assessment key (as shown in column one) was worked out by a Disease Measurement Committee of the British Mycological Society (B.M.S., 1947).

This key was successfully employed in local surveys (Moore, 1948) and for the study of foliage protection in spraying trials (Large, 1945). In 1950, when a new section for plant disease measurement and quantitative survey work was started at the Plant Pathology Laboratory (Large, 1953b, 1955a), the key was put to use in national surveys. These surveys, using a uniform plan, continued for 7 years, are reported by Large (1956). Thousands of records have been obtained from all parts of the country; for England and Wales, it is at last becoming possible to define, measure, and compare the blight epidemics occurring over a sequence of years and to put an evaluation of the losses the epidemics have caused upon a factual basis. This is a realization, in some part, of plans long laid by W. C. Moore, whose address to the Association of Applied Biologists in 1949 on the significance of plant diseases in Great Britain (Moore, 1949) provides the background for all that follows.

Two points on the curves obtained by plotting progress of blight on a time scale are of particular importance (Large, 1952a). The first is the 0.1-percent stage, defining the beginning of epidemic spread, or "outbreak," for purposes of forecasting and the timing of spraying. The second is the 75-percent stage of defoliation, at which time further tuber development is arrested (see fig. 8 and the section on computation of losses). This latter stage is discussed first, as the 75 percent maps (75 to 90 percent in practice) provide the best single picture of the severity and frequency of the epidemics in the several regions of the country (fig. 4).

Of the 6 years illustrated, 1950, 1953, and 1954 were "blight years," with losses of all the September growth over most of the south of the country, and losses of some of the August growth also in the southwest and the Fen district round the Wash, but with little or no loss in the north. In the other years losses of growth occurred in the west, but only here and there in the other zones. From a study of the maps (Large, 1958) it becomes possible to divide the country into four main "blight zones":

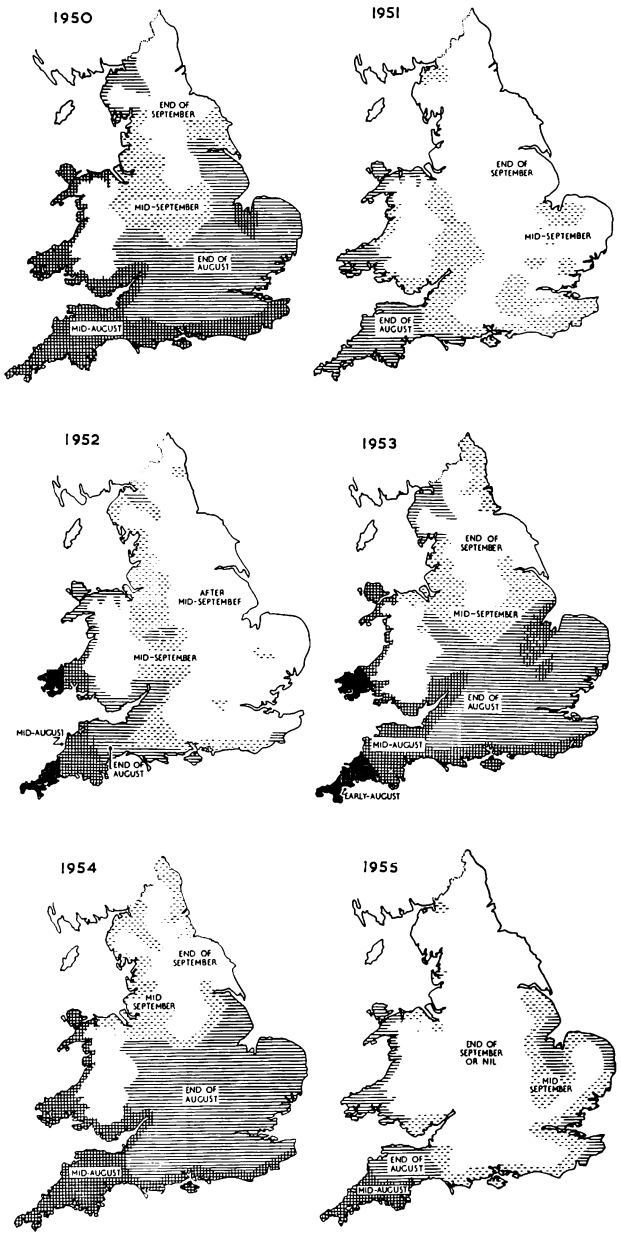


FIGURE 4.--Zoning of England and Wales according to the date at which the 75 to 90 percent blight stage was reached on unsprayed maincrop potatoes in the years 1950-55.

Southwest zone - - -A southwestern and west-coastal belt including the potato growing areas in Cornwall, Devon, Somerset, Gloucester, Monmouth, Glamorgan, Carmarthen, Pembroke, Cardigan, Merioneth, Caernarvon, and Anglesey; with an earlier subzone containing Cornwall and Pembroke.

Fen zone - - - - - - -An area round the Wash, roughly equivalent in acreage to that of the Isle of Ely and the Holland division of Lincolnshire, but extending somewhat into Hunts. and West Norfolk.

Southern zone - - -All the rest of the country south of Denbigh, Cheshire, Derby, and Notts., but including the Kesteven and Lindsey Divisions of Lincolnshire, and also the northern county, Cumberland, where the epidemics are similar to those in the south.

Northern zone - - -All remaining northern part of the country.

These zones are indicated in figure 5, and it will be seen how closely they represent the mean pattern of shading--for time of 75-90 percent defoliation--in both the blight years and the years with little blight in the east. Naturally, these zones are not in fact limited by county boundaries, but their areas are here reckoned in equivalent county potato acreages in order to arrive at the approximate percentage of the country's total maincrop acreage that is contributed by each zone. This, on the basis of the 1954 distribution (fig. 3), is given in table 1.

FREQUENCY AND SEVERITY OF THE EPIDEMICS ACCORDING TO ZONE

With the above zoning, and taking in the years 1947 and 1949, which were dry years, and 1948, a "blight-year" rather similar to 1950, the frequency of epidemics of differing degrees of severity, in the 4 zones, over the 10 years, 1947-56, was as shown table 1. The mean dates at which growth was stopped by blight are for unsprayed maincrops, and by reference to figure 8 and the section of computation of losses of which it is part, it is possible to proceed directly to estimates of the mean loss in yield due to defoliation on the unsprayed crops in each zone and for England and Wales as a whole over this period. These estimates are entered in the table--probably the first of their kind ever to be presented for an entire country.

This analysis indicates that if all the maincrop potatoes in the country had been left unsprayed during the 10 years, the mean annual loss due to premature defoliation by blight would have amounted to about 8 percent; that is to say, 8 percent of the total yield that would have been obtained had blight

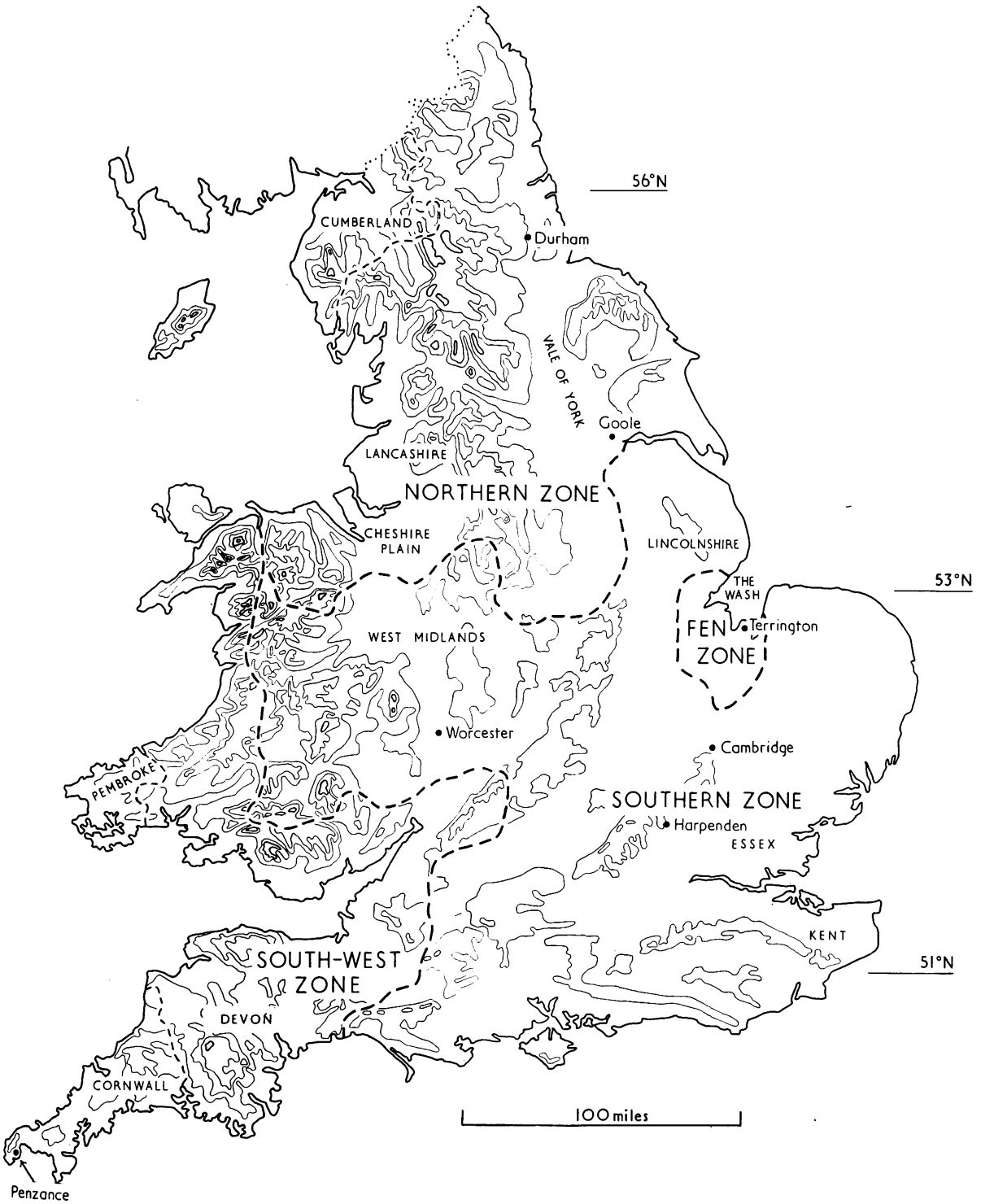


FIGURE 5.--Key map, showing blight zones in England and Wales.

been entirely absent. But in the southwestern zone, where every year was a "blight-year," the mean loss would have been about 20 percent; in the Fen zone, with 6 blight years in 10, about 14 percent; and in the large southern zone, with only five moderately severe blight years in 10, about 7 percent--less than the average for the country as a whole.

TABLE 1.--Frequency and severity of potato blight epidemics in England and Wales, 1947-56

Zone	Maincrop acreage	Number of years in 10 in which growth was stopped by blight at--				Mean loss per annum the 10 years to--	
		Mid-Aug. 28 percent loss	End Aug., 13 percent loss	Mid-Sept., 4 percent loss	End Sept., no loss	Zone	Whole country
	Percent					Percent	Percent
Southwest	8	5	5	0	0	20	1.7
Fens	13	4	2	1	3	14	1.8
Southern	51	0	5	2	3	7	3.7
Northern	28	0	0	5	5	2	0.6
England and Wales	--	--	--	--	--	--	7.8

In the worst of the individual blight years, such as 1950 or 1953, the national loss, on the same basis, would have been about 16 percent; and in the years with least blight, such as 1951, 1952, or 1955, a little over 2 percent.

COURSES OF THE EPIDEMICS IN THE FOUR ZONES

Having established the blight zones of the country by reference to the 75 to 90 percent maps, we may now consider the development of the epidemics within each zone. Figure 7, given in the section on forecasting (p. 18), shows the outbreak (0.1 percent) map, and the regional blight progress curves obtained for a "blight year" (1954). There is no constant relation between the outbreak date and the date at which tuber development is arrested. The progress curves may be steep, or they may be long-drawn-out, according to weather conditions. Even in severe epidemics it is rare for the attack to progress from the 0.1 to the 75 to 90 percent stage in less than 5 weeks, and in a lingering attack the period may be 2 months or more.

Blight is not found at the 0.1 percent stage in all the unsprayed crops in a region on the same date; there is commonly a range in time of about a fortnight, between the first and the last appearance of this small amount of blight. Table 2 gives the range of outbreak dates for each zone for the 7 years, 1950-56.

TABLE 2.--Times of outbreak, and weeks of growth lost at the end of the season, maincrop potatoes, 1950-56

Year[1]	Southwest zone		Fens zone		Southern zone		Northern zone	
	Outbreak	Growth lost	Outbreak	Growth lost	Outbreak	Growth lost	Outbreak	Growth lost
		Weeks		Weeks		Weeks		Weeks
1950-B...	Early July	7	Early July	7	Late July	5	Early Aug.-mid-Aug.	3-1
1951.....	Late July-early Aug.	3-5	End of Aug.	2-3	Early Aug.-mid-Sept.	1-3	Late Aug.-mid-Sept.	1
1952.....	Early July-early Aug.	5-8	Mid-Aug.-end Sept.	1-2	Early Aug.-end of Sept.	1-3	Early Aug.-mid-Sept.	1-3
1953-B...	Early July-late July	6-8	Early July	5-6	Late July-end July	5	Late July-late Aug.	1-3
1954-B...	Early July-late July	7-6	End of July	5	Late July-end July	5	End of July-late Aug.	1-3
1955.....	Late June-mid-Aug.	5-7	End of July-late Aug.	3-5	Late Aug.-end Sept.	1-3	Mid Sept.-end Sept.	0-1
1956-B...	Late July-early Aug.	5-7	End of July	6-7	Early Aug.	2-5	Early Aug.-late Aug.	2-3

[1] B = blight-year in the Fen and southern zones.

"Early July" signifies the first 2 weeks of that month; "mid-July" the middle 2 weeks; "late July" the last 2 weeks; and "end-July" the last week of July and the first week of August. In this table the 75 to 90 percent dates for the several zones and years are also given, but they are expressed in terms of the number of weeks before the end of September at which this stage was reached. The resulting numbers are in fact good code figures, of real biological significance, for expressing the severity of a blight epidemic, where, as in England and Wales, tuber development in crops free from blight normally ceases by that date. By reference to the histograms at the bottom of figure 8, or the growth curve above them, these code figures may be translated directly into probable losses in tons per acre, or in percentage of potential crop.

In the southwest zone outbreaks occur in July every year, with frequent outbreaks in June, and even in May on the early varieties in Cornwall and Pembroke. In the Fen zone they may occur early or quite late in July even in the blight years; while in the southern zone generally outbreaks are in late July in the blight years, with a tendency to be earliest in the coastal regions and latest in the central, inland area. In the northern zone, August outbreaks are most common, with many fields remaining unaffected until late August or September. Outbreaks tend to be somewhat earlier in Lancashire and the southern part of the Vale of York than elsewhere in the zone.

WEATHER CONDITIONS

Climagrams showing the long-term average rainfall and temperature conditions in the four zones are given in figure 6. The upper diagram, for Durham, in the northern zone, represents a district where the epidemics are latest and least severe; while the second diagram, for Penzance in the extreme southwestern subzone, represents conditions where they are earliest and most severe. It will be seen that even between these two extremes there is no very great difference in mean rainfall over the growing period. The principal difference is in the higher winter and spring temperatures at Penzance, which, with freedom from frosts in the sheltered coves, permit the spring cropping of first-early varieties.

However, very great local variations in both annual and summer rainfall occur in England and Wales. The country is mountainous to the west and north. On parts of the Pennines, the Welsh mountains, and the high moors of Devon and Cornwall, the annual rainfall exceeds 80 inches and it reaches 150 inches in a few places. Over most of the districts in which potatoes are grown, however, and certainly in the principal districts, which

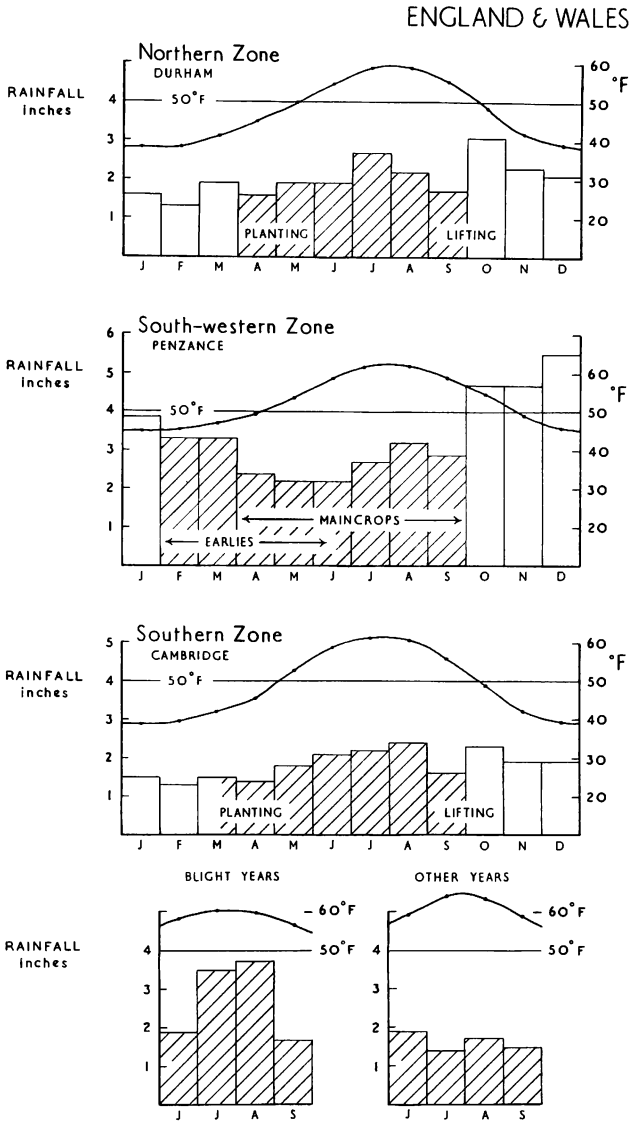


FIGURE 6.--Long-term average monthly rainfall and mean temperatures in relation to potato cropping for three zones in England and Wales, with July to September means for five blight years and five other years in the southern zone.

are at altitudes below 200 ft., the average annual rainfall does not exceed 30 inches.

Rainfall and mean temperature figures for the months of June, July, August, and September over the 10 years, 1947-56, are given in table 3. Data for Cambridge have been chosen, as the deviations from average at this station are fairly representative of a very large part of the important southern blight zone and also of Fens. The years are grouped into "blight years" and the "other years," in which the blight attack was late and caused little loss.

To bring out a fact that disturbs all preconceptions about reduction of potato yields in blight years, the mean potato yields for England and Wales, for each of the years,

TABLE 3.--Rainfall and deviations from average temperature at Cambridge for June to September, 1947-56, and mean national potato yields in "blight years" and other years

Year, average, and mean	Rainfall				Mean temperature				Mean Potato yield
	June	July	Aug.	Sept.	June	July	Aug.	Sept.	
	Inches	Inches	Inches	Inches	°F.	°F.	°F.	°F.	Tons/acre
Long-term average...	2.1	2.2	2.4	1.6	58	62	61	57	
"Blight years":									
1948.....	2.4	1.5	5.5	1.6	+2	0	+1	+3	7.6
1950.....	1.5	7.7	2.6	2.5	+5	0	0	-1	7.7
1953.....	1.9	2.0	2.5	1.3	-1	-1	0	0	8.7
1954.....	1.7	2.7	3.6	1.7	-1	-4	-2	-2	7.9
1956.....	1.9	3.5	4.9	1.4	-3	0	-4	+1	8.3
Mean.....	1.9	3.3	3.9	1.7	0	-1	-1	0	8.0
"Other years":									
1947.....	3.3	1.5	.2	1.0	+4	+3	+5	+3	5.8
1949.....	.9	3.3	1.2	.2	+2	+4	+3	+7	6.6
1951.....	1.2	.8	3.3	2.2	0	+1	-1	+2	7.9
1952.....	1.7	.5	2.6	2.3	+2	+2	+2	-4	7.9
1955.....	2.1	.5	1.6	1.6	0	+2	+4	+1	7.3
Mean.....	1.9	1.3	1.9	1.4	+1	+3	+3	+2	7.1

are added to table 3. The figures are taken from the last published Agricultural Statistics (M.A.F.F., 1956) with comparable estimates from other sources for the years 1955 and 1956. The figures are for all varieties (early as well as maincrop), but they serve well as index figures for the level of yield in each year.

The blight years are characterized by high rainfall and average or slightly low temperatures in the months of July and August; while the other years, with little or no blight, were associated with low rainfall and temperatures decidedly above the long-term average (+ 3°F.) in these months. These differences are shown in figure 6.

The first and overriding economic effect of the abundant rain and moderate temperatures in the blight years was to favor the growth of the potato plants, thus raising the yields above average despite whatever losses there may have been from potato blight.

That abundant rainfall and moderate temperatures in July and August also favor the development of severe blight epidemics is well brought out in table 3, but this also shows that a severe epidemic, such as that of 1953, can occur with only about average rainfall ($2\frac{1}{2}$ in.) and normal temperature (about 61° F.) in August. Such conditions can occur anywhere in the country, and they may or may not accompany severe blight attacks. The main differences responsible for the differing general levels of incidence of blight in the four blight zones are to be sought, not in mean temperature and rainfall, but in humidity.

HUMIDITY CONDITIONS IN THE FOUR ZONES

The southwest zone, in which severe or fairly severe epidemics occur almost every year, is exposed to southwesterly winds bringing in moist maritime tropical air. In this zone from June to September, there are 1,000 to 1,250 hours during which the relative humidity is 90 percent or more. These are mean durations as found by Smith (1954, 1956a) in his humidity surveys of the country over the years 1950-54. Cumberland is also exposed to this moist air stream; but most of the southern blight zone is in the lee of the mountains and high land to the southwest and has a seasonal mean of only 750 to 1,000 hours of such high humidity. In the northern zone particularly, dry areas occur in Lancashire and Cheshire in the immediate shelter of the Welsh mountains; and also in the lee of the Pennines in Yorkshire, where the count of high humidity hours is less than 750. This goes far to explain the low level of blight incidence in the northern zone. In the Fen zone, near the Wash, there is a high water table in low-lying land, with exposed water in many drainage channels. Undoubtedly the Fen zone differs from the rest of the south in high humidity due to these causes, and, in common with some other east coastal areas, it is occasionally affected by fogs coming in from the North Sea.

Even such regional humidity differences, however, do not entirely account for the differences in frequency and severity of blight

in the four zones, and in particular districts within the zones. These differences have been studied over the past 7 years in terms of the frequency and times of occurrence of Beaumont periods;[2] that is to say, of humidity periods of such duration and at such a temperature as to permit sporulation and spread of the blight fungus itself. The recording of these periods all over the country has been primarily for forecasting purposes; but it has also revealed the weather spells after the outbreak, during which further spread is favored and the epidemics can progress most rapidly. (See fig. 7.)

FORECASTING

Since 1950, potato blight forecasting by the Beaumont humidity-temperature rule, with instruments in screens 4 ft. above ground level at standard weather stations, has been investigated and developed throughout England and Wales. Some 60 weather stations have taken part in the work, and the validity of the forecasts (based on hourly records of humidity and temperature) has been tested by hundreds of observations of blight outbreak dates in the potato fields in all parts of the country each year (Large, 1953a, 1956). From this work it has been found that with observations in standard screens at weather stations and not actually in the crops, individual Beaumont periods are often at fault, but that "flushes" of such periods, occurring at a number of stations within a blight zone, as revealed by an "operations-chart" (fig. 7), provide a reliable basis for regional forecasting when an additional working rule is introduced. This additional rule is that in the southern, Fen, and northern blight zones, "flushes" occurring before the last week in June are disregarded, and that only "flushes" at or after that time are to be taken as warnings.

This is an adaptation of the Beaumont scheme to the particular circumstances within the blight zones in England and Wales (other than in the southwestern zone, where June flushes are valid). This adapation reflects the fact that although June flushes occur every year, and they do undoubtedly permit the sporulation of the blight fungus on the very few and widely scattered infected shoots arising from blighted tubers planted each year, they do not initiate epidemic spread. The June flushes give rise to small primary foci involving a few plants only, and it is not until the potato plants begin to meet the drills, reducing ventilation within the crop, and the next spell of critical weather occurs, that distant or epidemic spread begins. Epidemic spread occurs when blight at the 0.1 percent stage by the B.M.S. key (see p. 11) is found over a considerable area in a field crop, and this stage is taken as constituting an "outbreak" for forecasting purposes in England and Wales.

Important studies have been made by Hirst (1955) on the very early stages of the blight epidemics in England and Wales. However, there is still a cryptic and only partially explored phase in the development of blight epidemics, which includes the whole of the happenings in the fields between the inadvertent planting of blighted tubers in April and the first appearances of new infections at the 0.1 percent stage on the resulting foliage in July, August, or even September. Whatever the true story of this phase may be, forecasts based on the occurrence of the first flushes of Beaumont periods in screens after the last week in June are now enabling correct regional spray warnings to be given year after year in England and Wales. Thus, forecasting in this country is now moving out of its investigatory stage into firm establishment in practice. The maps (fig. 4) show plainly that it is chiefly in the southern and Fen zones that forecasting services are required, and it is here that the scheme as now developed is giving its best performances.

Figure 7 shows the operations chart for a blight year (1954). There was the usual flush in June, too early to herald the outbreaks. In 1954 it was the flushes about July 10 and July 17 that gave warning throughout the southern and Fen zones of first outbreaks occurring over the last week of July and the first week of August. In the following year, 1955, there was no flush of warnings after the end of June until about August 13 in these zones, correctly indicating the absence of outbreaks until the end of August, too late to justify protective spraying.

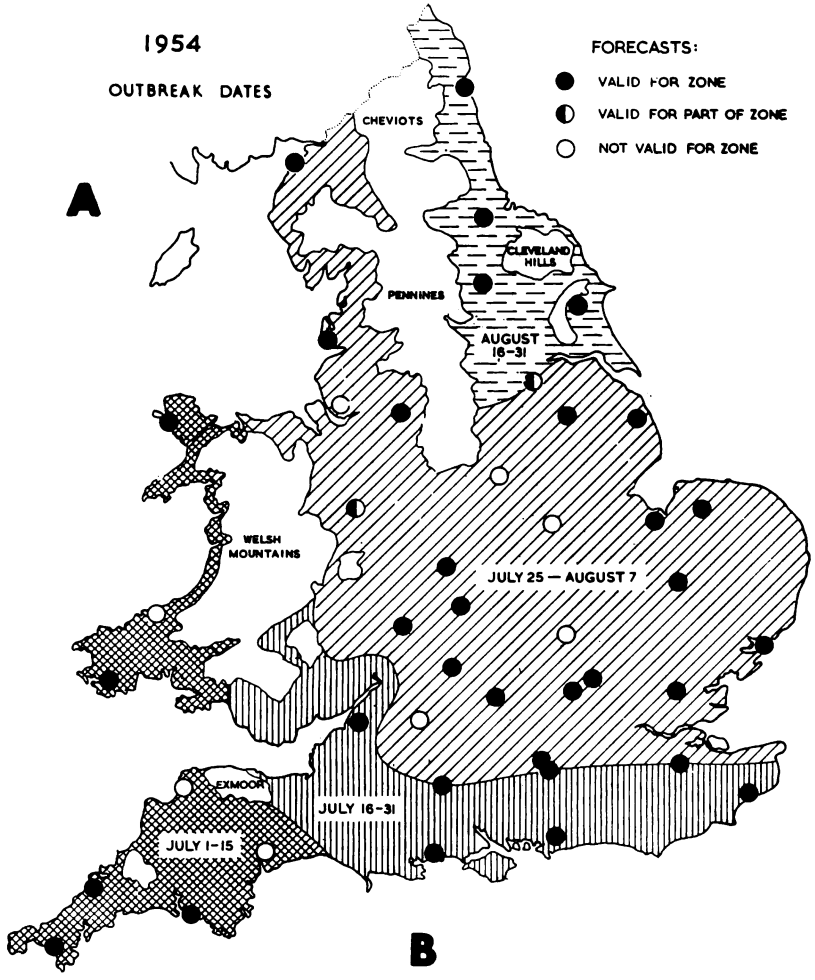
In England and Wales the possibility of forecasting by 90 percent humidity criteria has also been investigated (Smith, 1956b). By analyses over the 5 years 1950-54, it was found that the substitution of 11 hours at 90 percent relative humidity for the Beaumont humidity requirement would give some slight improvement in the performance of the scheme as now operated, but that the disadvantages of a changeover would, in practice, outweigh the advantages.

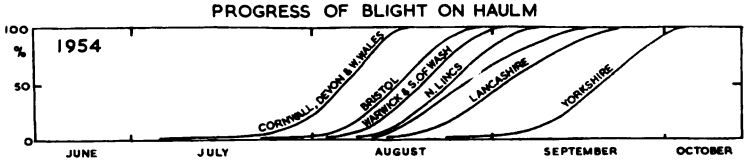
AMOUNT OF PROTECTIVE SPRAYING DONE

The percentage of the crops in England and Wales in which protective spraying or dusting is done is provided by records from a representative sample of some 2,000 crops each

[2] By the Beaumont rule (Beaumont, 1947), spells of not less than 48 consecutive hours during which the relative humidity does not fall below 75 percent and the temperature is not less than 50° F. are expected to be followed by blight outbreaks within 14 to 21 days. Near-critical periods are those in which these conditions are not broken for more than 1 hour in the 48.

ENGLAND & WALES





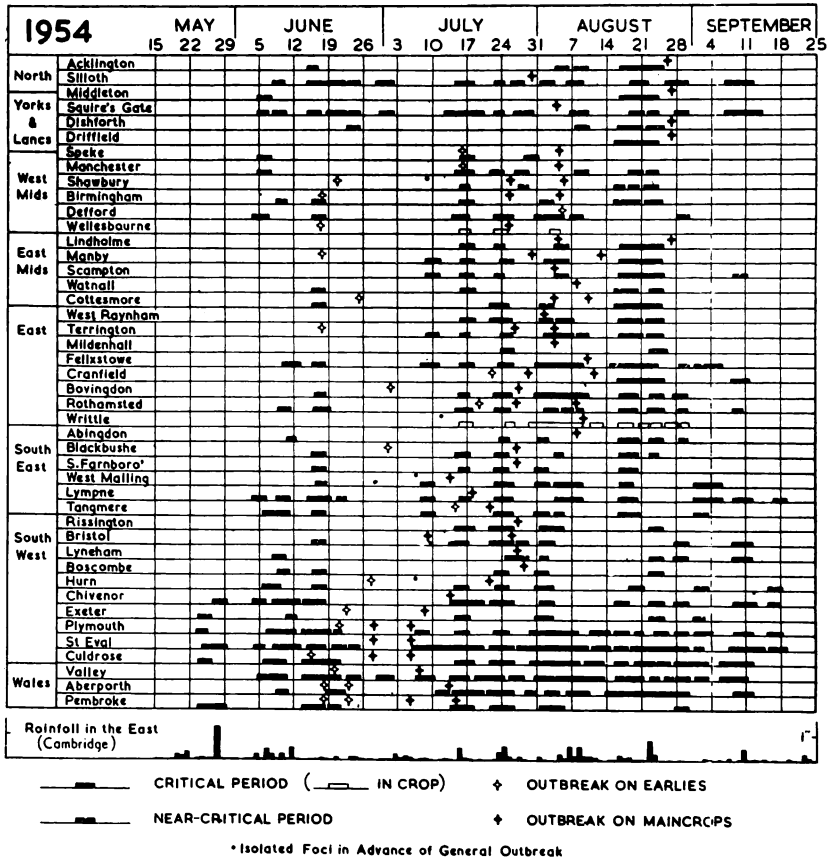


FIGURE 7.--A, Map, showing zoning of England and Wales according to date of blight outbreak in 1954, with validity of forecasts from individual stations; B, blight progress curves; and C, operations chart, showing blight outbreaks in relation to Beaumont periods at all stations.

year on which crop-check weighings are carried out for the purpose of estimating seasonal supplies.[3] Table 4 shows the percentages of the maincrops in the four blight zones which received any protective treatment in each of the years 1953-56.

TABLE 4.--Percentage of maincrop potatoes that received at least one protective treatment in England and Wales, 1953-56

Zone	1953	1954	1955	1956
	Per-cent	Per-cent	Per-cent	Per-cent
Southwestern.....	16	16	19	32
Fens.....	55	49	51	62
Southern.....	40	44	38	50
Northern.....	4	8	4	7
Average, England and Wales.....	28	32	28	39

On the showing of these figures the proportion of the crops protectively treated was about the same in the year with very little blight (1955) as in the blight years 1953 and 1954, but there was an increase in the blight year 1956, and the number of applications, not ascertained in these surveys, was undoubtedly greater in the blight years. The figures indicate that in recent years only some 30 percent of the crops (maincrop) in England and Wales were protectively treated; the proportion reached 50 to 60 percent in the Fens and some parts of the southern zone, notably Kent and Essex; 20 percent in the southwestern zone, and only about 5 percent in the northern zone. As regards variety, in 1956 about 60 percent of all the King Edward crops in the survey were sprayed; 30 percent of the Majestic; and also 30 percent of the other varieties.

Thus, it will be seen that in England and Wales, where more than half the crops are left unsprayed, it is possible first to estimate the loss caused by unrestricted blight epidemics on unsprayed crops, as has been done in table 1, and then to proceed to examine the extent to which this loss is, or could be, reduced by protective spraying, in each of the now-defined blight zones.

COMPUTATION OF BLIGHT LOSSES AND GAIN FROM SPRAYING

The derivation of the method, now employed in England and Wales, for estimating average losses of crop due to defoliation, from blight progress curves for the haulm read in conjunction with bulking curves for the tubers, has been given by Large (1945, 1952). The practical use of this method is here briefly explained by reference to fig. 8.

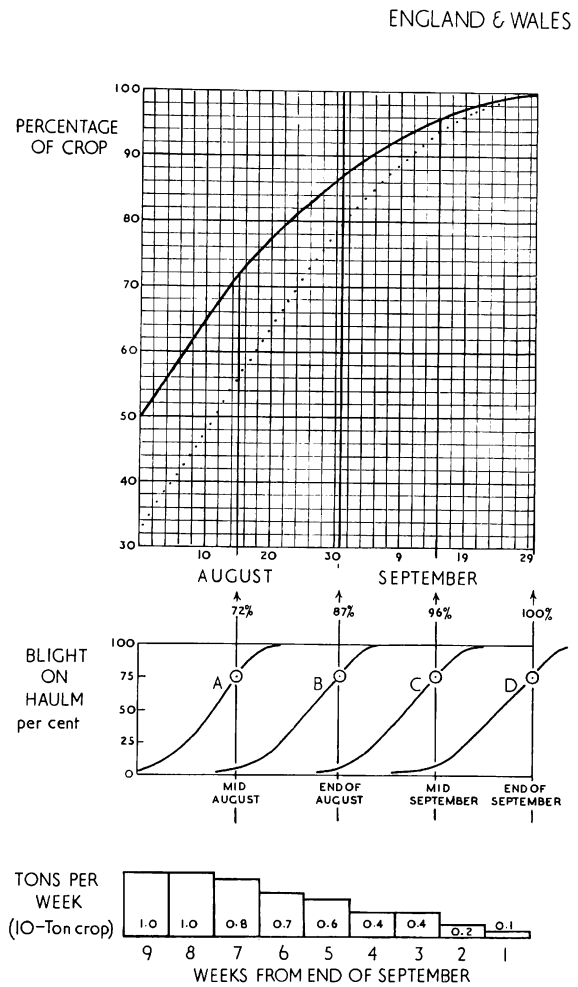


FIGURE 8.--Mean growth curve for maincrop tubers in England and Wales, showing percentage of crop obtained according to the date at which blight reaches 75 percent on the haulm. Also the mean tuber production per week in a 10-ton crop free from blight is shown. Dotted growth curve shows deviation in late-planted crops.

The upper graph in this figure gives the growth curve for maincrop tubers provisionally taken as normal for England and Wales when the haulms are unaffected by blight and die down naturally at the end of September. The curve is based on the results of fortnightly liftings on 60 crops in the 6 years 1940-45 (Doncaster and Gregory, 1948), and is therefore a mean curve. In some years the course of tuber development was relatively early and in others relatively late. The curve is for Majestic, the principal English variety, but experience so far has shown that within practical limits, it may also be used for the other early maincrop varieties grown in England and Wales, notably King Edward (Rosser, 1957).

[3] This work of crop check weighing is done by the Potato Marketing Board, with whose kind permission these and other supplementary figures were obtained for the Plant Pathology Laboratory in the course of the "crop-check surveys" included in this study. A brief account of the organization and scope of the surveys is given in a paper by Large and Honey (1955) on the incidence of common scab of potatoes in England and Wales.

Increase in the crop of tubers is taken to cease when blight on the haulm reaches the 75 percent stage; the slight increase, if any, after that stage is offset by the slowing down of growth before it, which begins at the 50 percent stage.

Hence, when the blight progress curve on the unsprayed haulm is as "A," in the middle diagram, and reaches the 75 percent stage in mid-August, only 72 percent of the potential crop is produced and the loss (of potential crop) is 28 percent.

If spraying retards the destruction of the haulm by a little over a fortnight, giving a progress curve as "B," with the 75 percent point at the end of August, then 87 percent of the potential crop is produced and the loss is 13 percent. The gain from the fortnight's prolongation of growth over the second half of August is therefore 28 minus 13, or 15 percent of the potential crop.

Except in those very rare cases in which the haulm is kept completely protected from blight until the end of the growing period, the potential crop, were there no blight, is not known. This can be estimated, however, from the growth curve. If the yield from a sprayed crop, with 75 percent point at the end of August is, for example, 12 tons per acre, then 12 tons is 87 percent of the potential crop. And the potential crop is therefore 13.8 tons per acre. Similarly, but with less accuracy, the potential crop can be estimated from the yield of the unsprayed areas.

The gain from a given number of days prolongation of growth over a given part of the growing period will vary according to the level of fertility of the field and the vigor of the potato stock, in short, according to the potential yield. Thus, to obtain a loss from blight, or gain from spraying, in terms of tons per acre, the percentages read off from the growth curve are multiplied by the potential yield in tons per acre. In the example given above, where the blight progress curve on the unsprayed is as "A," and that for the sprayed as "B," the gain from spraying, 15 percent, amounts to 1.5 tons per acre where the potential yield is 10 tons per acre, and to $2\frac{1}{4}$ tons, where the potential yield is 15 tons per acre.

The histograms at the bottom of figure 8 show the normal increment of yield produced in each week, numbered backwards from the end of September, for a potential crop of 10 tons. This is perhaps the most general level of yield in England and Wales, and the diagram is therefore useful for making quick approximate estimates of gains and losses with little calculation. If, for example, in a bad blight year, spray deposits are washed off rapidly by rain and cannot be renewed in time, only one week's growth (say week No. 6) is gained by spraying on a potential 10-ton crop, and this gain amounts to only 0.7 ton. The unrecovered loss (weeks 1 to 5) is 1.7 tons, and the yield obtained is 8.3 tons. On a 15-ton potential crop all these figures are one-and-a half times as much.

It must be remembered that the provisional normal growth curve is derived from the mean for a number of crops over a number of years. Its valid use is therefore for estimating mean losses over a number of years. Individual crops in individual seasons may vary considerably in rate and timing of tuber production, and on them the losses from blight and gains from spraying must be expected to vary about the long-term norm.

One of the principal causes of deviation is late planting (Dyke, 1956), which tends not only to reduce the potential yield but also to increase the weekly increments of growth in the latter part of the growing period. As a guide to the type of growth curve that may be expected where the crop is planted late (or has suffered retardation in its early stages), a dotted curve is added to figure 8, representing the mean course of tuber development in 16 late-planted crops unaffected by blight in the southern zone in the years 1955 and 1956. Where the growth curve follows the normal course, about half the potential crop is laid down by the end of July; but on the dotted curve only about a third of the potential crop is then present.

The prolongation of growth from spraying, i.e., the mean separation in time between the two more or less parallel blight progress curves for sprayed and unsprayed, is, strictly, best measured between the 50 percent, or "half-decay," points on the 2 curves (Large, 1945). As, however, the difference in time between the 50 and 75 percent stages is commonly less than a week and the rate of tuber bulking on the normal growth curve does not vary greatly over so short a time, the simplicity of estimating prolongation of growth between 75 percent points on the curves for the sprayed and unsprayed crops outweighs any possible slight gain in accuracy that would result from stepping back to the 50 percent points for this purpose.

CHECKS OF LOSS ESTIMATES BY SPRAYING TRIALS

Since 1941, several series of spraying trials, each over a number of years, have been carried out in various parts of England and Wales. In these trials yields determined by weighing the crop from replicated plots were related to the blight progress curves for the sprayed and unsprayed haulm. The "actual" gains from spraying were computed with the "expected" gains, calculated from the 75 percent dates on the haulm in accordance with the method and example given in the previous section, using the provisional normal curve for tuber development (fig. 8).

The first series was carried out by Beaumont and Large (1944) in Devon and Cornwall (southwestern blight zone) during the years

1941-46. In the 4 years 1943-46, the effect of two well-timed applications of freshly prepared bordeaux mixture (4.5.50), applied at about 100 gallons per acre, by 5- or 7-row horse-drawn or tractor sprayers with drop lances, was tested on uniform stocks of certified Majestic at a dozen centers or more each year. In table 5 the mean results (some hitherto unpublished) for each year are given for two groups: Cornwall and western districts of Devon where blight is exceptionally severe (extreme western subzone), and the rest of Devon where conditions are more representative of the southwestern zone as a whole.

TABLE 5.--Results of spraying trials with 2 well-timed applications of bordeaux mixtures on Majestic potatoes in Cornwall and Devon, 1943-46

Year and area	Crops	Date when blight on unsprayed haulm reached--		Prolongation of growth by spraying	Total yield of unsprayed plots	Gain from spraying	
		0.1 percent stage	75 percent stage			Actual by lifting	Expected from 75 percent dates
1943:	Number			Days	Tons/acre	Tons/acre	Tons/acre
Cornwall and western Devon.....	6	June 26	Aug. 8	17	8.6	2.7	3.5
Eastern Devon.....	5	July 21	Aug. 23	21	6.6	2.9	1.5
1944:							
Cornwall and western Devon.....	10	July 25	Aug. 20	18	13.7	2.8	2.8
Eastern Devon.....	5	Aug. 8	Sept. 9	12	12.5	1.1	.7
1945:							
Cornwall and western Devon.....	5	June 25	July 23	18	6.7	2.4	2.9
Eastern Devon.....	9	July 17	Sept. 19	21	8.9	1.6	2.0
1946:							
Cornwall and western Devon.....	4	July 7	Aug. 4	15	9.3	2.3	2.6
Eastern Devon.....	8	July 18	Aug. 23	18	11.5	3.2	2.2

Here the "expected" gains, especially when averaged over the run of years, are in good general agreement with the "actual" gains as determined by lifting, which for all the labor involved, were still subject to a standard error of at least half a ton per acre. In the more easterly part of the area (lower figures) the 75 percent stage of blight on the haulm was reached about a week after mid-August in 3 years out 4, and in early September in 1 year only (1944). This is in good accordance with the frequency for the southwestern zone over the later period of 10 years (1947-56) given in table 1. The computed mean total loss of potential crop by blight over the 4 years was 18 percent as against the mean of 20 percent entered in table 1, and the gain from spraying, averaging 2.2 tons per acre over the 4 years, was about 12 percent. In these trials, therefore, two carefully timed applications of one of the most rain-resistant spraying materials (freshly made bordeaux mixture) saved about two-thirds of the defoliation loss by blight.

The next series of trials was carried out by Beaumont, Bant, and Storey (1953) during 1947-51, at Goole on the Humber (fig. 5). This center is on the border of the northern and southern blight zones, where blight conditions more closely resemble those of Hertfordshire in the southern zone than those in the greater part of the north. The spraying was again done with freshly prepared bordeaux mixture (4.5.40), but with a knapsack sprayer. The two well-timed applications were put on at the rate of 200 gallons per acre on Latin-square plots of certified Majestic each year. The relevant results are shown in table 6.

In the two blight years, 1948 and 1950, the expected gain from 3 weeks prolongation of growth with blight at the 75 percent stage at the beginning of September was again in close agreement with the "actual" increase found by lifting, with yields subject to a standard error of about ± 0.3 ton per acre. In the two dry years, 1949 and 1951, when blight caused no loss, there was an indication of a loss caused by spraying. This could not be attributed to wheel damage, as the plots were sprayed by hand. It was probably due to copper injury following the insect damage common in dry years. Some

TABLE 6.--Results of spraying trials with 2 well-timed applications of bordeaux mixture on Majestic potatoes at Goole in Yorkshire, 1947-51

Year	Date when blight on unsprayed haulm reached--		Prolongation of growth by spraying	Total yield of unsprayed plots	Gain from spraying	
	0.1 percent stage	75 percent stage			Actual by lifting	Expected from 75 percent dates
			Days	Tons/acre	Tons/acre	Tons/acre
1947.....	Aug. 5	Sept. 28	14	14.9	+0.1	0
1948.....	Aug. 13	Sept. 6	21	10.3	+1.0	1.2
1949.....	Sept. 9	Sept. 28	10	15.5	-.9	0
1950.....	Aug. 4	Sept. 2	20	13.6	+2.1	1.6
1951.....	Aug. 28	Sept. 28	7	14.4	-.9	0

yellowing and scorching was observed on the sprayed plots.

The third series of trials was that conducted by Large, Storey, Taylor, and Yule (1954) over the 6 years, 1948-53, at Terrington, south of the Wash, and on silt land at the border of the Fen blight zone (fig. 5). The variety was King Edward, with good certified stocks in all years; the replicated plots were large--up to an acre in area and running the whole length of the field; and the spraying was done on contract. A 13-row tractor-hauled sprayer was used to apply 6 lb. per acre of copper oxychloride (50 percent Cu) at 100 gallons per acre, except in 1949 when a proprietary burgundy mixture was used. This high-volume spraying was compared with low-volume spraying, using an Agro air-blast machine with droplegs, and also with dry dusting. The number and timing of the respective applications were as shown in figure 9, which gives the blight progress curves for the several treatments and years. In table 7 the leading figures for the spraying treatments are abstracted.

In the course of these trials separate weighings were made from rows damaged and not damaged by the passage of the sprayer wheels. With 4 rows in 13 so damaged, the mean loss due to this cause was 4 percent of the potential yield. A deduction of 4 percent from the expected gain has therefore been made in the table. With this correction the "expected" gains are once again in close agreement with the "actual" gains as found by lifting the crop (yields subject to standard error of ±0.5 ton per acre). In these trials there was a statistically significant loss from spraying in the two hot and dry "no-blight" years, 1949 and 1952. This loss considerably exceeded the loss due to wheel damage, and it was probably caused by copper injury, as at Goole, but in this case following both insect and wheel damage in the hot dry season.

A fourth series of trials was carried out in the west Midlands over the years 1950-54 (Rosser, 1957). Here the trial variety was King Edward, the spraying was done with a knapsack sprayer, and copper oxychloride (50 percent Cu) was used at 5 lb. per 100 gallons per acre. There were always 2 and sometimes 3 applications, timed as far as possible in relation to Beaumont periods. The trials were made each year in each of the 5 counties, Cheshire, Shropshire, Staffordshire, Warwickshire, and Worcestershire. In general the epidemics were earliest in Worcestershire, and table 8 shows the leading results in this county.

Here again there was very good agreement between the expected and the actual gains, and in all cases the expected gains were within the standard error of those determined by lifting.

Occasionally, in individual trials, the estimated gain has varied significantly from that determined by lifting, owing sometimes to a greater effective prolongation of growth than that indicated between 75 percent points on the curves for sprayed and unsprayed where these have not shown the usual parallelism; and sometimes to exceptionally late bulking, to late planting, or to other causes.

In a comparable group of 32 crops of Majestic and King Edward, all planted about the same time--the first half of April--and all in the southern blight zone, on which fortnightly liftings were made in supplementary work on the crop check surveys in 1956, 15 reached the 75 percent stage, or were burned off, shortly before the end of August, and 17 did not reach this stage until mid-September. The mean yields, in tons per acre, for the two groups are shown in table 9.

The mean potential yield for both groups of crops was about 12 tons per acre. The percentages of the potential crop present on the several dates were, therefore, as shown in table 10.

The percentages in table 10 corresponded very closely to the normal growth curve in figure 8, and the mean gain from prolongation of growth from the end of August to mid-September, 1.3 tons per acre, was in exact accordance with expectation.

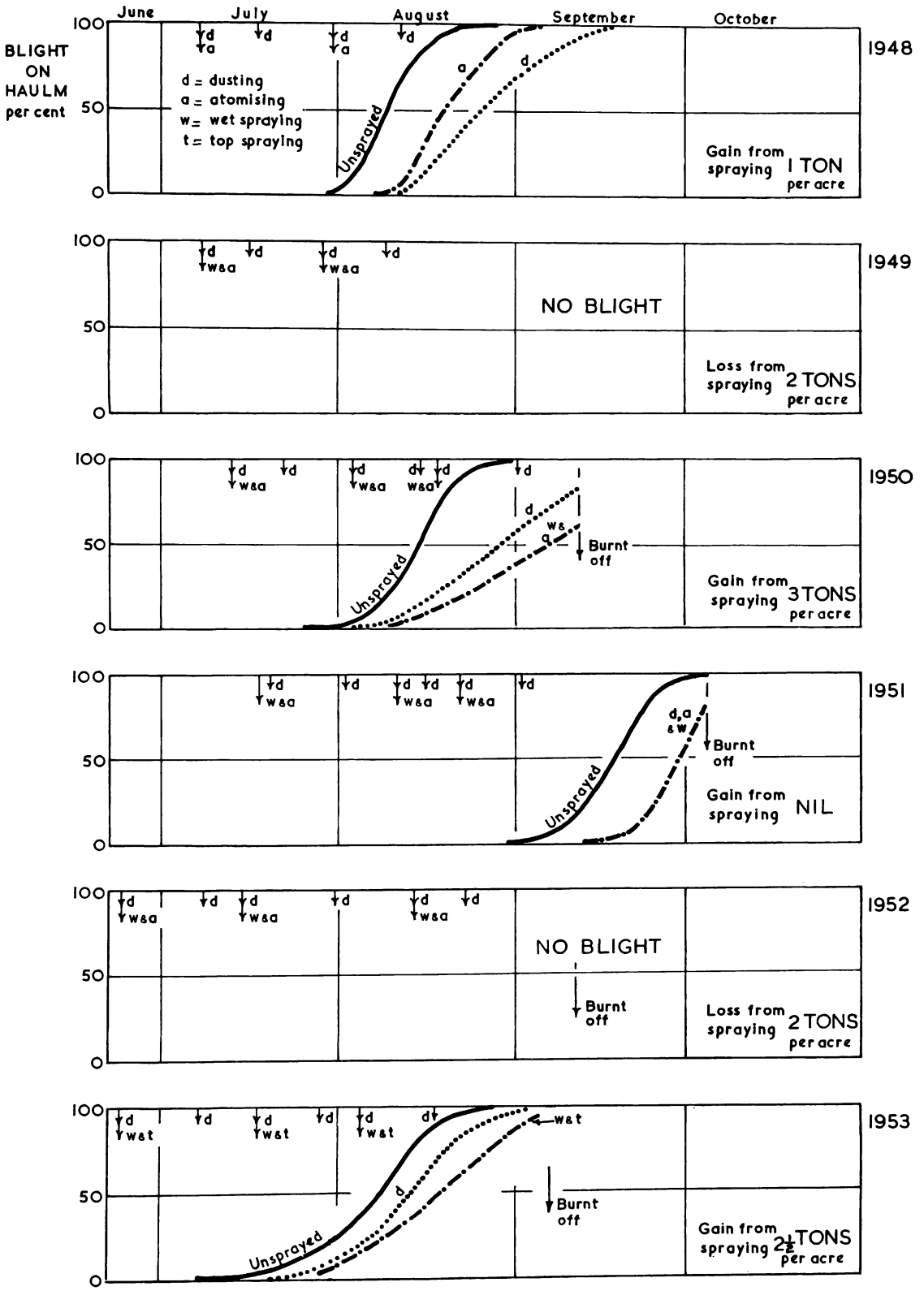


FIGURE 9.--Progress charts of blight on unsprayed, sprayed, and dusted King Edward potatoes in trials at Terrington, near the Wash, 1943-53, showing dates of applications and approximate gains and losses from spraying.

TABLE 7.--Gain or loss from spraying King Edward potatoes at Terrington, 1948-53

Year	Date when blight on unsprayed haulm reached--		Prolongation of growth by spraying	Total yield of unsprayed plots	Gain from spraying	
	0.1 percentage stage	75 percent stage			Actual by lifting	Expected from 75 percent dates
			Days	Tons/acre	Tons/acre	Tons/acre
1948.....	July 30	Aug. 13	12	16.3	+0.9	+1.9
1959.....	([1])	([1])	0	14.8	-2.0	-.6
1950.....	July 24	Aug. 17	25	14.0	+3.0	+3.0
1951.....	Aug. 30	Sept. 22	10	16.2	-.1	-.6
1952.....	([1])	([1])	0	18.9	-1.8	-.7
1953.....	July 7	Aug. 13	13	16.6	+2.6	+2.3

[1] No blight.

TABLE 8.--Gains from spraying King Edward potatoes in Worcestershire, 1950-54

Year	Date when blight on unsprayed haulm reached		Prolongation of growth by spraying	Total yield of unsprayed plots	Gain from spraying	
	0.1 percent stage	75 percent stage			Actual by lifting	Expected from 75 percent dates
			Days	Tons/acre	Tons/acre	Tons/acre
1950.....	July 24	Sept. 4	22	12.9	2.3 ± 0.9	1.5
1951.....	July 31	Sept. 20	10	11.8	.5 ± .7	.3
1952.....	Aug. 7	Sept. 16	14	10.4	1.0 ± .6	.5
1953.....	July 24	Aug. 24	3	10.5	-.4 ± .7	.3
1954.....	July 20	Sept. 4	16	14.4	1.6 ± .3	1.3

TABLE 9.--Mean yields of 32 crops of Majestic and King Edward potatoes in southern blight zones as related to date blight reached 75 percent stage, 1956

75 percent blight stage reached	Crops	Total yield				
		End of July	Mid-Aug.	End of Aug.	Mid-Sept.	End of Sept.
	Number	Tons/acre	Tons/acre	Tons/acre	Tons/acre	Tons/acre
End of Aug.....	15	6.1	8.4	9.9	10.3	10.3
Mid-Sept.....	17	5.6	7.6	10.3	11.5	11.6

TABLE 10. --Yields in table 9 expressed as percentages of mean potential yield (12 tons per acre)

75 percent stage reached--	Crops	Percentage of potential yield				
		End of July	Mid-Aug.	End of Aug.	Mid-Sept.	End of Sept.
	Number					
End of Aug.....	15	51	70	83	86	86
Mid-Sept.....	17	47	63	86	96	97
Expected yield (see fig. 8).....	--	50	72	87	96	100

Further work is required on checking the normal growth curve and in adapting the method of estimating blight losses for use on individual crops. Enough has already been done, however, to show that the present curve can now reasonably be employed without further delay for the computation of average blight losses over a number of seasons, in the several blight zones of England and Wales.

PROTECTIVE SPRAYING: MACHINES AND MATERIALS

Freshly prepared bordeaux and burgundy mixtures, although unsurpassed in point of efficiency, are now very little used for potato spraying in England and Wales. Their place has been taken by copper oxychloride and cuprous oxide preparations, usually applied at the same copper dosage (2.5 lb. Cu per acre). These preparations are much less resistant to washing off by rain than the bordeaux and burgundy mixtures (Large, Beer, and Patterson, 1946), and they save the need for a certain amount of skill and labor in the preparation of the spray fluid on the field. Unlike bordeaux and burgundy mixtures, copper oxychloride and cuprous oxide preparations can be used for low-volume application. Generally, they give nearly as good protection of the haulm as the bordeaux and burgundy mixtures, except where high retention is really needed to resist heavy rain, as in the Fens in the years 1954 and 1956, when the performance of the newer preparations was very disappointing.

Much of the more efficient spraying is now done on contract with high-volume machines (applying 80 to 100 gallons per acre), and with wide booms (11- to 15-row widths) to keep down wheel-damage as much as possible. The contract charge for such spraying, with 5 lb. per acre of copper oxychloride (50 percent Cu) was about 45s. per acre per application in 1956. Two sprayings are usually applied, three are sometimes given.

Air-blast low-volume sprayers (Agro sprayers) applying copper oxychloride or cuprous oxide in 10 to 20 gallons of water per acre came into fairly extensive use after 1945. These machines, with nozzles set well down between the rows on droplegs, gave about as good results as high-volume machines applying the same materials. But owing to the weight, complexity, and high cost of the Agro sprayers, they have since been replaced by low- or medium-volume machines of the type introduced for the application of 2, 4-D and MCPA weed killers on cereals. These machines apply 20 to 40 gallons of spray fluid per acre at pressures of 50 to 100 lb. per sq. in. through fine nozzles. Such machines, which are light, relatively inexpensive, and often already on the farm, make it easy for farmers to do more potato spraying themselves. The old difficulty of water cartage is greatly reduced. But it is doubtful if spraying the plants from above only, as is usual with these machines, gives as good protection of the foliage as spraying with the traditional droplances (Large and Taylor, 1953). As yet the machines are often not sufficiently adapted mechanically for the particular and rather exacting job of potato spraying; infinite trouble, as well as very poor spraying, will result from blockage of the fine nozzles unless the filters are kept in good order. With copper oxychloride (50 percent Cu) at 400s. per cwt., the cost to the farmer for materials only, is 18s. per application.

A considerable amount of dusting is done in the Fens. At one time 6 to 7 dustings were given in the course of the season, but the more usual number of dustings is now 3 or at most 4. Dusting is now by no means cheap in comparison with spraying. Copper dusts containing 20 percent Cu are the most popular, and these are applied at 16 to 20 lb. per acre. Such dusts cost about 170s. per cwt. in 1956, so that the cost of materials per application was about 30s. It is generally reckoned that 2 dustings are equivalent to one thorough spraying in protective effect, but dustings may do rather better than this if the applications are well timed in relation to the blight attack.

Since 1950 a considerable acreage of potatoes is now sprayed from the air in eastern and southern England. Both helicopters and fixed-wing aircraft are used. The standard amount of copper oxychloride is generally applied in 3 to 6 gallons of water per acre. The contract charge for this air spraying has

been about the same as for spraying with ground machines. Although many farmers have been well satisfied with the results and the wheel damage from the passage of ground machines is avoided, there is still a lack of critical trial data for assessing the efficiency of this form of application.

Dithiocarbamates were not launched on the market for potato spraying in England and Wales until 1957, and little experience has so far been gained of their use under English conditions. If the need for frequent renewal of the spray deposits (Large and Beer, 1946) can be overcome, they may have a useful field of application (Cox, 1957), especially in the eastern parts of the country where some copper injury (following insect attack) is caused by routine spraying in the warmer and drier seasons. In the wetter seasons when more blight develops, copper could be substituted for the later applications.

THE GAIN FROM SPRAYING

In estimating the net gain from spraying, one difficulty is in making fair allowance for the damage caused by the passage of the sprayer through the crop. In the trials at Terrington this damage was found to amount to 4 percent of the potential crop when a 13-row sprayer was used. The corresponding damage with an 11-row machine would be 5 percent, and with a 7-row machine as much as 7 1/2 percent. But the crops at Terrington were exceptionally dense and heavy; in lighter and more upright crops the damage is obviously less, but much spraying is done, especially by farmers, with machines of quite narrow row-width, and care is not always taken to drive the sprayer over old wheel tracks when repeating the applications. For the purpose of the present estimates a mean figure of 3 percent is taken for loss of potential yield by wheel damage.

There is also the matter of the copper injury to the haulm in hot dry seasons. This effect is certainly seen occasionally, but it must not be exaggerated. In order that the present estimates may be correct, at least in principle, a small loss from copper injury is assumed in the Fen and southern zones only, in the years (3 in 10) when the 75 percent blight stage is not reached until the end of September, if at all. The figure is put as equal to that by wheel damage, thus, in these zones and years, the total for loss by spraying damage is estimated at 6 percent of the potential crop.

As against this, the figures taken for gain from spraying in the blight years are put at their very best, and are such as can be achieved only by efficient spraying, with two well-timed applications in general, and three in seasons with exceptionally heavy rain. It is assumed, for simplicity of estimation, that the net gain from spraying (after deducting the loss by wheel damage) is equivalent to two clear weeks' prolongation of growth, at whatever time in August or early September it may occur, and that in effect the actual prolongation is some days more than this to compensate for the wheel damage. On this basis the gains and losses, according to the time at which blight reaches 75 percent on the unsprayed field, for maincrops of 10-ton potential yield are as shown in table 11.

For a 15-ton potential crop, which is the most common level of crops in trials, and on the better commercial crops on which most spraying tends to be done, all the above figures would be increased by a half. This increase would give a net gain from spraying in the worst blight years of about 2 tons per acre and for the other blight years (75 percent stage at end of August) about 1 1/4 tons per acre, despite the losses by wheel damage. Quite often, in individual cases, higher gains from spraying, up to 3 tons per acre, are obtained; but growers in the Fens, in such years as 1954 and 1956, would have been very content with gains of about 2 tons.

If the data from tables 1 and 11 are combined, the gains from spraying on maincrops, over the 10 years, 1947-56--assuming the

TABLE 11.--Net gain or loss from spraying according to the date when blight reaches the 75 percent stage on a potential crop yield of 10 tons potatoes per acre

75 percent blight on unsprayed crops by--	Yield of unsprayed crops	Net gain from spraying	Unrecovered loss		Potential crop
			By wheel damage	By blight	
	Tons/acre	Tons/acre	Tons/acre	Tons/acre	Tons/acre
Mid-August	7.2	1.4	0.3	1.1	10
End of August	8.7	.8	.3	.2	10
Mid-September	9.6	.1	.3	0	10
End of September	10.0	-.6	.3	0	10

TABLE 12. --Gain from routine spraying over 10 years (1947-56) for maincrop potatoes in England and Wales

Zone	Percentage of total acreage	Mean net gain from spraying	Percentage of acreage sprayed	Mean gain for zone	Contribution to national gain
		Percent		Percent	Percent
Southwest	8	11.0	20	2.20	0.18
Fens	13	5.5	55	3.02	.39
Southern	51	2.4	40	.96	.50
Northern	28	.3	5	.01	--
England and Wales	--	--	30	--	1.07

TABLE 13. --Gain from spraying only where needed over a 10-year period in England and Wales, 1947-56

Zone	Percentage of total acreage	Mean net gain from spraying	Percentage of acreage sprayed[1]	Mean gain for zone	Contribution to national gain
		Percent		Percent	Percent
Southwest	8	11.0	20 (10)	2.20	0.18
Fens	13	7.2	55 (6)	3.95	.52
Southern	51	4.0	40 (5)	1.60	.80
Northern	28	0	5 (0)	0	0
England and Wales	--	--	30	--	1.50

[1] Number in parentheses refers to years in 10 in which spraying is needed and assumed done.

amount of spraying done had been at its recent level over the whole period, that all of it had been efficient spraying, and that it had been done every year--would have been as shown in table 12.

Thus, if routine spraying were done every year on the percentage of the acreage now receiving any protective treatment and all this spraying gave the best results obtainable in practice, the mean gain over a 10-year period would be only about 1 percent of the potential maincrop yield from the country as a whole. This would represent a saving of about one-eighth of the total defoliation loss due to blight (table 1). With the actual mean yield at about 7.5 tons per acre, the mean potential yield (were there no blight) would be about 8.2 tons per acre. The gain would therefore be about 0.09 ton per acre, or a difference of one point (0.1 ton) on the average yield for the country.

If the price of potatoes is £11 per ton, this gain, on a half million acres of maincrops, would represent a gain of some 50,000 tons of potatoes worth about £550,000. With the mean cost of spraying of 2 applications by contract at 45s. per acre on 30 percent of the acreage each year, this gain would be obtained at a cost to the growers of about £675,000.

If the spraying were done on the same percentage of the acreage in each zone as that shown in table 12, but only in blight years, or, to be more precise, only in those zones and seasons where the 75 percent stage is reached by the end of August, then the analysis of gains and the saving in spraying would be as shown in table 13. Spraying on this basis would increase the long-term gain to about 0.15 ton per acre, and through the avoidance of spray damage in the "no-blight" years it would save nearly half (46 percent) of the spraying over a 10-year period. Thus, there would be a mean annual gain of 75,000 tons of potatoes worth about £825,000 at a cost for spraying of about £310,000. The justification for forecasting is that it can help toward the attainment of this better result.

In fact, protective spraying in England and Wales is not done either wholly by routine (table 12) or wholly according to need (table 13). Also, if the inefficiency of some of the spraying is considered, the mean national

gain is probably nearer the lower figure of 0.1 ton per acre on the long-term average.

In a bad blight year, such as 1953, however, the gain from spraying may amount to 0.35 ton per acre in the mean yield for the country. Such a gain is very substantial, reckoned on the whole acreage, but its value is lessened by the fact (brought out in table 3) that in the blight years the national yields tend to be above average, as the rain that favors the development of blight is even more favorable for the growth of the crop. In 1953, the actual yield was 8.7 tons, as against the average of 7.5 tons for the 10-year period, and more potatoes than were gained by spraying must have gone for stock feed at £4 per ton. The year 1953 was one in which the yield was exceptionally high, but the mean yield for the 5 blight years in the period 1947-56 was 8 tons per acre, as against a mean of 7.1 tons for the other 5 years. The years giving rise to shortage of supplies (and high prices) are not usually the blight years in England and Wales--they are the drought years in which there is little or no blight.

Despite these national considerations, the gain from spraying achieved by individual growers, or groups of growers in particular districts, is often very considerable. At present prices a net gain of only about 8 cwt. per acre will pay for two sprayings, and in a blight year in some districts there is a likelihood of obtaining 20 or even 40 cwt. increase for this outlay.

Routine spraying (spraying every year) is profitable in the southwest zone, and just profitable in the Fen zone. In the large southern zone, protective spraying is only profitable if it is done according to need. This implies a nice discrimination in selecting the crops to be sprayed--those of the higher potential yield and those of the more susceptible varieties, such as King Edward, which gives the best return from spraying--and an equally nice judgment of seasonal conditions. The forecasting work in England and Wales is designed to help in this latter connection, by indicating the time at which the first spraying can be given to the best advantage in blight years and by discouraging spraying in years when little blight is likely to develop.

BLIGHT IN THE TUBERS

Losses due to blight infection of the tubers vary greatly from crop to crop in England and Wales. Even in bad years for tuber infection more than half the crops suffer no loss, or a very trivial loss, from this cause. But, against this, a small proportion of the crops always suffer a heavy loss, even up to 2 tons per acre or more, and now and then the loss of an entire clamp is reported, owing to heating and secondary rots following blight. The occasional severe losses tend to color the picture and give the impression that the overall loss from blight in tubers is much greater than is in fact the case; while the sporadic and extremely variable incidence of the loss renders it extremely difficult to assess by survey methods.

Losses due to blight in the tubers may be divided into two fairly distinct parts, namely:

1. Losses caused by infection of the tubers in the ground before lifting and apparent at lifting.
2. Losses caused by infection at or shortly before lifting, and developing in store.

In some countries the second of these losses may be by far the greater, for if the potatoes are lifted when the haulm is still partly green and with the blight fungus actively sporulating on it and the lifting is done in wet weather, very extensive infection of the exposed tubers is to be expected and considerable losses will occur in store. It is also possible that some infection at lifting may occur from spores surviving in the soil for 10 days after the haulm is dead, as reported by Murphy (1921). In England and Wales, however, most of the maincrops are not lifted until October, and by or before that time much of the haulm has either been killed off by blight or by normal autumnal dying down. It is generally only in the late-maturing crops (notably in the northern blight zone), in some crops kept green unprofitably long by protective spraying, and in crops lifted early to supply an immediate market, that there is much real opportunity for infection at lifting to occur. Even so, if the lifting is done in a dry spell or the blight lesions on the haulms have dried up, very little infection may occur.

Opportunity for the tubers to be infected in the ground before lifting is not restricted to those comparatively few crops in which the haulm is still partly green near lifting time. Infection occurs wherever the soil permits access to the tubers of spores washed down by rain, and it persists over the entire period during which blight is sporing on the haulm--from the beginning to the end of the foliage attack, and perhaps for 10 days afterward. Moreover immature tubers are considerably more susceptible to infection than mature tubers at lifting (Boyd and Henderson, 1953). Thus, infection in the ground before lifting is responsible for the most widespread occurrence of blight in the tubers and possibly for the greater part of all the loss from this cause in England and Wales.

Losses Due to Infection Before Lifting

Weighings of blighted tubers carried out in the crop-check surveys since 1953 now provide good data on the waste due to blight infection before lifting in a representative sample of some 2,000 crops in England and Wales each year. Table 14 shows the mean

TABLE 14.--Mean losses of potatoes caused by blight infection before lifting, England and Wales, 1953-56

Blighted tubers	1953	1954	1955	1956
Hundredweight per acre	2.5	3.4	0.2	2.9
Percentage of crop....	1.3	2.0	.1	1.6

losses in all these crops over the country as a whole in the years 1953-56.

Thus, in the three blight years, 1953, 1954, and 1956, the mean loss was 2 percent; and in the dry year with very little blight on the haulm, the loss was negligible. The distribution varied greatly according to region, as shown by the maps (fig. 10) for 1953 and 1954. The variation according to region was from less than 1 cwt. to 10 to 15 cwt. per acre. In general, the losses were highest where the blight attack on the haulm had been earliest and most severe, with the important exception of the relatively heavy losses shown in parts of the northern zone in 1953. This was in accordance with past experience (Moore, 1946, 1948) that late attacks of blight in the north may, in some years but not in all, cause heavy losses by tuber blight.

The frequency of occurrence of different levels of loss among the crops is shown in figure 11 for 1954, the worst of the 4 years for blight in tubers. This diagram brings out the salient fact about the distribution of losses due to blight in tubers: The large number of crops that scarcely suffer at all; and the few crops in which the loss is high. In 1954, 57 percent of the 2,109 crops in the survey had no blighted tubers (or less than 1/2 cwt. per acre) before lifting; about 25 percent had 1 to 5 cwt. per acre; about 8 percent had 5 to 10 cwt.; and there were sharply decreasing percentages at higher rates. Although the mean national loss was only 3 1/2 cwt. per acre, more than 100 crops in the 2,109 had a loss of over a ton per acre, and two had over 3 tons.

No firm association can yet be established between the level of tuber infection and the type of soil; heavy losses may occur occasionally, and negligible losses very frequently on both heavy and very light soils. But the level of loss certainly varies according to the potato variety. In the 3 years, 1953, 1954, and 1956, the breakdown according to variety of the mean losses in the crop-check surveys is shown in table 15.

The mean loss was over twice as great in King Edward as in Majestic. In Arran Banner and Gladstone, the loss was over six times as great as in Majestic. Indeed, in the histogram for 1954 (fig. 11) of the 88 crops shown in which the loss was over 1 ton per acre, 23 were Arran Banner, 38 King Edward, 7 Gladstone, and only 12 Majestic,

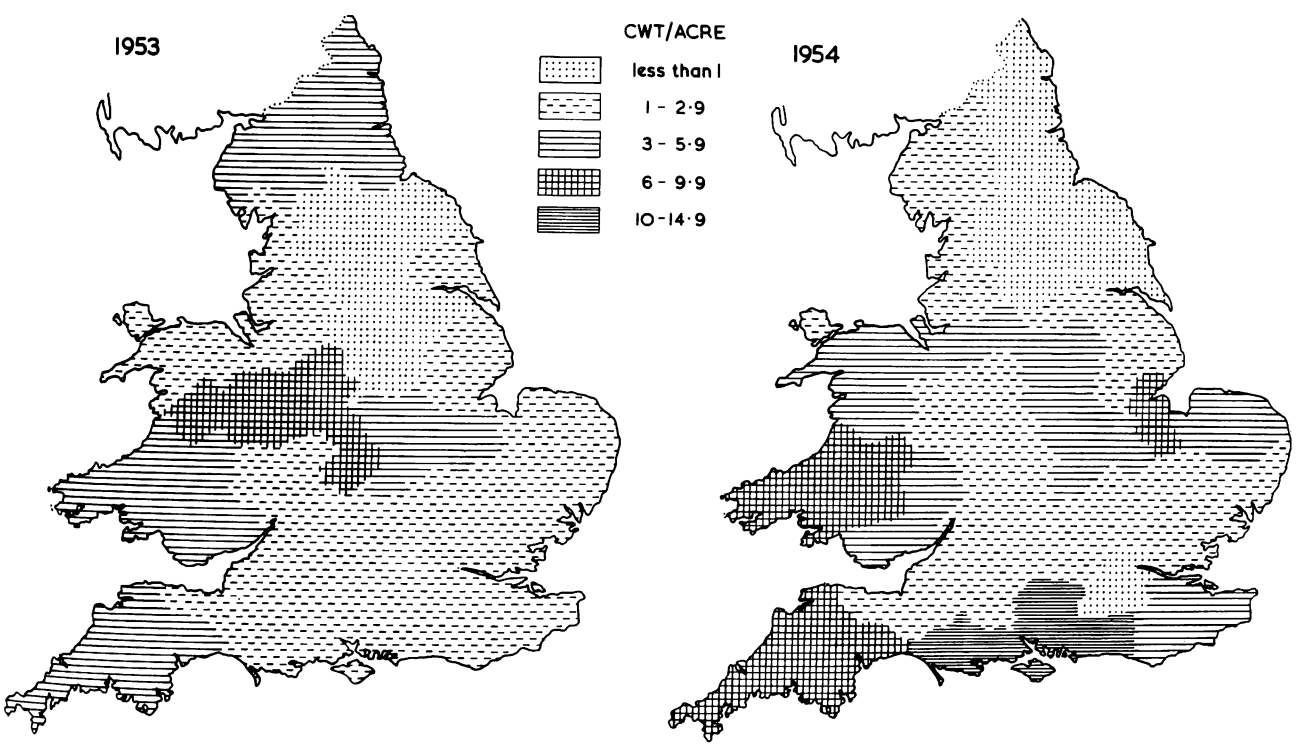


FIGURE 10.--Regional distribution of losses due to blight in tubers, 1953 and 1954.

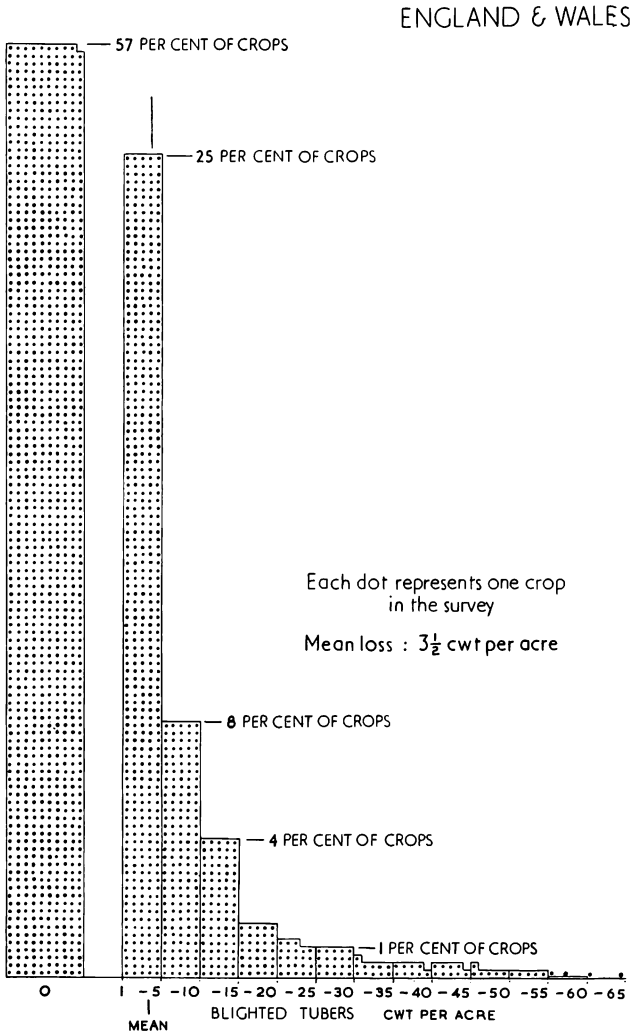


FIGURE 11.--Frequency of different levels of blight in tubers before lifting in a survey of 2,109 crops in England and Wales, 1954.

despite the preponderance of crops planted in Majestic.

The estimation of blighted tubers in the crop-check surveys has not yet been done in all types of season in which tuber infection may be prevalent. The reports on the diseases of the crops in England and Wales (Moore, 1946, 1948, and earlier bulletins) indicate that only the very dry years (like 1955) in which there is little or no blight on the haulm at the end of September can be regarded as "no-blight" years for the disease in the tubers. Years in which the 75 percent stage on the haulm is not reached until mid-September may be among the worst for blight in the tubers; and years in which this stage is reached at the end of August (blight-years for the disease on the haulm) are most frequently also bad years for blight in the tubers, although sometimes they are not. It is the slope of the blight progress curve, rather than the 75 percent date, that affects the amount of blight in the tubers. The opportunity for tuber infection is greatest when the attack on the haulm is long-drawn-out, least when it is rapid.

Losses Due to Infection at Lifting

The proportion of the maincrops in England and Wales in which the tubers may be infected from blighted haulm at lifting can be judged to some extent from table 16, which is based on observations made in the course of crop-check surveys.

It is evident that in more than two-thirds of the crops over this period of years, the haulm was dead well before lifting began, and that in all except the 2 years 1951 and 1952, in which the 75 percent blight stage was in mid-September, there was little growth left in the rest of the crops.

The only direct survey evidence bearing upon the amount of infection occurring at lifting and developing subsequently in the clamps, is that from a systematic sampling of 700 clamps in all parts of the country carried out by advisory mycologists in the 1942-43 storage season (Moore, 1948). In this survey the average loss from rots in March was about 6 percent--half of which was attributed to blight. In only 38 (5.4 percent) of the clamps did the loss from blight exceed 10 percent, although in several it reached 30 percent, and in one 43 percent. These figures indicate the same kind of distribution of losses in clamps as that shown in figure 11, for blighted tubers in the ground before lifting. The year 1942 was one with much blight in September (75 percent stage about the end of August in the worst-affected parts of the south, and a week or two later elsewhere) and the progress of the attack was fairly rapid. It was recorded at the time of the survey that the losses from tuber blight had been somewhat greater in the previous year, 1941, when the attack on the haulm was more drawn-out. In some years, therefore, the losses in clamps may be higher than in 1942, but in some other years, such as 1955, the losses are undoubtedly less. It may not be unreasonable, therefore, to take the mean figure of 3 percent, carefully determined by accurate sampling in 1942-43, as a provisional estimate of the mean annual loss caused by blight in clamps in England and Wales.

This loss is made up of the tubers infected at lifting together with a fairly high proportion of the tubers infected in the soil before lifting. Many of these latter, where they are obviously and severely blighted, are rejected when the crop is picked by hand, and they are not put into the clamp. The proportion is quite indeterminate, and must depend upon the weather at lifting, the type of labor employed, and other factors.

TABLE 15.--Mean losses of potatoes from blight infection of tubers before lifting, according to variety, 1953, 1954, and 1956

Variety	Crops in survey			Blighted tubers before lifting		
	1953	1954	1956	1953	1954	1956
	Number	Number	Number	Percent	Percent	Percent
Majestic	1,019	954	1,005	1	1	1
King Edward	379	566	591	2	3	2
Arran Banner	120	92	62	4	9	11
Gladstone	41	28	16	8	10	17
All varieties	2,070	2,109	2,057	1.5	1.7	1.7

TABLE 16.--Percentage of potatoes lifted in relation to state of haulm before lifting, England and Wales, 1951-56

State of haulm some days before lifting	1951	1952	1953	1954	1955	1956
	Percent	Percent	Percent	Percent	Percent	Percent
Dead	66	57	84	85	56	94
Little growth left	25	34	16	15	44	6
Much growth left	9	9	0	0	0	0

From a review of all the available evidence it would appear that the mean total loss from blight infection of the tubers for all varieties, and for England and Wales as a whole, is about 3 percent of the crop, and that this loss is made up of about 2 percent apparent at lifting and 1 percent developing in store.

This estimated mean loss due to blight in the tubers is less than half of the estimated mean loss caused by premature defoliation (table 1); but it is a more constant loss, and it probably occurs in all except the very dry "no-blight" seasons; that is to say in 8 or 9 years out of 10.

CONTROL MEASURES

The principal measures for the reduction of losses due to blight infection of the tubers in England and Wales are (1) efficient earthing up of the rows to insure good soil cover over the tubers; (2) the postponement of lifting until the haulm has been dead for 10 days; and, (3) the avoidance, as far as is practicable, of varieties like Gladstone, known to be very susceptible to tuber infection.

Protective spraying of the haulm has some effect in reducing tuber infection in the ground before lifting, by keeping blight off the haulm for about a fortnight in the early stages of the attack and thereby reducing the period during which washing down of spores can occur. But in England and Wales protective spraying is rarely employed for the purpose of protecting the tubers by keeping blight off the haulm altogether. This would often require far more applications than the two or at most three that are generally given, and it would scarcely be economic. As it is, protective spraying quite often prolongs the growth of partially blighted haulm beyond the stage at which useful increase of yield can result, and thereby increases the amount of tuber infection.

Cutting and removing the blighted haulm, as a measure for decreasing the amount of infection of the tubers, was advocated in the 19th century; indeed, almost as soon as the disease appeared in Europe. However, the measure was expensive and difficult to carry out on any large acreage. In the early 1930's one of the chemical manure and sulfuric acid companies in Norfolk carried out experiments on the spraying of the haulm with diluted sulfuric acid as a substitute for mechanical destruction. The kill of the haulm was quite spectacular, and by 1934 several large growers in Norfolk and Lincolnshire who had been persuaded to give the new process a trial were hailing it with great enthusiasm. They sprayed 3,500 acres in that year and claimed that crops from unsprayed areas, on being taken from the clamps, frequently contained up to 50 percent of blighted tubers, whereas those potatoes from the areas "burned-off" with sulfuric acid were almost completely free from the disease.

The first critical trial was carried out by Bates and Martin (1935) under what can now be seen to have been optimum conditions, on a crop of King Edward at Terrington, near the Wash. A 10 percent solution of B.O.V. (Brown Oil of Vitriol, 77 percent H_2SO_4) was applied to the green haulm at 100 gallons per acre on September 16, 1934, when only a few plants were yet affected by blight, and, as the yields showed, almost the whole obtainable crop was already under the plants. (See fig. 8 for expectation of increase of crop after September 16.) After the date of spraying blight spread all over the unsprayed plots, giving opportunity for washing down of spores for some 3 weeks, until the potatoes were lifted on October 6, when much of the blighted haulm was still green. The total produce from the sprayed and unsprayed plots was stored separately in the same clamp, and examined for blighted tubers at the end of January 1935, when the clamp was opened. Table 17 shows the results.

TABLE 17.--Percentage of King Edward tubers with blight in clamp from plots sprayed with sulfuric acid, Terrington, January 1935

Treatment	Total yield	Blighted tubers	
	Tons/ acre	Cwt./ acre	Percent of crop
Unsprayed.....	11.9	9.1	3.9
Burned off with 10 percent B.O.V. ..	12.0	1.6	.7
Standard error.	±.03	±1.4	--

These results were obtained under about optimum conditions. The total percentage of blighted tubers in the unsprayed crop was about 4 percent, and the acid spraying, done when there was still very little blight on the haulm, reduced the figure to about 1 percent.

Since 1935, "burning-off" the haulm has become firmly established in practice, and indeed it is extremely popular among potato growers. This is not only because it can, in some circumstances, save a good deal of blight in the tubers, but because it undoubtedly facilitates lifting and kills weeds. It "cuts losses," saves further concern about the progress of blight in the crop, and, apart from the lifting, it puts an end to the job for the season.

Most of the acid spraying at the present time is done by contractors, who apply 20 gallons of undiluted Brown Oil of Vitriol per acre with special acid-resistant machines. The contract price for this treatment in 1956 was about £4 per acre, the value of about 7 cwt. of ware potatoes.

In 1951, when there was a world shortage of sulfur, sodium and potassium arsenite mixtures were introduced for haulm destruction in England and Wales. Their use has increased very rapidly since that time, despite the availability of acid. In 1956 about half of all the destructive spraying was being done with arsenites and half with acid. The arsenites, usually in the form of liquid preparations containing 10 lb. of As_2O_3 per gallon, are applied both by high- and low-volume machines, at the rate of 1 gallon in 80 to 100 or in 20 to 30 gallons of water per acre, respectively. The action of the arsenites is slower than that of acid--the leaves take up to a week to go brown, while those sprayed with acid are blanched and limp on the day of application; but there is little to choose in point of eventual completeness of destruction of the haulm. The contract charge for spraying with arsenites in 1956 was considerably less than that for acid, being about £2 15s. 0d. per acre. Arsenites have the advantage that they can be applied by farmers themselves, with sprayers available on the farm that are often unsuitable for the application of acid.

The first systematic trials of haulm destruction at a number of centers and over several years, in England and Wales, were those carried out by the National Agricultural Advisory Service in 1951-53, for the purpose of testing substitutes for sulfuric acid (Large, 1952b, 1952c, 1954). The destructive spraying was done at each center at a time in accordance with practice in the district, and the percentage of blighted tubers in the sprayed and unsprayed parts of the crops was determined both at lifting and after a period of 6 weeks in storage. The mean results, with acid, for 9 trials in 1951, 11 in 1952, and 11 in 1953, were as shown in table 18.

Despite the fact that many of the untreated plots in these 31 trials were lifted while there was still a little growth left in the haulm, blighted tubers from the unsprayed plots exceeded 3 percent after storage in only 9 trials and were less than 1 percent in 17 trials.

In the crops where heavier tuber infection occurred, the destructive spraying showed advantages varying according to the date on which it was done, the progress of blight on the unsprayed crop, the lifting date, and the rainfall at lifting. All these variable factors are illustrated for 1953 in figure 12, which also shows the use made of blight progress curves in the study of haulm destruction. As a result of the trials as a whole it was concluded that destructive spraying, whether with acid or with arsenites, as usually carried out in practice, can at best save only about half of the infection occurring in the ground before lifting. Here and there, it may save considerable infection at lifting if the weather happens to be wet and the haulm would not

TABLE 18.--Percentage of blighted tubers at lifting and after storage in spraying trials with sulfuric acid, 1951-53

Treatment	Blighted tubers					
	1951		1952		1953	
	At lifting	After storage	At lifting	After storage	At lifting	After storage
	Percent	Percent	Percent	Percent	Percent	Percent
Acid sprayed	2.2	2.6	0.4	0.9	1.7	2.5
Untreated	2.2	2.8	1.3	2.4	3.5	3.7

otherwise have been dead in time. Similar results were obtained with mechanical haulm-cutters or pulverizers, which are now available and are used on a relatively small acreage in England and Wales; and also by spraying with certain tar oil fractions, which have not come into any extensive use in England and Wales but are nevertheless excellent non-poisonous and noncorrosive haulm killers (Large, 1952b, 1952c, 1954).

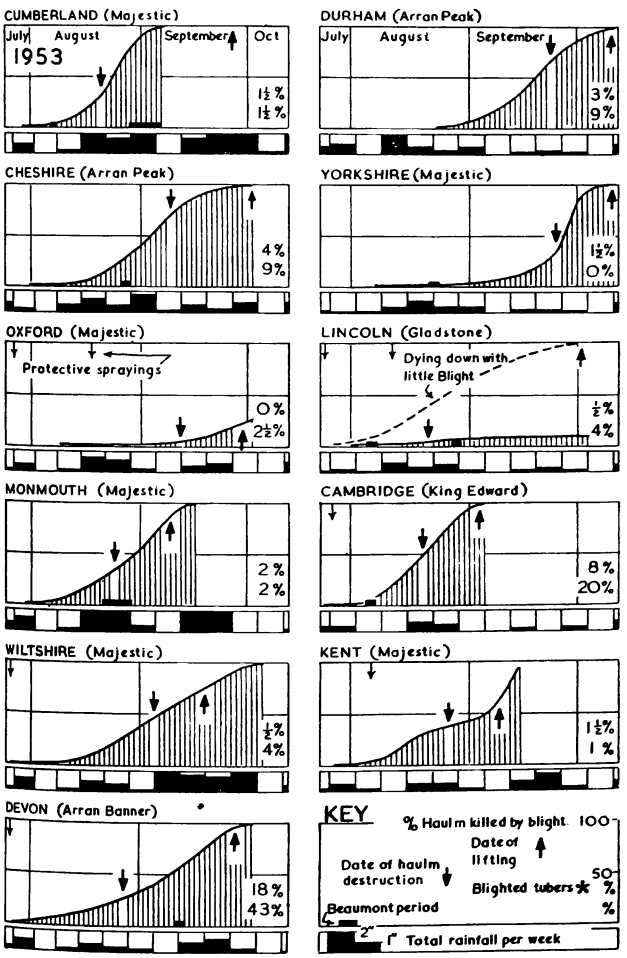


FIGURE 12.--Percentage of blighted tubers in relation to progress of blight on haulm, dates of haulm destruction and lifting, and rainfall at 11 trials in England and Wales in 1953. Upper figures indicate percentage of blighted tubers with haulm destruction; lower figures indicate percentage of blighted tubers without haulm destruction.

GAINS AND LOSSES FROM HAULM DESTRUCTION

The amount of haulm destruction now done in England and Wales may be judged from the percentages of the crops in the crop check surveys on which farmers carried out this treatment: 17 percent in 1953; 22 in 1954; 10 in 1955; and 30 in 1956.

In 1956 haulm destruction was carried out on 47 percent of the 591 King Edward crops; on 21 percent of the 1,005 crops of Majestic; and on 26 percent of the 461 crops of other varieties.

The mean weights of blighted tubers per acre, before lifting, in the untreated crops, and in the crops on which haulm destruction was done, with or without protective spraying, are shown in table 19.

Apart from the indication that the mean weight of blighted tubers was increased in 1954 by protective spraying without subsequent haulm destruction, these mean figures from some 8,000 crops provide no evidence of any general reduction of blight in tubers as a result of haulm destruction. However, haulm destruction was probably done where it was most needed, so that the figures are not inconsistent with the probability that there were considerable gains on some crops.

Against this, reduction of blight in tubers by destructive spraying of the haulm can generally only be achieved at the expense of some loss of the healthy crop. The loss caused by stopping the growth of the haulm too soon in destructive spraying can be judged from the diagrams in figure 12 and the mean worth of each week's growth in August and September as shown in figure 8. If the haulm is destroyed when blight reaches the 75 percent blight stage, then the loss of yield due to shortening of the growing period will be

TABLE 19.--Mean weights of blighted tubers per acre before lifting after various treatments, England and Wales, 1953-56

Treatment	Mean weight of blighted tubers before lifting			
	1953	1954	1955	1956
	Cwt./acre	Cwt./acre	Cwt./acre	Cwt./acre
Haulm destruction after protective spraying.....	3.2	4.2	0.02	2.7
Haulm destruction only.....	3.4	3.4	.01	3.1
Protective spraying only...	2.8	5.6	0	3.1
No protective or destructive spraying.....	2.3	2.8	.40	2.4

negligible. However, there will then be little reduction of the period during which the spores can wash down into the soil, and therefore little hope of much reduction in the amount of blight in the tubers before lifting. If, on the other hand, the destruction is done at the 25 percent blight stage or earlier, there can be considerable reduction of the period during which the spores can wash down, but there will be a curtailment of useful growth.

This question of the crop sacrifice attendant upon haulm destruction was investigated extensively in the spraying trials carried out on King Edward in all the counties of the West Midlands over the years 1950-54 (Rosser, 1957). In each trial there were plots that received no protective spraying but which were burned off in early August (mean date, August 8); at the end of August (mean date, September 1); and in mid-September (mean date, September 18). The mean total yields and weights of blighted tubers in the 30 trials were as shown in table 20. The expected reduction in yield from the premature killing of the haulm, as read from figure 8, is added for comparison.

TABLE 20.--Effect of haulm destruction at various dates on total yield and on weight of blighted tubers in trials on King Edward potatoes, England and Wales, 1950-54

Item	Mean date of haulm destruction			
	Aug. 8	Sept. 1	Sept. 18	Sept. 30
Blighted tubers.....tons/acre..	0.25	0.40	0.60	0.65
Total crop.....tons/acre..	9.50	12.60	13.40	13.80
Percentage of potential yield.....	68	91	97	100
Expected percentage (fig. 8).....	62	88	97	100

These trials provide confirmation that within practical limits the growth curve for Majestic, given in figure 8, is also valid for King Edward in England and Wales. They also left no doubt about the loss of crop involved when premature haulm destruction is employed in attempts to reduce tuber infection before lifting. Haulm destruction in early August reduced the weight of blighted tubers from 13 to 5 cwt. per acre at the expense of a loss of 4 tons in the total crop. Haulm destruction at the end of August reduced the blighted tubers from 13 to 8 cwt. per acre at the expense of 1 ton of the total crop; and haulm destruction in mid-September caused no significant reduction either in yield or in the weight of blighted tubers.

In view of the loss of some healthy yield that is almost inseparable from haulm destruction as normally practiced, and the low mean level of blight in tubers in England and Wales, as revealed by the trials and surveys, it would appear that the mean national gain from reduction of blight in tubers by haulm destruction may well be almost nil. For the individual grower it may be very profitable now and then. But as the reduction of blighted tubers has to be 10 cwt. per acre to pay for the treatment and for some few cwt. of sound crop lost, the chances of its being profitable are not more than 1 in 10 on King Edward and 1 in 20 on Majestic (see frequency diagram, figure 11 et seq.). It is perhaps best to regard haulm destruction in England and Wales as a farm operation worth its cost in preparing the field for lifting, especially needed when the crop has to be lifted early, and sometimes paying a bonus by reducing blight in tubers in other circumstances.

RESISTANT VARIETIES

Potato breeding for blight resistance throughout the world owes much to the pioneering work done in England by the late Radcliffe N. Salaman on the employment of Solanum demissum as a source of blight resistance, and the recognition by him and his coworkers at Cambridge of the existence of biotypes of the blight fungus in the early 1930's (Salaman, 1949). The progress made up to 1939, and

the prospects of success in breeding for resistance from R-genes, and for what is now called "field resistance," as seen by those two great exponents of the rival schools of thought, Salaman and Pethybridge, was presented in their lifetime and with their aid by Large (1940). The influence of Salaman and Hudson, and the exploration of Hawkes in South America (Hawkes 1941, 1947) led to the establishment of the Commonwealth Potato Collection at Cambridge,[4] to provide potato breeders with new sources of R-resistant and other genetically valuable material. Much work on the fundamental problems of breeding for blight resistance has been done, not only by Black in Scotland (q.v.) but also by Howard at the Plant Breeding Station, Cambridge (Howard, 1953), and by Müller and others at the National Institute of Agricultural Botany, also at Cambridge (Müller, 1953; Müller, Cullen, and Kostrowicka, 1955).

Since 1945, six named R-gene resistant varieties, raised in Scotland and Northern Ireland, have been submitted to trial at numerous centers in England and Wales by the National Institute of Agricultural Botany (N.I.A.B.). All six of these varieties are attacked by blight on the haulm before the end of their growing period, and all six are susceptible to blight in the tubers. The one variety of the R_3 genotype--Pentland Ace (1951), a second-early potato--has been found to pulp badly on cooking. Of the five named varieties of the R_1 genotype, Craig's Snow White (1948), a maincrop (comparable with Arran Peak in point of maturity), has failed because of its extreme tolerance of virus Y, its late maturity, and its indifferent cooking quality. Craig's Bounty (1943), also a maincrop, has failed because of its poor quality and long stolons. Ulster Torch (1955), another maincrop, is still promising, but has badly shaped tubers. Pentland Beauty (1955), a first-early variety, is all right so far.

Of the six varieties, only one, Orion (1947), an early maincrop (comparable with Majestic for maturity), has survived the long series of registration and N.I.A.B. trials (which take 10 years from the production of the first seedling by the breeder) to reach the stage of recommendation by the N.I.A.B. in 1956. That honor was shared with only four varieties for lifting as maincrops: Majestic, King Edward, Ulster Supreme, and Arran Viking; but it was a restricted recommendation for special purposes, as Orion has yellow flesh and in England and Wales it is suitable for chipping or processing only.

Potato breeding, specifically for "field resistance" to blight as defined by Müller (1953), has scarcely yet started in England and Wales, but breeding for as much practical resistance as possible has been going on for at least three-quarters of a century. Such resistance has always been one, among the many desirable qualities that the breeders have striven to obtain. A number of excellent new potato varieties, other than those few with R-genes, have come into commercial cultivation in England and Wales in recent years.

The testing of potato varieties is the responsibility of the N.I.A.B., and Cullen, in charge of this work, has recorded the performance of these new varieties in trials throughout the country (Cullen, 1953, 1955, 1956). Home Guard (1943) and Ulster Premier (1945) are among the best in the first-early group; Craig's Alliance (1948), Craig's Royal (1948), and Ulster Dale (1950) in the second-early varieties; and Dr. McIntosh (1944), Arran Viking (1945), and Ulster Supreme (1946) among the maincrop potatoes. Of these last, Dr. McIntosh and Ulster Supreme are about equal to Majestic in point of susceptibility to blight, while Arran Viking (as yet) is distinctly more resistant.

Apart from their long period of testing before recommendation, potato varieties in England and Wales, as elsewhere, undergo an inexorable process of screening, in practice, as a result of which the more blight-susceptible varieties fail to establish themselves or pass out of cultivation, unless, like King Edward, they have some other compensating quality that renders them profitable to grow. The very susceptible varieties, Up-to-Date and British Queen, despite their unrivaled quality, have almost disappeared, and Gladstone, very susceptible to blight in the tubers, is going the same way. On the other hand, it is undoubtedly largely because of its low susceptibility to blight in the tubers that Majestic has reached and still maintains its place as the predominant maincrop variety. The adoption of Majestic probably represents the most economically effective measure of blight control yet achieved in England and Wales.

The importance of this can be seen from table 15. If an "improved King Edward" could be produced by the breeders, to combine the shape, pink particolored skin, and accepted quality of King Edward with the tuber resistance of Majestic, that achievement alone would save the country at least 1 percent of the present King Edward production, or about 14,000 tons of potatoes almost every year.

Another little realized, but nonetheless significant measure, adopted in England and Wales for the reduction of blight losses, is represented by the local preference for Arran Banner as the principal maincrop variety in Cornwall and other parts of the southwest where the earliest blight epidemics occur. Arran Banner, with its high susceptibility to blight in the tubers, can scarcely be said to have much resistance to the disease, but because of its heavy yield and early bulking it can produce a good crop before blight

[4] Now at the John Innes Horticultural Institution, Bayfordbury, Herts.

defoliation losses begin. This is an example of control, not by disease resistance, but by "disease escape."

SUMMARY: ENGLAND AND WALES

Work on the definition and quantitative measurement of blight epidemics, by their effects both on the foliage and the tubers, began in England in 1941. Since 1950 systematic surveys designed to provide the necessary information for the realistic evaluation of national losses have been carried out over the whole country each year. On the foundation of this work it now becomes possible, for the first time, to attempt a preliminary but closely documented estimate of the present economic significance of potato blight in England and Wales. The attempt has here been made, and the many facets of the work, as well as the methods used, have been described in some detail. Briefly, in England and Wales, "blight-years," characterized by 75 percent defoliation of the unsprayed maincrop potatoes between mid-August and the end of August, occur in about 5 years out of 10 in the southern half of the country, with later epidemics in the other years. The mean loss by premature defoliation on unsprayed crops over a 10-year period is about 8 percent of the potential crop for the country as a whole. Of this, less than one-half could be recovered by efficient protective spraying. In fact, only about 30 percent of the crops are sprayed, and the actual gain from spraying does not amount to more than about 1 percent of the total potato production on a long-term average. The mean loss due to blight in the tubers is about 3 percent on the same basis. This loss, on which destructive spraying, practiced on a third to a half of the crops, makes little or no impression, probably affects the national economy more than the greater losses by defoliation, which are in general more than offset by high yields due to the abundant rain in the blight years. The tuber loss occurs in all except the few outstandingly dry years, that is to say, in 8 or 9 years out of 10, and 3 percent of the national production represents some 120,000 tons of potatoes, or the produce of 15,000 acres.

Although the mean national gain from protective spraying is slight, the gain to individual growers in some districts and in some seasons may be very appreciable--typically 2 tons per acre where the 75 percent blight stage is reached on the unsprayed haulm by mid-August, and about 1 ton where this stage is reached at the end of August. Individual gains from destructive spraying may also be considerable here and there, especially when the crop has to be lifted early, but the chief gain from this process is a saving of time and trouble at lifting.

SCOTLAND

Scotland is noted for its production of high-grade seed potatoes, most of which are sold to plant the ware acreage in England and Wales. Seed potatoes are exported to a number of other European countries, notably Spain, and also to South Africa. In 1955, of the 135,000 acres of potatoes grown in Scotland, approximately 60 percent (80,000 acres) were for seed production. Seed potatoes are grown throughout the country. Consumption of ware potatoes is on a level similar to that in England and Wales--approximately 200 lb. per head per annum. Average yields are around 8 tons per acre.

POTATO DISTRIBUTION AND VARIETIES

A large part of Scotland consists of mountainous areas unsuitable for arable cultivation. Cropping is largely confined to the lower ground, in particular the coastal and inland districts running up the east of the country. The largest concentrations of potatoes are found in the three adjoining eastern counties: Angus, Perth, and Fife. Elsewhere in the east, Aberdeen, Kincardine, and East Lothian are important potato areas. In the southwest in Ayrshire there is an early potato district confined to a narrow coastal strip with its main center around Girvan. Figure 13 shows the distribution of potato growing in Scotland.

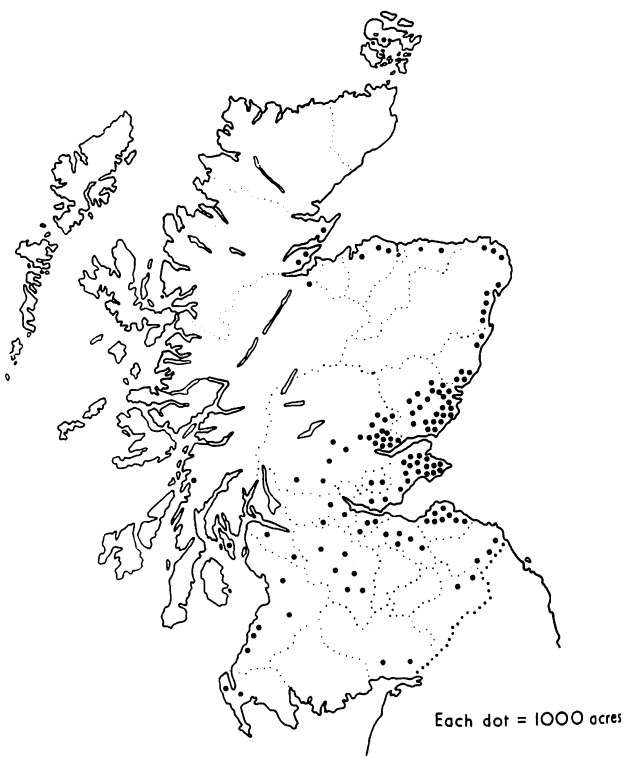


FIGURE 13.--Distribution of potato growing in Scotland.

Although well over 50 different named varieties are grown, 7 varieties account for 80 percent of the total potato acreage. Three of these, Arran Pilot (early), Majestic, and King Edward (maincrop), are grown almost entirely for export as seed. The remaining four varieties, Epicure (early), Kerr's Pink, Redskin, and Golden Wonder (maincrop) are grown principally for home ware consumption. A description of the varieties grown is given in a publication on seed potatoes (Scotland, Department of Agriculture, 1952).

SOIL AND CLIMATIC CONDITIONS

Most of the crop is grown on well-drained sandy or silty loams. These are usually in a state of high fertility, due to the system of farming practiced, with its emphasis on a balance between crops and livestock. Summer temperatures are low: Mean monthly figures at this time of the year do not usually exceed 60° F. Rainfall is usually adequate, although in some potato areas, notably parts of East Lothian, conditions in the summer may sometimes be too dry for the crop. A marked feature of climatic conditions in the potato growing areas is the variation, particularly in rainfall and humidity, within short distances. This results from the hilly or mountainous nature of the countryside and the varying distance of the crops from the sea.

Early potatoes are planted at the end of February or early March, and lifted in June; the maincrop season is from the end of April to October.

BLIGHT EPIDEMICS: GENERAL

It would be unrealistic to attempt to review blight epidemics for Scotland as a whole, owing to variations in the severity of the disease from place to place and the differences in climatic conditions. Some division of the country is necessary before the problem can be approached. Unfortunately, it is not possible to divide the country up into a small number of climatic regions. The position is further complicated by the growing of early and maincrop varieties side by side in the seed-growing areas, with variations in the incidence of blight on the 2 types of potatoes. For the purposes of this study, a simple division into 3 main regions has been made, based on the 3 advisory regions of the Scottish Agricultural Advisory Service. These three regions--the north, the east, and the west--are shown in figure 14, and they can be described briefly as follows:

North region.--Includes 20 percent of the total Scottish potato acreage. Most of the potatoes are grown on relatively low ground near the coast, from the south of Kincardineshire to just north of the Moray Firth. Elsewhere, scattered crops are grown in the valleys, with some production on the islands, notably the Orkneys.

East region.--62 percent of the potato acreage. A very important seed-growing area lies to the north and south of the Firth of Tay. Ware and seed potatoes are produced in the Lothians and Berwickshire.

West region.--18 percent of the potato acreage. Potatoes are grown throughout the area, principally on low ground, with concentrations near Dumfries (seed), southwest Wigtownshire (early ware), and Girvan (early ware).

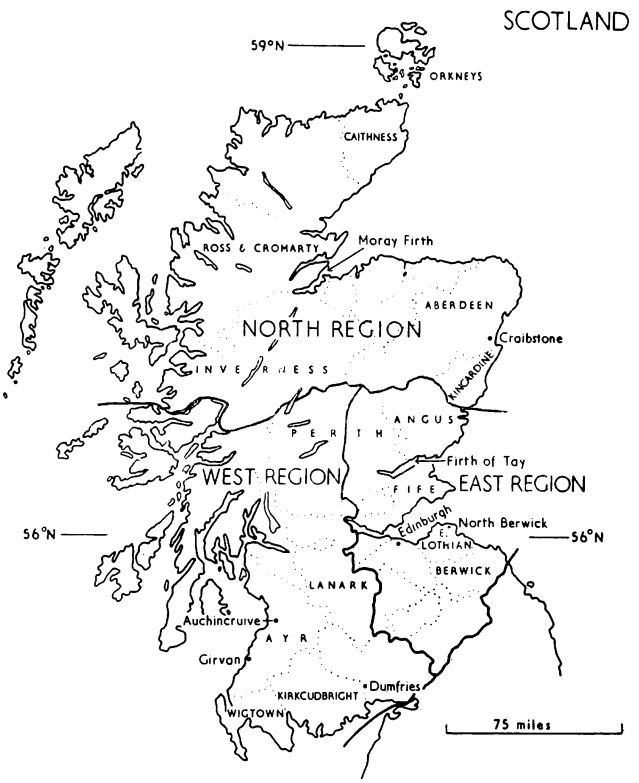


FIGURE 14.--Advisory regions and localities of Scotland referred to in text.

C. E. Foister has provided a summarized account of potato blight in Scotland for each of the years from 1946 to 1955. These accounts have been built up from records supplied by the three regional plant pathologists of the advisory service and by the potato seed

inspectors of the Department of Agriculture for Scotland. This material is not published. Some additional information has been incorporated by Foister from annually published accounts on the productivity of the principal Scottish arable crops, given in the Transactions of the Royal Highland and Agricultural Society of Scotland.

Table 21, which has been condensed from Dr. Foister's account, shows the incidence of blight on a regional basis over the 10-year period.

TABLE 21.--Incidence of potato blight in Scotland, 1946-55

Amount of blight	North Region	East Region	West Region
Moderate.....	1949, 1953	1948, 1949, 1950, 1954	1950, 1953
Slight.....	1948, 1954, 1955	1946, 1951, 1953	1947, 1952, 1955
Negligible.....	1946, 1947, 1950, 1951, 1952	1947, 1952, 1955	1946, 1948, 1949, 1951, 1954

It is not possible to define exactly what is meant by "negligible," "slight," and "moderate" attacks of the disease, but in the analysis given in table 21, the terms used refer to the combined effect of the blight attack on the haulm and on the tubers.

The most noticeable feature of table 21 is the number of years in which the disease is described as "negligible" or "slight." In the north region, the disease was "negligible" or "slight" in 8 out of 10 years; in the east region in 6 out of 10 years; and in the west region in 8 out of 10 years. The east region is the worst affected by blight during the 10 years under review, and this is the most important potato-growing area. Within the east region blight is most serious in its effects in the seed-growing areas near the Firth of Tay, but the principal losses here appear to be caused by tuber infection.

BLIGHT ON HAULM

Although reports of isolated primary foci may be made very early in the summer, generalized field outbreaks of the disease in particular areas very seldom occur before the end of July or the beginning of August. According to Foister, blight usually appears first in the southwest of Scotland. Gray, Clouston, and Biggar (1952) have analyzed first reports of blight for the north region from 1943 to 1952. During this 10-year period, these reports came between late June and the third week in July, but they did not signify general outbreaks. For the west region, Grainger (1955) has given the times of the first appearance of blight on his disease phenology plots at Auchincruive over the period, 1944-52. These were as follows:

Mid-July	End July	Early Aug.	Mid-Aug.	End Aug.
1948	1944	1946	1945	1949
	1947	1950		
	1951			
	1952			

Blight occurred every year, with outbreaks at the end of July or in early August in 6 out of the 9 years. It seems very probable that the first appearance of the disease on the plots at Auchincruive will precede generalized field outbreaks on maincrop varieties in the west of Scotland. Similar data are not available for the east region, but, in general, field outbreaks there are most unlikely to occur before outbreaks in the west.

The most detailed information on the effect of blight on the haulm comes from the west region and has been provided by Grainger, again from data obtained on the Auchincruive plots. Table 22 sets out the dates on which 100 percent blight destruction of the tops occurred, for 2 potato varieties, over the period 1949-54.

TABLE 22.--Date on which 100 percent blight of haulm occurred at Auchincruive, Scotland, on Kerr's Pink and King Edward potatoes, 1949-54

Year	100 percent blight on haulm of--	
	Kerr's Pink	King Edward
1949.....	September 12	September 16
1950.....	28	10
1951.....	27	28
1952.....	16	10
1953.....	17	10
1954.....	20	5
Average date (6 years).....	September 20	September 13

The 100 percent stage was generally reached around the middle to the end of September. The 75 percent blight stage will have occurred some days before this, but, even so, the evidence from table 22 is that, at this center, annual yield losses through premature defoliation of the plants are very small.

For the north region, Elizabeth G. Gray has informed the writers that seed crops are usually burned off before blight reaches the 75 percent stage, and blight on the haulm is not often severe enough to affect yield, except in coastal districts. In the east region, A. E. W. Boyd has reviewed his observations made between 1949-56, from which he concludes that the 75 percent date for Majestic in the east and southeast of Scotland is usually during the first week in September; but he stresses the variations in blight incidence throughout the region.

In Scotland, it is unusual for the 75 percent blight defoliation stage to be reached much before early- to mid-September in any year. If this is so, yield losses through defoliation are likely to be small. The data for England and Wales (fig. 8) indicate that when blight reaches the 75 percent stage by mid-September, there is an average loss of only 4 percent of the potential potato yield. The Scottish potato-growing season is somewhat later than in England, so that the 75 percent stage by mid-September probably indicates a slightly greater loss than 4 percent, but this does not happen every year. The lack of precise information on these various points shows the necessity for more detailed survey work, although the variable topography and weather conditions may render this rather difficult.

An appraisal of defoliation losses in Scotland must take account of the predominant part played by the seed potato crop. The practice among growers is to destroy the tops of their seed crops at the time, usually during the first half of September, when they consider that they have obtained the maximum yield of seed-sized tubers ($2\frac{1}{4}$ in. x $1\frac{1}{2}$ in.). Thus, the defoliation losses by blight in seed crops are likely to be very small indeed, as the majority of these crops are burned off before the 75 percent blight stage is reached.

If the acreage of early ware crops is added to the acreage of seed crops, these two are found to account for three-quarters of the total Scottish potato acreage. It is therefore on only a quarter of the total acreage (the maincrop ware) that defoliation losses of any importance are likely to occur, and even here they have been shown to be small.

BLIGHT IN TUBERS

There can be no doubt that blight in tubers is the problem which is of most concern in Scotland, because of the importance of the seed crop. Since 1953, figures have been obtained in the course of crop-check weighings by the Ministry of Food and Potato Marketing Board, in Scotland as in England and Wales, which give the weights of blighted tubers present at lifting in a representative sample of 600 to 800 Scottish potato crops each year (principally maincrop varieties). Table 23 shows the results for 1953-56. In 1953, 1954, and 1956 a fair amount of blight was present on the potato haulm, at any rate in parts of Scotland.

Over the 4-year period, the average amount of tuber infection caused by blight before lifting was under 2 cwt. per acre, which, expressed as a percentage of the average potato crop, equals about 1 percent of the actual yield. This puts the problem into perspective. It means that in most of the crops, even in blight years, tuber infection in the soil is either absent or very slight. The few crops in which really heavy infection occurs, with a loss of up to 3 tons

TABLE 23.--Mean weights of blighted tubers recorded at lifting, Scotland, 1953-56

Region and county	1953	1954	1955	1956
North region:	Cwt./acre	Cwt./acre	Cwt./acre	Cwt./acre
Ross and Cromarty, Inverness, Caithness	3.7	0.4	0.7	0.2
Aberdeen, Kincardine	2.5	.7	.3	.3
East region:				
Perth, Angus	1.6	2.8	0	2.2
Fife	3.0	1.4	0	4.9
Lothians, Berwick	4.4	1.6	0	3.6
West region:				
Ayr, Lanark, Argyll	3.7	2.4	2.3	2.7
Dumfries, Kirkcudbright	1.0	9.9	1.0	1.0
Scotland (all regions)	2.8	1.6	.2	1.9
Number of potato crops in survey	600	810	782	732

of potatoes per acre, tend to get an undue amount of publicity with a consequent exaggeration of the problem.

It would appear from table 23 that tuber blight infection is least important in the north region, where in 3 out of the 4 years only very small amounts of the disease were recorded, but it is too early to draw any firm conclusions about regional differences. Varietal susceptibility to blight infection of the tubers and soil conditions are important and need further analysis.

Blight infection of the potatoes at lifting, by contact with diseased haulm, is potentially a greater source of loss in Scotland than in England and Wales. This follows from the later growing season in Scotland combined with a shorter harvest period. Particularly in seed crops, however, this problem has been tackled by chemical and mechanical haulm destruction. In 1956, for example, haulm destruction was carried out in at least 50 percent of all Scottish potato crops. Recent field and laboratory experiments carried out in the east of Scotland and reported by Boyd and Henderson (1953) have indicated that as potato tubers mature, their resistance to blight infection increases. From this, the authors conclude that "very early lifting for seed or for the early ware market, with blight present on the haulm, will have much more serious consequences than later lifting, when the haulm is only slightly green."

BLIGHT AND WEATHER DATA

NORTH REGION: Long-term average temperature and rainfall figures for Craibstone, the North of Scotland College farm near Aberdeen, are shown in figure 15, together with planting and lifting times. The low summer temperature, which in the two hottest months, July and August, does not exceed a mean of 56° F., is one of the principal factors in the generally small importance of blight at this center, despite a relatively high rainfall. The temperature figures for Craibstone are fairly typical for potato growing throughout the region, but rainfall and humidity conditions vary widely. Blight is usually worst near the coast, where humidities are increased by coastal fogs.

EAST REGION: Conditions here, although very variable, are generally drier than in the other two regions. At North Berwick (fig. 15), for example, average annual rainfall is only 24 inches, and the normally low summer rainfall, here and throughout East Lothian, is one of the factors associated with the low incidence of blight. In the east region, blight is most serious along the north and south banks of the river Tay, and this may be partly ascribed to the frequency of sea mists ("haar") leading to high humidity conditions during the potato-growing season. Long-term weather records

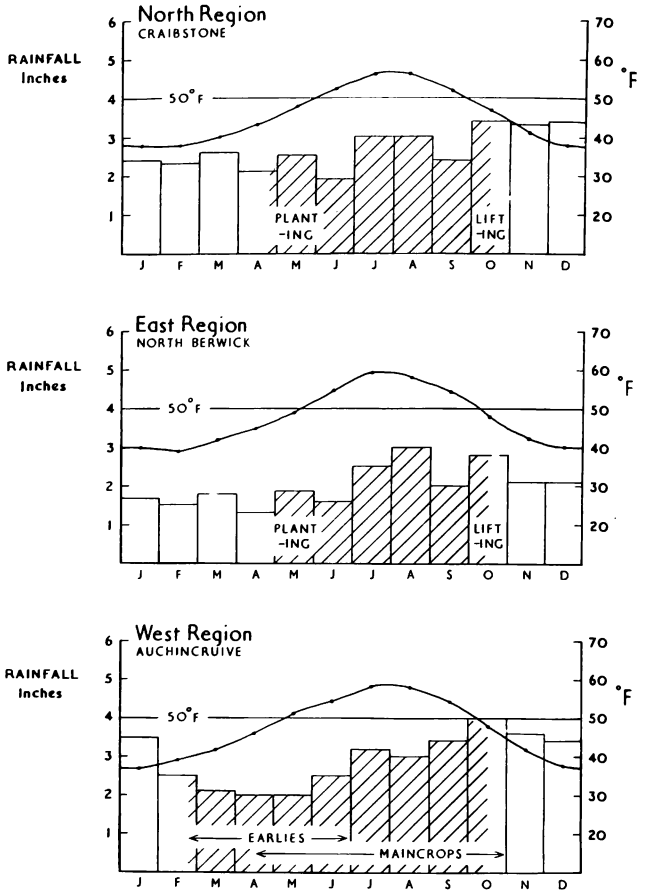


FIGURE 15.--Long-term average monthly rainfall and mean temperatures in relation to growing periods for three centers in Scotland.

for Perth, at the head of the Tay estuary, show that mean temperature conditions there are very similar to those at North Berwick (i.e., 58° to 60° F. in July and August), but average rainfall is higher (2.9 inches in July and 3.4 inches in August).

WEST REGION: Figure 15 shows long-term weather data for Auchincruive in relation to the growing season for early and maincrop potatoes in the southwest of Scotland. The most important early-growing district is centered around Girvan, which is about 20 miles south of Auchincruive. Average temperature and rainfall conditions at Girvan are similar to those shown in the diagram. That potatoes can be produced during such a cold growing season (end of February to June) is due to two main factors: (1) Only a limited number of fields, very near to the seashore and practically frost free, are used for these early crops; and (2) the potato variety grown is Epicure, which has a remarkable capacity to recover after being damaged by frost. This early ware crop virtually escapes any damage from blight, a fact that is, no doubt, closed linked with the low-temperature conditions.

Despite the relatively high summer rainfall at Auchincruive, blight on the haulm is of only minor importance in maincrop potato varieties. This may be, in part, a temperature effect.

CONTROL MEASURES

Copper compounds, of which copper oxychloride is the most important, are used in protective spraying against blight. A high proportion of this work is carried out by contractors, who normally spray at high-volume rates. Low-volume spraying is not practiced on any scale. The close spacing of the seed crops (about 12 in. x 26 in.), combined with the generally moist growing conditions leads to a luxuriant growth of the potato haulm, and considerable damage may be done by the passage of spraying equipment through the crop. This problem has been referred to by Gray, Clouston, and Biggar (1952), in writing about the north region. They say that it is noteworthy that there is probably more enthusiasm for spraying in the island counties than anywhere else in the north. The reason for this is that on the island crofts spraying is done by hand (chiefly with knapsack sprayers) without accompanying mechanical damage to the potato tops.

The amount of protective spraying carried out varies in different parts of the country. Most is done in the important seed-growing areas near the Firth of Tay. There can be little doubt that the object of some of this spraying combined with later haulm destruction, is to keep the tubers free from blight infection, rather than to prolong the growth of the potato crop. In some of the counties of southwest Scotland, notably Ayr, Wigtown, Kirkcudbright, and Lanark, there is little or no protective spraying.

Data from the "crop-check surveys" (table 24) show the approximate percentages of the maincrops on which protective spraying and chemical or mechanical haulm destruction have been practiced during recent years for the whole of Scotland.

Boyd (1952) has reviewed the various methods of haulm destruction used in Scotland. At the present time, spraying with sulfuric acid is the method most commonly employed. The main aim of haulm killing is not to protect the tubers from blight infection, although this end is served. In seed crops, it is to stop growth when the maximum quantity of seed-sized tubers have been formed. The practice is not compulsory, as in other countries (e.g., Holland and France), where the haulms of seed crops have to be destroyed by a certain date to prevent the late spread of virus diseases. Little or no critical experimental work has been done in Scotland on the economics of this premature killing in the seed crop. Whether it pays or not will depend very much on the variety and on the relative value of seed and ware potatoes. Up till now, the practice seems to have been accepted as a good one without question, but experimental evidence is required against which to test it.

BLIGHT FORECASTING

Grainger (1950) has discussed the results of forecasting potato blight in the west of Scotland during 1944-48, using Beaumont periods as the criteria on which warnings are based. The method was found to be successful, provided that the conception of a "zero date" (in this case, July 1) before which warnings were considered invalid, was employed. Further evidence that this method is a success in the west of Scotland has been provided by Grainger (1955), and in this later paper, he describes an apparatus for automatically recording the occurrence of Beaumont periods. A limited test of the same method of forecasting blight in the north of Scotland during 1943-46 has also been reported as successful by Gray, Clouston, and Biggar (1952).

Since 1949, the Department of Agriculture for Scotland, in conjunction with the Meteorological Service, has been investigating the possibilities of a blight forecasting service for the whole country. Each year, an attempt has been made to correlate Beaumont periods at a number of weather stations with observed outbreaks of blight in the field: these latter reports to be sent in chiefly by the Department's potato seed inspectors. The method has not operated so successfully in the east of Scotland, where most of the potatoes are grown, as it has in the other areas.

The rapid changes in micro-climatic conditions over short distances make it very difficult to apply a forecasting system to the whole of Scotland. Fortunately, with the present

TABLE 24.--Number of potato crops in Scotland survey and percentage of crops sprayed and haulm destroyed, 1953-56

Item	1953	1954	1955	1956
Potato crops in survey.....number..	600	810	782	732
Protective spraying.....percent..	27	32	25	30
Haulm destruction.....percent..	52	49	47	52

emphasis on seed-potato production, coupled with a generally late attack of blight, the need for such a service is not so great as in many other countries.

POTATO BREEDING

W. Black of the Scottish Society for Research in Plant Breeding, now at Pentlandfield, Roslin, Midlothian, has bred a number of blight-resistant potato varieties, which have come on to the market since 1948. In all cases, the resistance to blight was derived from Solanum demissum. The best known of these varieties has been Pentland Ace, containing the R_3 gene; but none of the varieties have been accepted commercially on a large scale. All have been attacked by specialized races of the blight fungus soon after their introduction. (See also England and Wales: Resistant Varieties.)

Black (1952), in parallel with workers in other countries, has been responsible for much of the pioneer research on the genetics of blight resistance. The genetics of so-called "major gene" resistance has been most fully explored. In this type of resistance, which is shown by S. demissum derivatives, the plants exhibit a hypersensitivity reaction to Phytophthora infestans, which is controlled by a number of single major genes, either alone or in combination. The presence of four such genes has been demonstrated. Recently, Black, Mastenbroek, Mills, and Peterson (1953) have proposed that an international nomenclature should be adopted in designating these genes, and for this purpose have recommended the adoption of Black's system. In this, the four genes have been named R_1, R_2, R_3, and R_4. The 15 possible genotypes of potatoes containing these genes, together with the recessive (r) are shown in figure 16 alongside the equivalent genotype designations previously used by Mills and Peterson in the U.S.A. and by Mastenbroek in Holland.

The same workers have also suggested the adoption of an international system for naming blight races, to be based on the reaction of particular races to the previously named genotypes. Races are named according to the genotypes that they attack. Thus, race 0 attacks none of the resistant genotypes; race 1 attacks the recessive and genotype R_1; race 1,2 (pronounced: "one, two" and not "twelve") attacks the recessive, and genotypes R_1, R_2, and R_1R_2, but all other genotypes are resistant to it. No genotype is resistant to blight race 1,2,3,4. This interrelationship between host and parasite are shown in figure 16 with the

GENOTYPE				RACES OF Phytophthora infestans															
Scotland				A	B[1]	H	J	D	G	E	B[2]	-	C	I	-	-	F	-	-
U.S.A.				A	D	C	-	B	-	-	BD	-	BC	-	-	-	-	-	-
Holland				NI	N2	N5	-	N4	-	-	N7	-	N6	-	-	N8	-	N9	-
International				O	1	2	3	4	1,2	1,3	1,4	2,3	2,4	3,4	1,2,3	1,2,4	1,3,4	2,3,4	1,2,3,4
r	r	r	r	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
R_1	D	R_9	R_1	-	S	-	-	-	S	S	S	-	-	-	S	S	S	-	S
R_2	C	R_7	R_2	-	-	S	-	-	S	-	-	S	S	-	S	S	-	S	S
R_3	-	R_8	R_3	-	-	-	S	-	-	S	-	S	-	S	S	-	S	S	S
R_4	B	$R_{2,5}$	R_4	-	-	-	-	S	-	-	S	-	S	S	-	S	S	S	S
R_1R_2	CD	-	R_1R_2	-	-	-	-	-	S	-	-	-	-	-	S	S	-	-	S
R_1R_3	-	-	R_1R_3	-	-	-	-	-	-	S	-	-	-	-	S	-	S	-	S
R_1R_4	BD	-	R_1R_4	-	-	-	-	-	-	-	S	-	-	-	-	S	S	-	S
R_2R_3	-	-	R_2R_3	-	-	-	-	-	-	-	-	S	-	-	S	-	-	S	S
R_2R_4	BC	-	R_2R_4	-	-	-	-	-	-	-	-	-	S	-	-	S	-	S	S
R_3R_4	-	-	R_3R_4	-	-	-	-	-	-	-	-	-	-	S	-	-	S	S	S
$R_1R_2R_3$	-	-	$R_1R_2R_3$	-	-	-	-	-	-	-	-	-	-	-	S	-	-	-	S
$R_1R_2R_4$	BCD	-	$R_1R_2R_4$	-	-	-	-	-	-	-	-	-	-	-	-	S	-	-	S
$R_1R_3R_4$	-	-	$R_1R_3R_4$	-	-	-	-	-	-	-	-	-	-	-	-	-	S	-	S
$R_2R_3R_4$	-	-	$R_2R_3R_4$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	S	S
$R_1R_2R_3R_4$	-	-	$R_1R_2R_3R_4$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	S

- = Resistant S = Susceptible

FIGURE 16.--International system of designating interrelationships of genes and races of Phytophthora infestans.

names previously given to the blight races by the different workers. It is claimed that "The advantages in designating genes and races in this manner are (a) it probably allows for any extension that may be necessary in the future; and (b) it illustrates immediately the inter-relationships between races and between genes and races without referring to diagrams or tables."

This system of naming genes and races has now been adopted by all the leading workers throughout the world. Black's work, which has included the identification of blight collections from many countries, has brought to light the fact that the common race of blight throughout the world is now race 4.

The chief emphasis in Black's search for blight-resistant potato varieties is now placed on "field resistance," as "major gene" resistance in a variety is of short duration, owing to specialization of the blight fungus. A recent review of blight resistance work in Scotland has been given by Black (1954).

SUMMARY: SCOTLAND

A predominant part is played by seed production in the potato industry, and defoliation losses caused by blight are not usually considered important in Scottish seed crops, owing to the almost universal practice of prematurely destroying the haulm in these crops chemically or mechanically. Present indications are that blight does not normally cause serious yield losses through premature defoliation in any of the major potato-growing areas. More detailed survey information, particularly for maincrop ware varieties, is needed to be sure of this, but climatic differences throughout the country make it difficult to carry out systematic surveys. Data from surveys of tuber blight infection suggest that there has probably been a tendency to overestimate the losses from this cause. Dr. Black of the Scottish Society for Research in Plant Breeding has carried out fundamental work of world wide importance on the genetics of blight resistance.

NORTHERN IRELAND

Northern Ireland, with a population according to the 1951 census of about 1.4 millions, has a total area of $2\frac{1}{2}$ million acres under crops and pasture. In 1951 (Northern Ireland, Ministry of Agriculture, 1956), about 144,000 acres were under potatoes and the total production was 1,197,000 tons, of which 265,000 tons were used for human consumption, indicating a consumption per head of about 400 lb. per annum. In Northern Ireland, as in Scotland, a high proportion of the potato crops are grown for seed. In 1951 the shipments of seed amounted to 84,000 tons, and 171,000 tons were used for planting in Northern Ireland. Also, 126,000 tons of ware were shipped, and in that year, in which the yield was high (8.3 tons per acre), 324,000 tons were used for stock feed.

Potato growing is fairly equally distributed among the six counties (fig. 17). The most important seed-growing areas are in the northern parts of Londonderry, Antrim, and mid-Down; the maincrops for ware are chiefly in a middle belt; and most of the early and second-early varieties for ware are in County Down and parts of County Antrim in the Lagan Valley.

The principal maincrop varieties are Arran Victory, Kerr's Pink, and Arran Banner. Of these, the purple-skinned late maincrop variety Arran Victory is by far the most popular for ware, and it accounts for some 38 percent of the acreage. Kerr's Pink follows with about 17 percent, and Arran Banner, also much in demand for seed for export, occupies about 15 percent. The whole range of British varieties is grown for seed, with fairly large acreages of Gladstone and Arran Peak (5 to 6 percent), and 1 to 2 percent each of Majestic, King Edward, Dunbar Standard, and Arran Consul. Ballydoon is extensively grown as a first-early variety for the home trade, and British Queen as a second-early. In Northern Ireland, the predominant Arran Victory is among the varieties least susceptible to blight.

INCIDENCE OF BLIGHT

As would be expected from the distribution of the rainfall in the months of July, August, and September (fig. 18), blight conditions in Northern Ireland are generally severe, and more so in the north and west than in the south and east. The climagram for Garvagh in Londonderry (fig. 19) shows that the average rainfall there is higher than that for "blight years" only in the southern zone of England and Wales (fig. 6). The rainfall figures for Armagh, perhaps more typical of the ware-growing area, for the months of July and August in the years 1947-56 are given in table 25 as against the potato yields for Northern Ireland taken from the official statistics. It will be seen that, as in England and Wales, 1947 and 1955 were dry years (and also years in which the yield was lowest), but even at Armagh, where the rainfall is lower than in Londonderry, 8 years out of the 10 had over $5\frac{1}{2}$ inches of rain in the 2 months of July and August.

The necessity for routine spraying is not in question in Northern Ireland. Professor Muskett of Queen's University, who, with R. W. Wallace of the Ministry of Agriculture, has

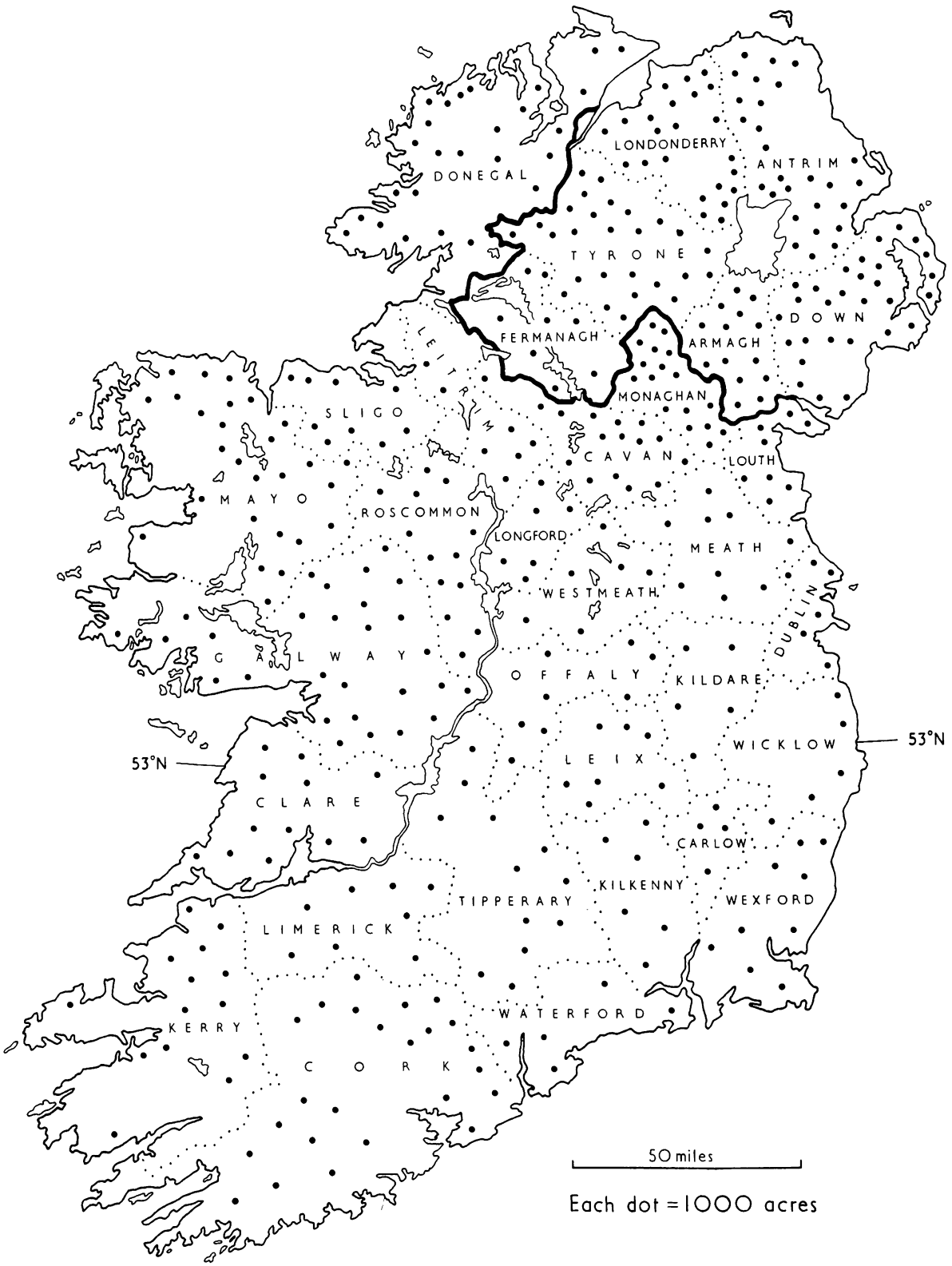


FIGURE 17.--Approximate distribution of potato growing in Northern Ireland and the Irish Republic.

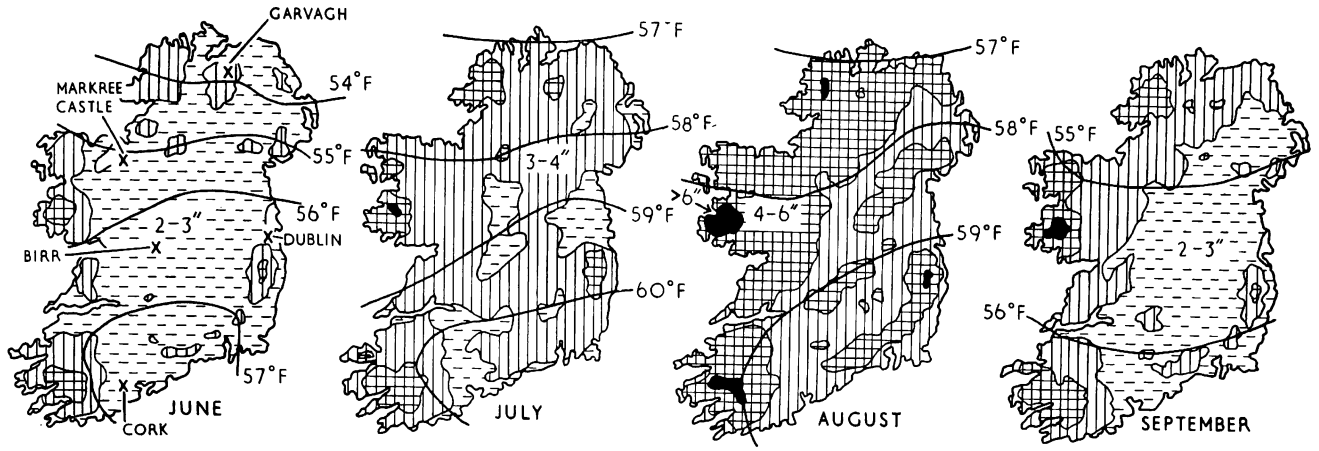


FIGURE 18.--Average monthly rainfall and temperatures in Northern Ireland and Irish Republic, showing weather stations referred to in text.

kindly provided most of the information on which this section of the review is based, recalls that in his 35 years' experience there have been very few years with less than a ton gain from spraying in the maincrops grown for ware in Northern Ireland, and the usual gain in Arran Victory is $1\frac{1}{2}$ to 2 tons per acre.

Outbreaks of the disease on the haulm occur by mid-July; the attack is almost always under way on unsprayed maincrops in the second half of July, and thereafter its progress may be very rapid, with complete killing of the haulm by early August in the north. Such very rapid attacks are exceptional, however; and attacks from mid-August to late August are more usual for Northern Ireland as a whole.

The first spraying, which should perhaps ideally be given at the end of June or beginning of July, is in practice generally given in mid-July, with great regularity. The second spraying is given toward the end of July. About 98 percent of the farmers put on the first spray, and about 85 percent the second. The keenest growers give a third spraying about mid-August. A mean gain of $1\frac{1}{2}$ to 2 tons per acre is consistent with an average of about a fortnight's prolongation of growth, due to spraying. In seed crops the gain in yield is much less, as even the maincrop varieties are burned off before the end of August, but the protective spraying has the very important function of minimizing the risk of infection of the tubers.

SPRAYING MATERIALS AND SPRAYING TRIALS

Burgundy mixture is the material still chiefly used for protective spraying; the preferred program is to use the 1 percent mixture for the first application (to avoid injury to the young haulm by the stronger mixture) and to use the 2 percent mixture for the second and third applications to give as much protection as possible from mid-August into September.

The leading results of a series of trials of dusting versus spraying with burgundy mixture, carried out in County Down over the years 1924-30 (Muskett, 1929; and Muskett and Cairns, 1931) were as shown in table 26.

In the trials in 1924 and 1925 two applications of 1 percent burgundy mixture were compared with two of copper dust (15 percent Cu) at 20 lb. per acre. In 1927 two applications of similar dust at 30 lb. per acre were compared with two applications of 2 percent burgundy; and in 1930 three applications of dust (16 percent Cu) were compared with three applications of burgundy, the first two at 1 percent and the third at 2 percent. It was concluded that dusting was neither so efficient nor so economical as spraying with burgundy mixture.

In the three consecutive years 1924-26, a series of spraying trials was carried out at 4 or 5 centers in each of the 6 counties, covering the whole range of maincrop varieties. The mean results of these trials (hitherto un-

TABLE 25.--Rainfall in County Armagh, and potato yields for Northern Ireland, 1947-56

Rainfall and potato yields	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956
Rainfall in--										
July.....inches..	3.4	2.5	2.7	4.8	3.3	1.7	4.1	4.6	1.8	3.8
August.....do..	.6	3.5	3.0	5.3	4.5	3.9	3.7	2.3	1.1	6.3
Potato.....tons per acre..	5.6	7.9	7.6	7.5	8.3	7.9	8.1	7.0	6.5	7.0

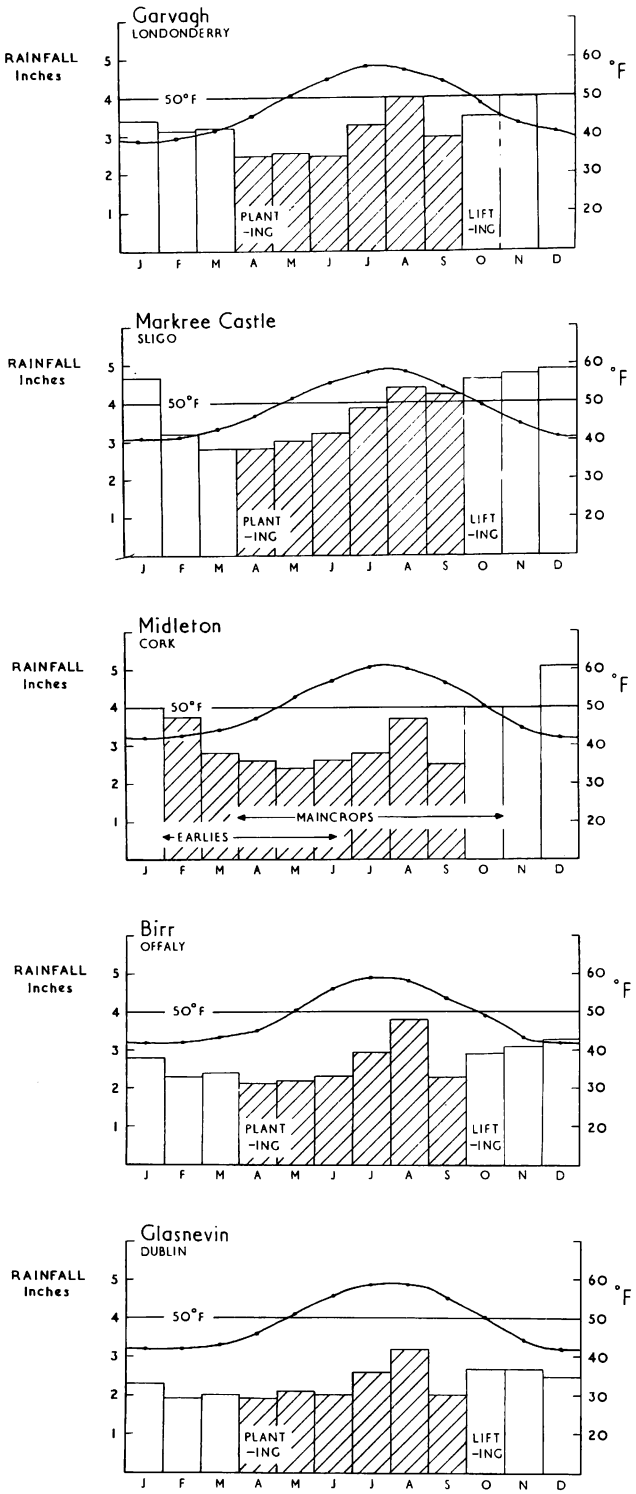


FIGURE 19.--Long-term average monthly rainfall and mean temperatures in relation to growing periods for five centers in Ireland.

published), for two sprayings with 1 and 2 percent burgundy mixture, respectively, are shown in table 27.

The results of such trials carried out at many centers over consecutive years constitute a survey and leave no doubt about the level of blight losses. On the basis of the bulking curve for Majestic in England (fig. 8) the mean yield for the unsprayed (9.3 tons, or 74 percent of a potential yield of about $12\frac{1}{2}$ tons) would indicate a 75 percent date for the unsprayed haulm about mid-August; with corresponding dates for the haulm twice sprayed with 1 and 2 percent burgundy mixture, about September 7 and September 15, respectively. This agrees very well with general observations on the course of the disease on sprayed and unsprayed haulm in Northern Ireland.

Numerous other spraying trials were carried out over the years 1936-40 at Hillsborough Agricultural Research Institute in County Down; at Greenmount Agricultural College, Muckamore, in County Antrim; and again at 20 to 30 centers throughout Northern Ireland, in connection with pioneer work on the testing of the then-new copper oxychloride and cuprous oxide sprays. The main indication from these many trials was that 2 percent burgundy mixture was perhaps unnecessarily strong, at any rate for the first application, and that both cuprous oxide and copper oxychloride preparations, when used at the same copper dosage as 1 percent burgundy mixture (0.25 percent Cu) would have about the same protective effect.

A series of trials, again hitherto unpublished, was made at Hillsborough in each of the 5 years, 1936-40 on the second-early variety British Queen. The trial crops were generally planted rather late (in May) and they ripened off about the second week in September. The leading results for the controls and plots twice sprayed with 2 percent burgundy mixture (8.10.40) are given in table 28. It has been possible to estimate the 0.1 and 75 percent dates for the unsprayed haulm very closely from the notes made on the condition of the haulm at various dates, although no blight key was then used. The 75 percent dates on the sprayed haulm were indeterminate as blight and ripening-off effects were concurrent in September.

The blight attack was evidently somewhat later than usual in 1940, but on the average over the 5 years the spraying appears to have given a useful prolongation of growth from about mid-August until the end of August or just into September each year, with an average gain in total crop of $2\frac{1}{2}$ tons per acre.

TABLE 26.--Results of dusting versus spraying trials on potatoes in County Down, Ireland, 1924-25, 1927, 1930

Year	Trials	Potato variety	Mean total yield		
			Unsprayed	Dusted	Sprayed
	Number		Tons/acre	Tons/acre	Tons/acre
1924	2	Lochar	12.6	12.3	13.3
1925	3	..do	15.4	15.9	17.2
1927	1	Up to date	--	9.3	10.7
1930	1	British Queen	12.4	12.9	14.4

TABLE 27.--Mean results of spraying with burgundy mixture on maincrop varieties throughout Northern Ireland, 1924-26

Year	Trials	Mean total crop			Blighted tubers		
		Unsprayed	Twice sprayed		Unsprayed	Twice sprayed	
			1 percent mixture	2 percent mixture		1 percent mixture	2 percent mixture
	Number	Tons/acre	Tons/acre	Tons/acre	Cwt./acre	Cwt./acre	Cwt./acre
1924	27	9.0	10.7	11.1	15	12	12
1925	28	9.1	11.4	11.9	10	5	5
1926	21	9.8	12.3	13.2	5	5	3
Mean	--	9.3	11.5	12.1	10	7	7

TABLE 28.--Results of spraying trials on British Queen potato in County Down, Ireland, 1936-40

Year	Date on which blight on unsprayed haulm reached--		Total yield		Blighted tubers	
	0.1 percent	75 percent	Unsprayed	Sprayed	Unsprayed	Sprayed
			Tons/acre	Tons/acre	Cwt./acre	Cwt./acre
1936	July 14	Aug. 10	6.8	8.3	7	2
1937	July 22	Aug. 15	9.1	11.8	4	1
1938	July 22	Aug. 10	11.3	15.7	11	6
1939	Aug. 3	Aug. 21	12.3	15.0	8	20
1940	Aug. 5	Aug. 24	12.7	13.6	3	2
Mean	.....	Aug. 16	10.4	12.9	6	6

HAULM DESTRUCTION

Haulm destruction to prevent both virus and blight infection of the tubers is obligatory in all seed crops in Northern Ireland entered for Stock Seed Certificates. The early varieties are burned off about the last week in July, and the maincrops about the last week in August--a little earlier or later in each case, according to the conditions of the season. Sodium chlorate is chiefly used, the rate of application being about 28 lb. per 100 gallons of water per acre. Sodium chlorate is preferred to sulfuric acid, as it does not require acidproof machines, and it acts more slowly, giving opportunity for the tubers to ripen off. Little burning off is done on the ware crops.

A good indication of the losses due to blighted tubers in ware crops protectively sprayed in the usual way is given in a report on variety trials (Northern Ireland, Ministry of Agriculture, 1954). In trials at 13 centers in 1954 and 99 centers in previous years the mean percentage of blighted tubers in Arran Banner was 4.2 percent of the total crop (14 cwt. per acre) and in Majestic 2.3 percent (7 cwt. per acre). These figures are of the same order as those shown in the spraying trials, and indicate a general loss of 2 to 4 percent by infection before lifting. Tuber infection tends to be less on the close soils of North Derry than on the poorer open soils of mid-Antrim.

POTATO BREEDING

Many of the principal new British potato varieties in recent years have been raised in Northern Ireland by John Clarke on his small farm at Mosside, near Ballycastle in the north of Antrim. His introductions include Ulster Chieftain, Ulster Premier, and Ulster Prince as first-early varieties; Ulster Ensign and Ulster Emblem as second-early potatoes; Ulster Torch, Ulster Beacon, Ulster Tarn, and Ulster Knight as maincrop varieties, and Ulster Supreme, a late maincrop. This wealth of new varieties can be compared only with the famous Arran series raised by Donald Mackelvie on the island of Arran in Scotland earlier in this century.

Much work is done by the Ministry's Inspectors and by Professor Muskett's staff at Queen's University to assist potato breeding in connection with the important Northern Ireland seed trade; and the National Institute of Agricultural Botany have potato centers for raising virus-tested stocks in North Antrim, and for multiplying new stocks near Coleraine for trials in England. Blight-resistant seedlings and new blight-resistant varieties are tested at these centers under the prevailing severe blight conditions; but the commercial cultivation of R-gene resistant varieties in Northern Ireland is so far negligible. The choice of varieties for ware crops is dictated by the consumers' demand for quality rather than by any consideration of blight susceptibility.

Doling (1957) has recently surveyed Northern Ireland for races of Phytophthora infestans. In the commercial varieties he found only race 4 to be widely distributed. In 73 isolates, 70 were race 4 and only 3 were race 0.

SUMMARY: NORTHERN IRELAND

Potato blight is severe almost every year in Northern Ireland. Routine protective spraying is universal, and the need for this has been well established by a great number of spraying trials carried out systematically throughout the country. Any unsprayed haulm is killed by blight between the end of July and the end of August, according to locality, variety, and season, with mid-August as the mean 75 percent date. The mean gain from 2, or rarely 3 sprayings is $1\frac{1}{2}$ to 2 tons per acre or about two-thirds of the total defoliation loss caused by blight. There is a constant loss of 2 to 4 percent in ware crops due to blight in tubers. Northern Ireland has an important seed potato trade. In the seed crops, some of the yield of ware-sized tubers is lost by burning off the haulm in August, but the blight losses are slight.

REPUBLIC OF IRELAND

The Republic of Ireland (Eire), with a population, according to the 1951 census, of about 3 millions, has a total land area of about 17.4 million acres. In 1954, some 292,000 acres were under potatoes, 1,516,000 under corn and other crops, and 7,929,000 under pasture. The potato production in that year was about $2\frac{1}{4}$ million tons, or about 7.7 tons per acre (Ireland (Eire) Central Statistics Office, 1955). The consumption of potatoes per head in 1947-48 (F.A.O. 1948) was 420 lb. per annum, or about twice that in England and Wales.

The acreage under potatoes, apart from temporary rises to 500,000 and 430,000 acres, respectively, in the first and second World Wars, has fallen steadily from about 458,000 acres at the beginning of the century to 292,000 acres in 1954. But, against this, the yield per acre has risen from 4.2 tons in 1900-1909 to 7.8 in 1940-49, and it was over $8\frac{1}{2}$ tons per acre in the years 1950-53.

The rise in yield during this century reflects the work done by the Department of Agriculture in the promotion of good cultivation and

manuring, varietal improvement, the suppression of virus diseases, and campaigning for spraying against blight.

Sugar beet has played an important part in the recent history of the root crop in Ireland. This crop, introduced in 1926, was occupying 74,000 acres in 1954, with a production of 674,000 tons. Thus: In 1900-1909, 458,000 acres produced 1,853,000 tons of potatoes for a population of 3.2 million; in 1954, 366,000 acres produced 2,248,000 tons of potatoes plus 674,000 tons sugar beet for a population of 3.0 million.

Also, to the account for 1954, there must be added an important export trade in seed potatoes of the highest quality and freedom from virus diseases, built up since the 1920's through the devoted labors of Davidson, Delaney, and their coworkers in the Potato Inspectorate, aided by the pioneering investigations of Pethybridge, Murphy, and McKay. Davidson (1937) describes the foundation of the industry, and McKay (1955) provides a practical account of all the work on potato diseases that has contributed to the present well-being of the potato in Ireland.

DISTRIBUTION AND VARIETIES

As the map (fig. 17) clearly shows, potato growing is fairly evenly distributed over the whole of Eire. The chief seed-producing districts are in Donegal, Mayo, and around Athlone; early varieties are grown most extensively in the south--in Cork, Waterford, and Wexford--and also in the Dublin area; but maincrops for ware are also grown in all districts. The cultivation is mostly on small farms.

The principal maincrop varieties are now Kerr's Pink and Arran Banner. Kerr's Pink, a late maincrop variety, popular for its good yield and quality, is grown in all parts of the country, and probably accounts for about half the present acreage. Arran Banner, the other most extensively grown variety, is notably earlier in maturity. It is grown not only for ware but also for seed--large quantities of which are produced for export, principally to Mediterranean countries. Majestic, King Edward, and the whole range of British varieties are also produced for seed. Culinary quality in potato varieties is traditionally appreciated in Ireland, and small acreages of the superb Golden Wonder, and also some of the best varieties of the past, even Champion, are still grown. Up-to-Date, despite its present high susceptibility to blight, is still in demand for its quality in many parts of the world, notably South Africa, and it is still grown in Ireland both for seed and ware.

The second-early variety, British Queen, is also widely grown, again because of its quality and despite its high susceptibility to blight. Epicure is still one of the most popular first-early potatoes.

Small acreages of Alpha and Voran are grown here and there, but the production of potatoes for industrial purposes is very small. However, the production of potatoes for industrial purposes (alcohol, starch, etc.) in Ireland has been carefully investigated by Drew (1941) and Drew and Deasy (1939), who concluded that continental varieties had little superiority in point of starch production over Arran Banner and other high-yielding varieties already grown in Ireland.

CLIMATIC CONDITIONS

Ireland has a temperate climate with abundant rainfall, particularly well suited to the potato crop, of which it is the traditional European home. Conditions are not so cold in winter or so warm in summer as in eastern England or in continental Europe. In configuration the country is a "saucer," or large central plain, comprising the drainage area of the river Shannon with much bog land, surrounded by broken mountainous country to the north and west and by hills to the south and east. The country is swept by maritime air from the southwest, and humidity conditions tend to be fairly uniform over most of the country as the mountains are too broken to afford much shelter in their lee. In the absence of surveys for the 75 to 90 percent stages of blight, such as have been made in England and Wales in recent years, it is not possible to zone Ireland for severity of blight as has been done for England and Wales in figures 4 and 5. On the whole the worst districts for blight are those with the highest rainfall in the months of July, August, and September; and the long-term average rainfall distribution maps, given in figure 18, serve to indicate the regional differences. The blight epidemics tend to be severe in the west, and perhaps most severe in Galway, Roscommon, and parts of Offaly and Westmeath. They tend to be least severe in the east, notably near Dublin, which is in the driest part of the country.

The climagrams (fig. 19) enable the mean rainfall and temperature conditions in various parts of Ireland to be compared with those in England and Wales--and other parts of the world. At Markree Castle, County Sligo, which, with Garvagh in Londonderry in Northern Ireland, fairly well represents the mountainous and wind-swept seed-growing areas of Mayo, Sligo, and Donegal, the mean temperatures in July and August are relatively low, reaching only about 58° F., and the rainfall in the months of July to September is very high. At Cork, in the south, given as fairly typical of the southern coastal zone from Cork to Wexford where many early

varieties are grown, the diagram is very similar to that for Penzance (fig. 6). At Birr, Offaly, in the central area, the long-term average rainfall and temperatures over all years are similar to those of the "blight years" only in the southern and Fen zones of England. At Dublin, although this represents the driest part of Ireland, the average rainfall follows the same pattern as at Birr, and it is not very much less. Even in this area blight epidemics tend to be more frequent and severe than in the southern zone of England. Although there are regional differences in the incidence of blight in Ireland, these differences are much less than in England and Wales. For the purpose of estimating average blight losses it may not be greatly misleading to treat Ireland as a whole--as a single blight zone--with a higher frequency of severe epidemics than any other such zone in the British Isles.

As the climagrams would suggest, planting and lifting dates for the potato crops in Ireland (Eire and Northern Ireland) are similar to those in the south of England and Wales. Early varieties in the southern coastal districts are planted in February and March for lifting at the end of May and in June. The maincrops are generally planted in April, and lifted in October (Kerr's Pink) or during September (Arran Banner).

RECENT BLIGHT EPIDEMICS

In the famine year 1846, Father Matthew recorded that the potatoes from Dublin to Cork were blooming in all the luxuriance of an abundant harvest on July 27, while on August 3 there was one wide waste of putrefying vegetation. In terms of our present (B.M.S.) scale for blight assessment on the foliage this would suggest that the attack, which had probably started in early July, was still inconspicuous from the roadside, though perhaps up to 25 percent by July 27, but that it was at 50 to 75 percent a week later. Such very early defoliation, which would now be expected to result in a loss of half the crop, still occurs in some years in unsprayed crops of susceptible varieties in county Galway, but 75 to 90 percent dates before mid-August appear to be exceptional, and in many years the bulk of the defoliation loss occurs in September.

The dates of first outbreaks of blight have been well determined in Ireland, where the Department's instructors and potato inspectors have been systematically reporting on first occurrences since 1907. A retrospect of the results of this work for 50 years (1907-56) has now been published by McKay (1957). This unique record shows clearly that the first outbreaks (often on clamp sites or waste heaps) usually occur in May or early June in the early-potato districts of Cork, Waterford, and Wexford; and at about the same time, or at most a little later, in Galway and Mayo. In only 9 years out of the 50 was the appearance of blight delayed beyond mid-June, and in most years it became more or less prevalent throughout the country from the end of June onward.

These early outbreaks were by no means always followed by severe epidemics, as the progress of the disease was frequently checked by subsequent warm dry weather--rarely until the end of the season but quite often until late August or early September.

The general courses of the blight epidemics after the outbreaks each year, for many years past, have been described by McKay in appendices to the Annual Reports of the Minister for Agriculture. The accounts of the epidemics for the 10 years from 1947 to 1956 (McKay, 1948-57) enable these years to be grouped into "blight years," when the disease was more or less severe, and "other years," when its incidence was relatively slight. What constitutes a "blight year" in Eire may be seen from the following brief extracts from McKay's notes, which refer to the general incidence of blight. As protective spraying is the rule in Eire, the progress of the disease, as described, must be taken as referring in the main to sprayed crops and not to the unrestricted epidemic were the crops left unsprayed.

Blight years	Blight conditions
1948	Appeared early, but not general until near mid-September, then rapid. Tuber infection low.
1950	General from beginning of August, but not virulent until mid-September. Tuber infection low.
1951	Prevalent from beginning of August, then a severe epidemic, during which the superiority of burgundy mixture was shown up. Tuber infection high in some parts.
1952	Common from mid-July onward, rapid kill of tops in September. Tuber infection low.
1953	General from mid-July onward, long-drawn-out attack, reaching its peak in September. Some heavy tuber infection from lifting while tops not completely dead.
1954	Widespread from mid-June onward, but development somewhat erratic up to harvest.
1956	General by the end of June, little severe killing of the foliage until the end of August, then rapid. Long-drawn-out attack with some heavy tuber infection.

Other years	Blight conditions
1947	Prevalent from end of June, but spraying and very warm weather in August stopped spread on maincrops. Became active again in September. Tuber infection negligible in late varieties.
1949	Only of minor importance throughout the season, owing to the exceptionally dry, warm weather.
1955	Warm weather in July halted the attack, but sporing continued on lower leaves and revived on unsprayed crops in September. Some serious tuber infection from lifting when tops not completely dead.

Table 29 shows the mean rainfall, for Eire as a whole, in the months of June, July, August, and September in each of the years 1947-56, and also the mean temperatures in each month in terms of degrees Fahrenheit deviation from the long-term averages shown in figure 18. It would have been correct to express these temperature deviations as a range; e.g., as "-1 to +1" for July 1950 instead of "0," but for simplicity the mean of the two extremes of the range is given, and this serves well enough to differentiate between the warm and the cool seasons. The mean potato yields for Eire, each year, as given by the official statistics, are also entered in the table.

The distinction between "blight years" and "other years" cannot be made very precisely for Eire, as indeed there was only 1 of the 10 years (1949) in which the blight attack was negligible, but the data in table 29, read in conjunction with McKay's notes, would suggest that the frequency of "blight years" is 7 or 8 in 10, and that in these "blight years," despite all the spraying that is done, the growth of such maincrops as Kerr's Pink is generally stopped by blight in September--probably by about mid-September; with the unsprayed crops going down some weeks earlier.

Table 29 shows clearly the checking effect of low rainfall and higher mean temperatures during July and August on the blight epidemics. It also shows that, as in England and Wales, the years of low average national yield are not usually the "blight years," but the years with relatively warm dry summers in which blight is least severe. This would not be so in Ireland but for the protective spraying, which enables the crop to reap the benefit of the good growing conditions in the blight years.

PROTECTIVE SPRAYING

After half a century of use and many challenges from other materials, burgundy mixture is still the material officially recommended and most generally used for potato spraying in Ireland. The main reason for this lies in the high resistance of the deposits

TABLE 29.--Mean rainfall, mean temperature deviation from long-term averages, mean potato yields for Eire, 1947-56

Year and average	Rainfall				Mean temperature deviations[1]				Mean potato yield
	June	July	Aug.	Sept.	June	July	Aug.	Sept.	
	In.	In.	In.	In.	°F.	°F.	°F.	°F.	Tons/acre
Long-term average.....	2.8	3.7	4.2	3.2	--	--	--	--	--
Blight years:									
1948.....	3.9	3.1	3.9	3.9	-1	-1	0	-1	8.5
1950.....	2.6	5.0	6.3	6.4	-1	0	+1	-1	8.5
1951.....	2.4	3.2	5.2	5.0	+1	+1	-1	+1	8.6
1952.....	2.5	1.4	3.6	2.4	0	+1	+1	-3	8.6
1953.....	1.3	5.5	4.3	4.7	0	0	+1	+2	8.8
1954.....	2.7	4.2	3.2	5.7	-1	-2	-1	-2	7.7
1956.....	3.1	5.3	3.6	4.9	0	0	-2	+2	9.2
Other years:									
1947.....	4.7	4.0	1.2	3.7	+1	-1	+5	+2	6.8
1949.....	1.2	3.2	4.0	2.6	+3	+2	+2	+4	7.7
1944.....	5.1	.9	2.1	3.5	0	+3	+4	-1	7.4

[1] See figure 18 for average temperatures.

to washing off by rain and the consequent relatively long period of protection given, which, as may be seen from McKay's notes, is important not only for prolonging the growth of the haulm to increase yield, but also for keeping blight off the haulm as long as possible to reduce the opportunity for the infection of the tubers.

One percent burgundy mixture (freshly made up with 4 lb. copper sulfate and 5 lb. washing soda per 40 gallons of water) is now the standard spray, but 2 percent burgundy is still preferred in the west, and is resorted to elsewhere in wet seasons. The mixture is applied at the rate of 120 gallons per acre, still often by knapsack sprayers, but by horse- or tractor-drawn machines on the larger farms. The first application is generally recommended toward the end of June, and the second about 3 weeks later, but the application dates vary according to the prevalence of blight, forwardness of the crop, and weather conditions. A third application is occasionally given; hence, again the need for a spray material that, applied for the last time towards the end of July, will give protection for the longest possible time in August. Copper oxychloride and cuprous oxide sprays, at the same copper dosage as 1 percent burgundy mixture, are used to some extent in Eire, but despite their convenience in use, they have not made the same headway as in England and Wales or other parts of Europe.

The predominant variety, Kerr's Pink, would normally grow on to the end of September in the absence of blight or with very efficient spraying. In Galway blight can devastate Kerr's Pink during July, and in the worst years the unsprayed crops would be dead by the first week in August, with a loss of about half the crop. Although this is rare, even with three sprayings most of the haulm is usually killed by mid-September. In Monaghan and the north midlands Kerr's Pink is sometimes sprayed only once in the drier years. In Wexford and Waterford, where the unsprayed haulm is sometimes killed by mid-August, and almost always by the end of August, two sprayings are usual, with a third in wet seasons. The variety Up-to-Date, where it is still grown, suffers rather more severe attack than Kerr's Pink, but when sprayed as for Kerr's Pink the differences in loss of yield are not great. Arran Banner, which occupies a considerable part of the potato acreage in most districts, often escapes much reduction of yield by blight, as it reaches maturity about the end of August. It is, however, very susceptible to blight in the tubers. Where grown for seed, as in Donegal, it is often sprayed only once, about the first week in July, and then the haulm is burned off with chlorate about mid-August.

Relatively little haulm destruction is done in Eire, except on the seed crops. No doubt the rapid destruction of the haulm by blight in September commonly renders the treatment unnecessary. Where haulm destruction is done, the material chiefly used is sodium chlorate. No arsenites are employed.

SPRAYING TRIALS

A series of spraying trials on the variety Up-to-Date was carried out to a uniform plan over the years 1927-32 at Glasnevin, Dublin, by Murphy and McKay (1933). These trials were made over a run of years in which slight, average, and severe attacks appear to have been very fairly represented, in comparison with the general accounts of the epidemics in more recent years. The spraying was done by knapsack sprayer, using generous amounts of 2 percent burgundy mixture, with 2 applications in 1927 and 1930, and with 3 applications in the other years. The leading results are given in table 30.

From these results it will be seen that even at Dublin the haulm was completely killed by blight at the end of August or in early September 5 years in 6. The mean gain from spraying over the 6 years was 2.5 tons per acre. Additional trials with 3 sprayings were also made on British Queen and Arran Victory in 1931, and on Golden Wonder in 1932, and the mean increase of marketable crop from all 7 trials in which 3 sprayings were given was $3\frac{1}{2}$ tons per acre.

In discussing the losses due to blight and the economics of spraying Murphy and McKay pointed out that in most of the many field experiments on spraying in Ireland the increase of sound yield was from $1\frac{1}{2}$ to 2 tons per acre. Even with this gain, the sprayed plots always suffered to a greater or less extent despite the spraying. The authors considered that $3\frac{1}{2}$ tons per acre, the gain achieved with fairly complete protection by the 3 sprayings in their trials on all varieties would not be an overestimate of the total average loss from blight in Ireland as a whole. In other words, the normal practical spraying in Ireland saves about half the total loss from blight; an estimate in close accordance with the findings, in this study, on the efficiency of spraying in blight years in England and Wales.

Some phytotoxic checking of the growth of the haulm by the very strong 2 percent burgundy mixture was noted by Murphy and McKay in their trials. In the very severe blight year 1932, in which 1 percent burgundy was included for comparison, it gave as good results as the 2 percent mixture. A wealth of trial data on the comparison of 1 percent and 2 percent burgundy mixtures is to be found in the historic reports by Pethybridge (1910-19) on potato diseases in Ireland. The average results of a series of trials carried out in Galway over the years 1911-18 were as follows:

TABLE 30. --Spraying trials at Glasnevin, Dublin, on Up-to-Date potatoes, 1927-32

Year and mean	Rainfall			Attack	Blight started	Unsprayed haulm dead by--	Marketable crop		Blight in tubers	
	July	Aug.	Sept.				Unsprayed	Gain over sprayed crops	Sprayed	Unsprayed
	In.	In.	In.				Tons/acre	Tons/acre	Percent	Percent
1927.....	3.3	6.0	3.5	Average	Mid-July	Sept. 1	10.4	1.8	1.4	2.6
1928.....	1.3	2.7	.7	..do.....	..do.....	Sept. 18	10.2	2.2	.1	5.0
1929.....	2.2	4.9	.4	Very slight	Mid-Aug.	Sept. 15	15.1	.4	0	.3
1930.....	3.0	5.5	6.3	Severe	Mid-July	Aug. 30	12.3	1.5	8.0	8.4
1931.....	3.7	3.4	5.4	..do.....	End June	Sept. 9	7.0	6.4	5.4	25.0
1932.....	4.7	1.6	2.4	Very severe	Mid-July	Aug. 25	8.8	2.5	1.8	2.8
Mean.....	--	--	--	--	--	--	--	2.5	2.8	7.3

Crop:	Tons per acre from crops sprayed with burgundy mixture of--	
	1 percent	2 percent
Healthy-------	10.8	10.8
Blighted ------	.5	.4
Total-------	11.3	11.2

Thus, it would appear that the expensive and very strong 2 percent burgundy mixture has little advantage over 1 percent burgundy, except where very heavy deposits are required to persist as long as possible from the last spraying.

Copper dusting was compared with spraying in the trials of Murphy and McKay, and even at very heavy rates of application dusting was inferior to the burgundy mixture. Bouisol, the first of the colloidal copper fungicides, was included in the trials in 1931 and 1932; not until its rate of application (in terms of Cu dosage) was brought up to half that of 1 percent burgundy mixture (namely to 1.25 lb. Cu per 100 gallons) did the results approach those of burgundy mixture.

SPRAYING IN RELATION TO THE DEVELOPMENT OF THE POTATO PLANT

Following up clues that became apparent in the course of the trials made with McKay, Murphy (1939) went on in the years 1934-37 to evolve a new kind of potato spraying trial that was to reveal the essential relationship between increase of yield and protection of foliage, and provide the yardstick by which blight epidemics could be measured, not only in Ireland, but throughout the world. No longer content with determining yields from the sprayed and unsprayed crops, he studied the whole course of growth and decline of the haulm, and of increase in weight of the tubers (1) in plots kept completely free from blight by frequent applications of a weak copper fungicide having no phytotoxic effect, (2) in plots commercially sprayed, and (3) in plots left unsprayed.

It was not until 1937 that the method was perfected, and in this year, which was one in which the blight attack (starting on July 24) was average at Glasnevin (with 2.0 inches of rain in July, 2.7 in August, and 1.4 in September), Murphy at last had plots of Up-to-Date in which the haulm was kept completely free from blight, with no phytotoxic effects and no premature dying off owing to dry weather--a more or less perfect crop growing on to the end of its growing period.

Fortnightly liftings on this protected crop showed the proportion of the final or potential crop that was present on various dates from July 5 onward. These figures are given in table 31, and to this table are added the corresponding figures later determined for Majestic in England and Wales (see fig. 8).

There is remarkably close agreement between Murphy's first figures for Up-to-Date and the mean figures obtained for Majestic in England; which indicates that, in 1937 at any rate, the late maincrop Up-to-Date was bulking in Ireland at about the same average rate as Majestic in England.

From periodic weighings of the leaves and total haulm, which he also made in the course of his trials, Murphy concluded that when the weight of the haulm had been reduced to about 55 percent of its maximum and the weight of the leaves to between 30 and 40 percent of their maximum, tuber production ceased. At this point of stoppage of tuber formation he described the field as looking gray green at a distance, with stalks still green, but with all the leaves dead except for tufts of 6 or more at the apices of the shoots. This stage, corresponding to 75 to 90 percent on the later evolved B.M.S. scale (B.M.S., 1947) occurred about August 28 on the unsprayed plots at Glasnevin in 1937. In effect, as Murphy pointed out, the final yield from the unsprayed plots should be approximately the same as the yield reached by August 28 on the plots kept entirely free from blight by frequent spraying.

TABLE 31.--Progress of tuber development of Up-to-Date potato in Glasnevin Ireland, 1937, and of Majestic in England

Date lifted	Up-to-Date		Majestic, proportion of total mean yield
	Yield	Proportion of total yield	
	Tons/acre	Percent	Percent
July 5.....	1.74	12	--
July 19.....	3.90	27	34
Aug. 2.....	6.87	47	52
Aug. 16.....	9.90	68	73
Aug. 30.....	12.24	84	86
Sept. 13.....	13.93	96	96
Sept. 27.....	14.64	100	100

From a plotting of the tuber growth curve from the data in table 31, the total yield under the perfectly protected plants on August 28

was 11.9 tons per acre. The actual yield as determined by lifting was 11.7 tons per acre, in almost exact accordance with the theory. The total yields present by various dates in the plots that received each of the 3 treatments are shown in table 32.

TABLE 32.--Total yields of Up-to-Date potatoes at Glasnevin, Ireland, with 2 treatments and no treatment, 1937

Treatment	Yield						
	July 5	July 19	Aug. 2	Aug. 16	Aug. 30	Sept. 13	Sept. 27
	Tons/acre	Tons/acre	Tons/acre	Tons/acre	Tons/acre	Tons/acre	Tons/acre
Complete control.....	1.7	3.9	6.9	9.9	12.2	13.9	14.6
2 percent burgundy (3 sprayings).....	2.1	4.3	7.3	9.6	11.3	12.9	13.6
Unsprayed.....	1.9	4.6	7.5	10.0	11.5	11.7	11.7

The date of stoppage of growth in the plots sprayed with 2 percent burgundy mixture (on June 30, July 16, and August 9), as estimated by Murphy's weighing method, was September 24, very little different from that in the plots with complete control (Sept. 26). But the curves given in his paper for the progress of decline of the foliage show a wider separation in late August and early September, so that the 75 percent point by the English method would have been perhaps a week earlier, in better accordance with the difference of yield. However, there was a lower maximum weight of haulm in the plots sprayed 3 times with the strong 2 percent burgundy mixture, which indicates some checking effect on growth that may also have affected the yield.

ESTIMATION OF BLIGHT LOSSES IN IRELAND

The method that Murphy's work suggested of estimating blight losses, from a mean growth curve for the tubers and survey information on the dates at which growth is stopped by blight on the sprayed and unsprayed crops, has not yet been applied and developed in Ireland as it has been in England and Wales. There are not the necessary data for any close analysis of the blight losses in Ireland region by region or year by year, and it may well be that Kerr's Pink often puts on rather more of its tuber weight in September than is indicated by Murphy's data for Up-to-Date in the single season, 1937. It is of interest, however, to take Murphy's figures as a basis and then see what measure of defoliation loss they would indicate when some near estimates are made of mean dates of stoppage of growth by blight.

Perhaps it would be fair to say that in 7 or 8 years out of 10 in Eire the average date at which blight would stop growth on the maincrops, if they were left unsprayed, would be about the end of the third week in August (earlier in Galway, later in Dublin, but August 23 on average). Spraying with 3 applications sometimes defers the stoppage of growth by blight until mid-September or even until the end of the season, but it is probable that with the usual 2 sprayings, and sometimes only 1, the average gain from spraying can be put at about half a month's full growth at the end of August and beginning of September, equivalent to stoppage of growth on September 8. The total defoliation loss from blight and the gain from spraying, on a 12½-ton potential total crop, on the basis of Murphy's figures would then be as shown in table 33.

It is difficult to form any estimate of the mean loss due to blighted tubers in Ireland. As in England and Wales, the losses in individual crops may range from negligible amounts to several tons per acre. Perhaps the loss of 4 or 5 percent as found by Pethybridge over his long series of trials is fairly representative for sprayed ware crops, and the loss could be expected to be twice as great in the unsprayed. Estimates of 4 and 8 percent, respectively, for the losses due to blighted tubers are entered in table 33. The mean total loss on a 12½-ton potential crop due both to defoliation and to blight in tubers then becomes 3.8 tons per acre; of this loss, 2.3 tons per acre is recovered by the usual commercial spraying.

These figures are in reasonable agreement with the estimate of 3½ tons per acre total loss made by Murphy and McKay on the basis of their trials; and they serve to illustrate that the method of estimation based on Murphy's growth curve gives results of at least the right order. It should be borne in mind, however, that table 33 is for ware maincrops and not for the seed crops that are burned off prematurely, and in which the percentage of blighted tubers is much less. It is also based on the growth curve for a late maincrop, and

TABLE 33.--Loss estimations for maincrops in Eire on basis of Murphy's findings

Item	Unsprayed	Sprayed	Potential crop (no blight)
Date of stoppage of growth	Aug. 23	Sept. 8	Sept. 27
Percentage of potential crop (from Murphy's growth curve)	76	92	100
Total crop ... tons per acre	9.5	11.5	12.5
Gain from spraying ... tons per acre	--	2.0	--
Total defoliation loss ... tons per acre	3.0	--	--
Percentage of blighted tubers	8	4	0
Healthy crop ... tons per acre	8.7	11.0	12.5
Gain from spraying ... tons per acre	--	2.3	--
Total loss ... tons per acre	3.8	--	--

it may not hold for Arran Banner. In the occasional dry, warm seasons, such as 1949 and 1955, the blight losses are undoubtedly less, but the lack of rain reduces the crop.

FORECASTING

With severe or moderately severe blight epidemics occurring in 7 or 8 years of 10, routine spraying every year is well justified in Ireland. The requirements of a forecasting system for Ireland are different from those in England and Wales, where over much of the country spraying is rarely needed at all, and even in the Fens only about every other year is a blight year. In England one of the main objects of forecasting is to discourage spraying in the "no-blight" years when it can do positive harm. In Ireland spraying is needed almost every year, but the fact remains that the Irish farmers are attempting to combat severe epidemics with a very small number of spray applications--generally only two, and at most a reluctant three. The highly retentive burgundy mixture is used, and this helps, but still the mean gain from spraying is only about half the total loss from blight, and there is every inducement for trying to raise the overall efficiency of the spraying by the best possible timing of the spray applications in relation to the weather conditions.

In 1952, a new approach to forecasting was made by Austin Bourke of the Irish Meteorological Service. In this system, as it has since been developed and put into use in Ireland (Bourke, 1953a, 1953b, 1955), the stress is on detecting every progressive spell of weather favorable for the development of blight and on advising farmers whenever the more important of such spells occur, from June through August, so that not only their first sprayings but also their second and, where necessary, their third sprayings can be applied knowledgeably and to the best advantage. The very early spells of blight weather, corresponding more or less to the first few outbreaks, which, as McKay (1957) has so clearly shown, often occur in May or even in April, are not made the subject of press notices, as this would confuse the growers and might lead to premature spraying. It is not until the early blight weather spells have been such as to permit 3 to 5 generations of the fungus that an initial warning of the onset of the disease is issued. This is almost invariably in the latter half of June, when it has the effect of strongly reinforcing the Department's long-standing advice that the first spray should be put on about that time, according to weather conditions.

A minimum humid period favoring the spread of potato blight consists, according to Bourke's "Irish Rules," of

> Twelve consecutive hours with relative humidity not below 90 per cent and temperature not below 50° F, followed immediately by a further four hours with the plants wet, either due to rain, drizzle or high humidity (fog, mist or dew).

Such a minimum "blight weather spell" means one having an "effective duration" of 1 hour; any longer spell has an effective duration of 1 hour plus the excess over the required minimum.

This is a temperature-humidity rule, similar to the Beaumont rule as employed in England and Wales in that it has the same minimum temperature requirement and that it demands a continuous spell of high humidity; but the rule differs from the Beaumont rule in that it was derived from a theoretical consideration of the findings of Crosier (1934) on the conditions required for the sporulation and infection processes of the fungus and in that a shorter minimum period at higher relative humidity is taken as critical.

In the operation of the system, routine hourly weather reports from a network of 9 or 10 weather stations are used, and the "effective durations" of all "blight weather spells" (humidity conditions measured in standard screens 4 ft. above ground level) are entered on maps from day to day at the Central Forecast Office in Dublin. The probable geographical limits of each spell are then determined by examination of the synoptic weather charts for the period in question.

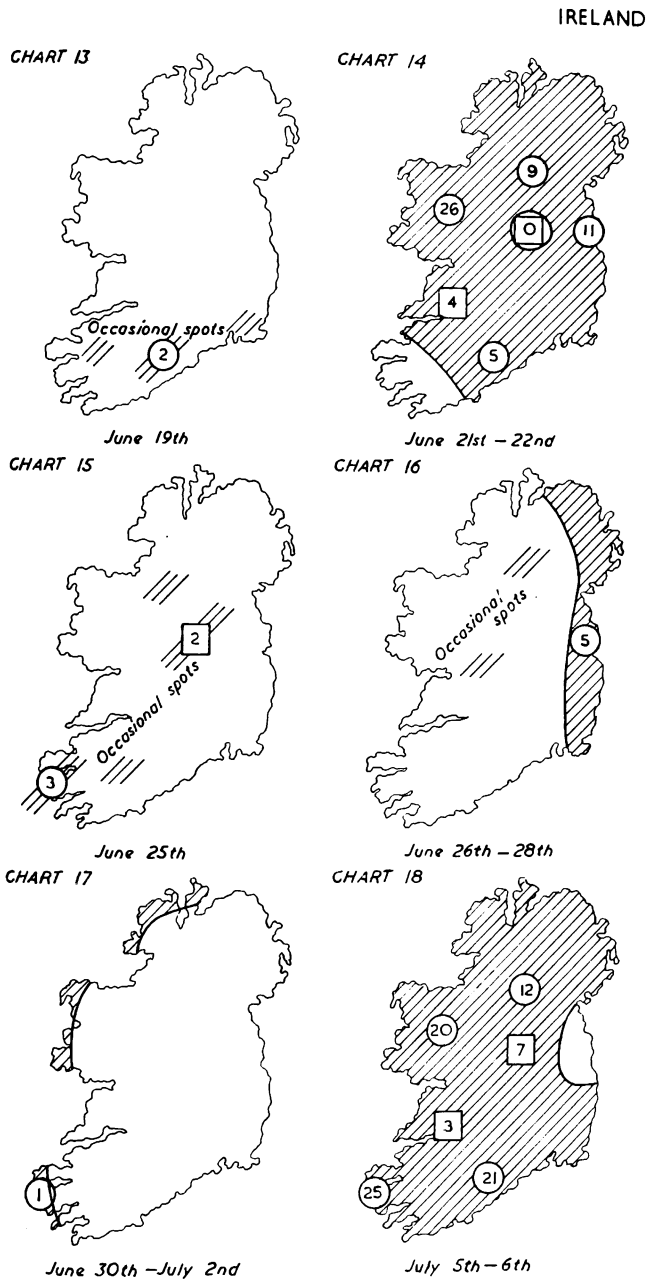


FIGURE 20.--Part of a series of charts showing areas of Ireland affected by successive spells of blight weather in 1953. Effective durations of the spells at the several stations are given in hours. (Bourke, 1953b.)

A part of the sequence of these maps for 1953, from Bourke (1953b) is here reproduced in figure 20 to illustrate the method. After the spell shown on June 21-22, a first spray warning was broadcast on June 22 as follows:

> Weather favorable for the spread of potato blight occurred over most of Ireland during the past week-end, and is likely to recur in the west during the next few days. Blight may be noticeable about mid-week in many areas. Weather will be suitable for spraying during most of the week.

Other warnings were issued following the spell shown for July 5-6, and later spells on July 19-20, August 4-9, and August 29 (for burning off). In effect, these warnings gave very good advice for the season, which was one in which blight became more or less general from mid-July onward.

It has not been possible to test the Bourke system of forecasting in Ireland so thoroughly as the Beaumont system (with operations charts) has been tested in England and Wales, owing to the lack in Ireland of any systematic blight surveying and assessment by standard key. The forecasts have nevertheless been in reasonably good accordance with the general observations on blight made by the Department's inspectors who have participated in the work, and there is no doubt that Bourke's method is among the most sensitive yet proposed for the measurement of "blight weather." The application of the method in Chile is illustrated in figure 79 of this study.

The advance made by Bourke does not lie so much in the choice of the humidity criteria, for Smith's (1956b) work on forecasting by 90 percent humidity criteria in England and Wales has indicated that there is usually a fairly close correspondence between Bourke and Beaumont periods when the principal spells of blight weather occur. Both methods give good results in the hands of those experienced in their use. The important step forward is the correlation of critical humidity periods (however defined) with specific weather situations as revealed by synoptic maps and with air mass analysis (Bourke, 1957). This is a procedure that may find an application in many parts of the world, especially where forecasting has to be attempted for a wide area with no very close network of weather stations. To illustrate the possibilities, Bourke's chart for mid-July 1956 is here reproduced (fig. 21). Working in Dublin and from a study of the synoptic maps alone, he was able to see that a severe blight weather spell which occurred in Ireland over the period July 14-17 must also have occurred in England and Wales, and indeed over much of western Europe. This was fully substantiated for England and Wales, and as far as could later be ascertained, it was also true for the areas indicated in other countries--from the Baltic countries to northern France.

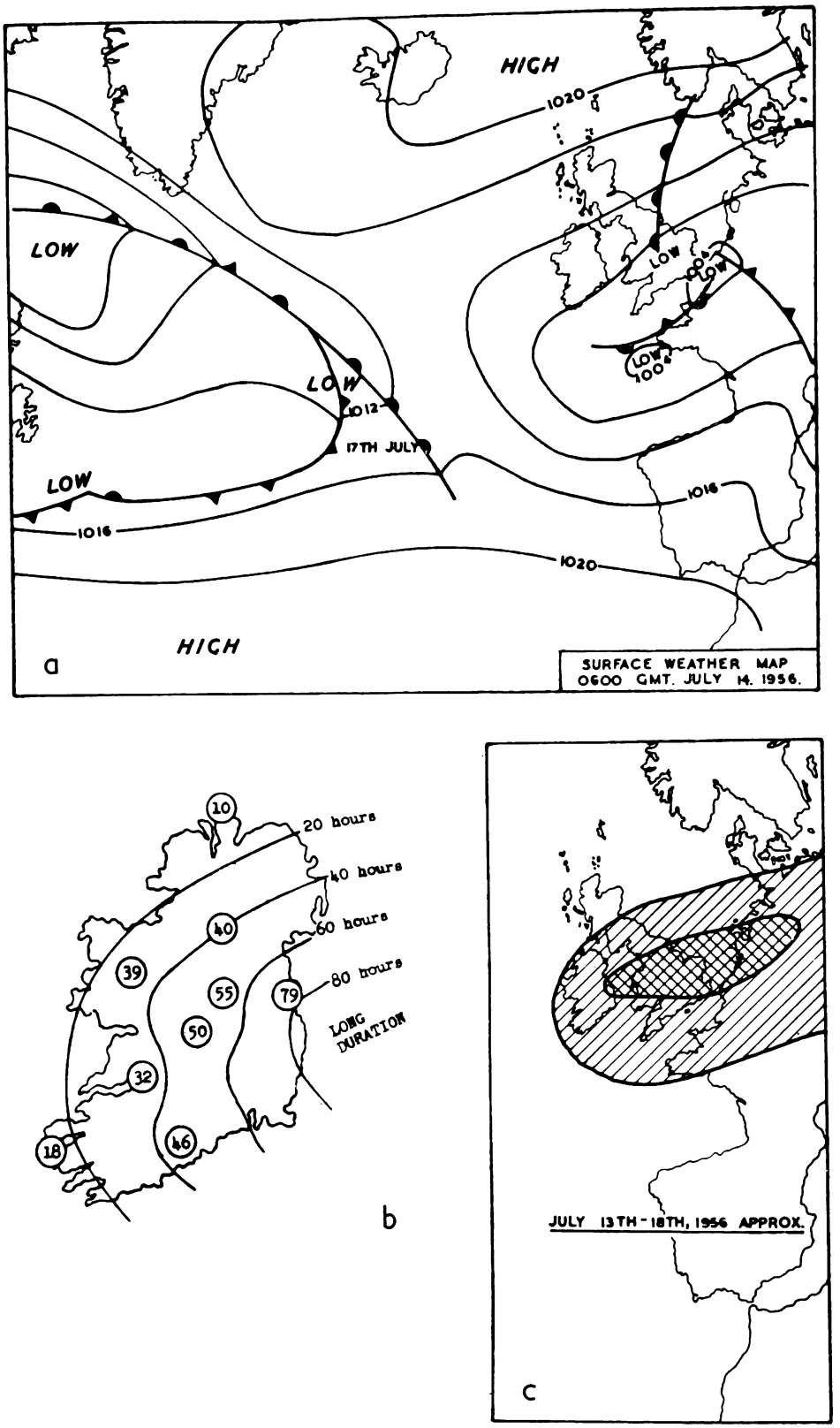


FIGURE 21.--Blight weather in Ireland and parts of western Europe, July 13-18, 1956 (Bourke, 1957): a, Surface weather map for July 14, showing continental slow-moving, or "puddle," low; b, effective duration of blight weather in Ireland, July 15-18; and c, approximate limits of blight weather arising from the synoptic situation (cross hatching shows the area most seriously affected).

SUMMARY: REPUBLIC OF IRELAND

Potato spraying is now so universal in Eire that it is difficult to estimate what the loss from blight would be in its absence. No blight surveys or critical series of spraying trials have been carried out recently. But from consideration of the weather conditions, general accounts of blight in each year, and the results of trials under similar conditions in the past, it is estimated that in Ireland the haulm of unsprayed maincrops would be killed by blight between mid-August and the end of August in 7 or 8 years out of 10, with a mean loss through premature defoliation and blight in tubers of $3\frac{1}{2}$ to 4 tons per acre. Of this loss about $2\frac{1}{2}$ tons per acre can be saved by 2 or 3 applications of burgundy mixture, which prolongs the useful growth of the haulm by 2 or 3 weeks and also substantially reduces tuber infection. Eire has an important seed-potato trade. Burning off is practiced on the seed crops, and blight losses in them are small. Many fundamental contributions to knowledge of potato blight, including its relation to the growth rhythm of the potato plant and more recently to forecasting methods, have come from Ireland--the traditional home of the potato in Europe.

FRANCE

France grows annually about 2,500,000 acres of potatoes. Half the crop is used for human consumption, about 284 lb. per head each year (Russell (E. J.), 1954). Large quantities are fed to livestock, principally pigs; small amounts are manufactured into starch; and the rest is used for seed. Certified seed production is on a small scale. In 1954 it accounted for slightly under 3 percent of the total potato acreage. But the seed growers have been responsible for much of the technical progress made in French potato production during recent years. An account of the seed-potato industry and its future trends has been given by Demesmay (1954). The output of French certified seed plus imports of such seed from other countries, mainly Holland, is sufficient to plant only about one-fifth of the total acreage. This may, in part, account for the rather low average yield of potatoes in France, which for the period 1948-50 was 5 tons per acre (F.A.O., 1955).

POTATO DISTRIBUTION AND VARIETIES

The distribution map (fig. 22) shows a scatter of potatoes throughout the whole country. There is a marked concentration in Brittany (19 percent of the total potato acreage was in this province in 1954), and smaller concentrations in north-central France (the Paris basin through to Nord), eastern France, and across the center of the country (northern part of the Central Massif). The main early potato-growing areas are in Brittany and in the departments surrounding the mouth of the river Rhone in the south of France. In the latter area, 56 percent of the potato acreage is planted with early varieties. Early varieties are also grown in the vicinity of the large towns; e.g., in the Paris basin and near Bordeaux. Brittany is also the most important seed-growing area, accounting for approximately 70 percent of the total seed acreage. The only other important seed district is in northern France, concentrated in the five departments, Nord, Pas de Calais, Somme, Oise, and Aisne.

Some idea of the relative importance of the different potato varieties grown in France can be gaged from figures published by the Seed Growers' Association: They have also given a description of these varieties (Federation Nationale, 1955a, 1955b). Table 34 shows the acreages of the 10 leading French potato varieties grown for seed in 1955.

TABLE 34.--Acreages of leading potato varieties grown for seed in France, 1955

Variety	Certified seed
	Acres
Bintje	43,171
Ackersegen	5,928
Institut de Beauvais	2,438
Etoile du Léon	2,354
Saskia	2,240
Arran Banner	2,191
B. F. 15	2,065
Ker Pondy	1,529
Krasava	1,294
Urgenta	1,065

The outstanding point is the preponderance of Bintje, which is widely grown throughout France. It is very susceptible to blight, but, as it is relatively early maturing, Bintje often escapes the full severity of epidemics. Ackersegen is the most popular late variety, and Etoile du Leon and Saskia the most common early varieties.

SOIL, CLIMATE, AND CULTIVATION

In Brittany and the Central Massif (fig. 23), the potato soils are generally light, and are derived from underlying granite and schist rock formations. in northern France, including the Paris basin, and in eastern France, the soils are heavier, but usually overlie a subsoil that is predominantly sandy.

France exhibits the three main European climatic types--maritime, continental, and Mediterranean. In the potato-growing areas of Brittany, the climate is predominantly maritime, although it is modified in the departments farthest from the coast. This maritime climate is characterized by a marked autumn and winter rainfall peak, relatively mild winters, and cool summers. Total annual rainfall is around 30 inches. In northern France (Nord, Pas de Calais), there is a modified maritime climate, whereas farther south in the Paris area continental influences are more important. The potato-growing districts of eastern France are under the influence of a fully continental type of climate. Summer and winter temperatures are more extreme than in the

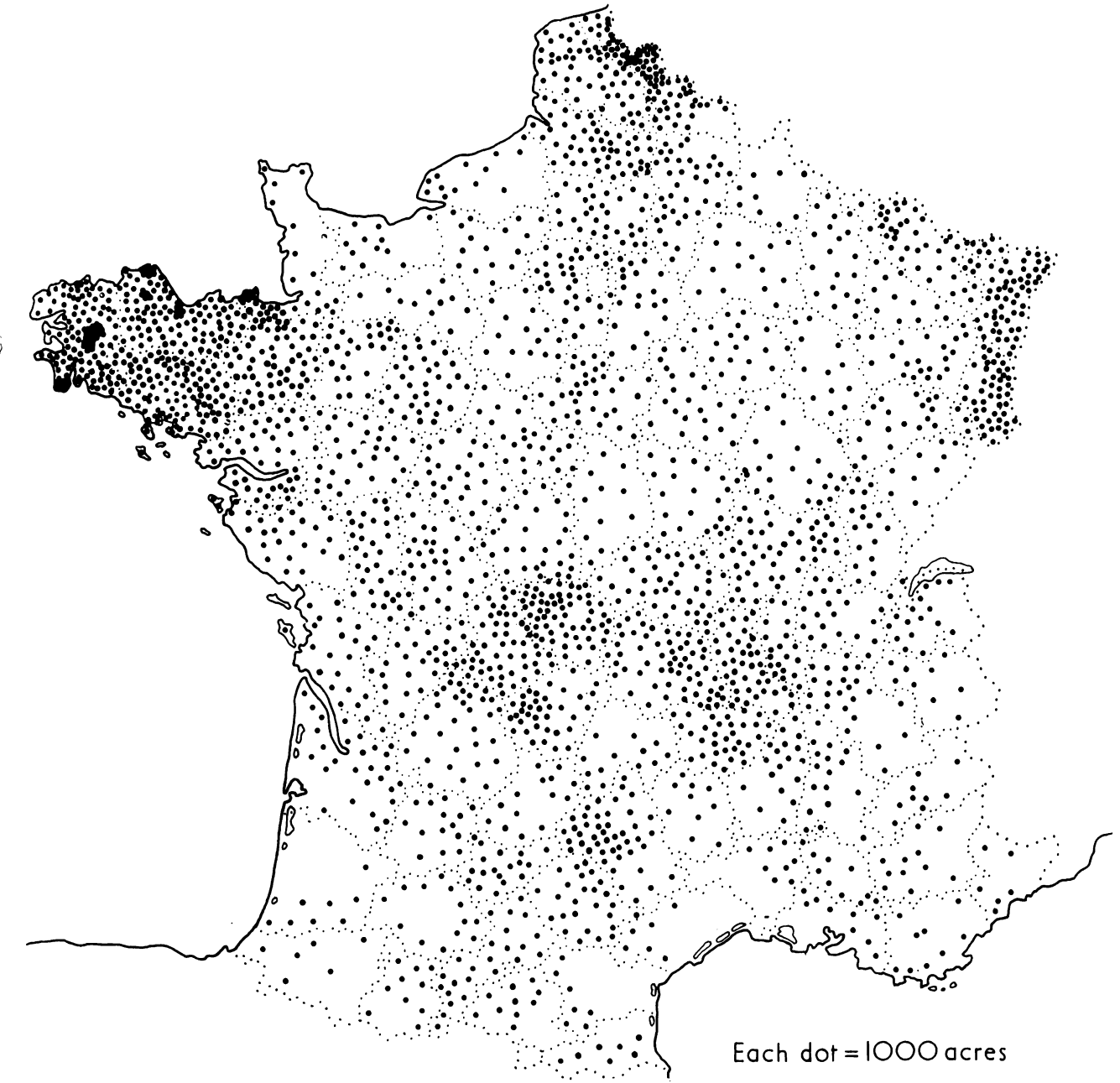


FIGURE 22.--Distribution of potato growing in France, 1954. (After Klatzmann, 1955.)

west, and the rainfall peak occurs in the summer months. Total annual rainfall, approximately 24 in., however, is lower than in the west. The true Mediterranean climate with its hot summers and characteristic periods of drought is confined to the coastal areas of southern France. Generally speaking, this is not an important potato-growing area, apart from the early crops grown around the mouth of the river Rhone.

The main planting takes place in mid-April. Planting of early varieties in Brittany is carried out at the end of February to early March. Seed crops in Brittany are burned off compulsorily in mid-July. The maturity of mid-season and late varieties varies from approximately mid-August to mid-September.

One-third of the total manpower in France is still engaged directly in agriculture, and apart from the north-central area of the country, mechanization is not very far advanced. Potatoes are still largely planted by hand. The seed is not usually cut. Potato rows are about 28 in. wide, and mid-season and late

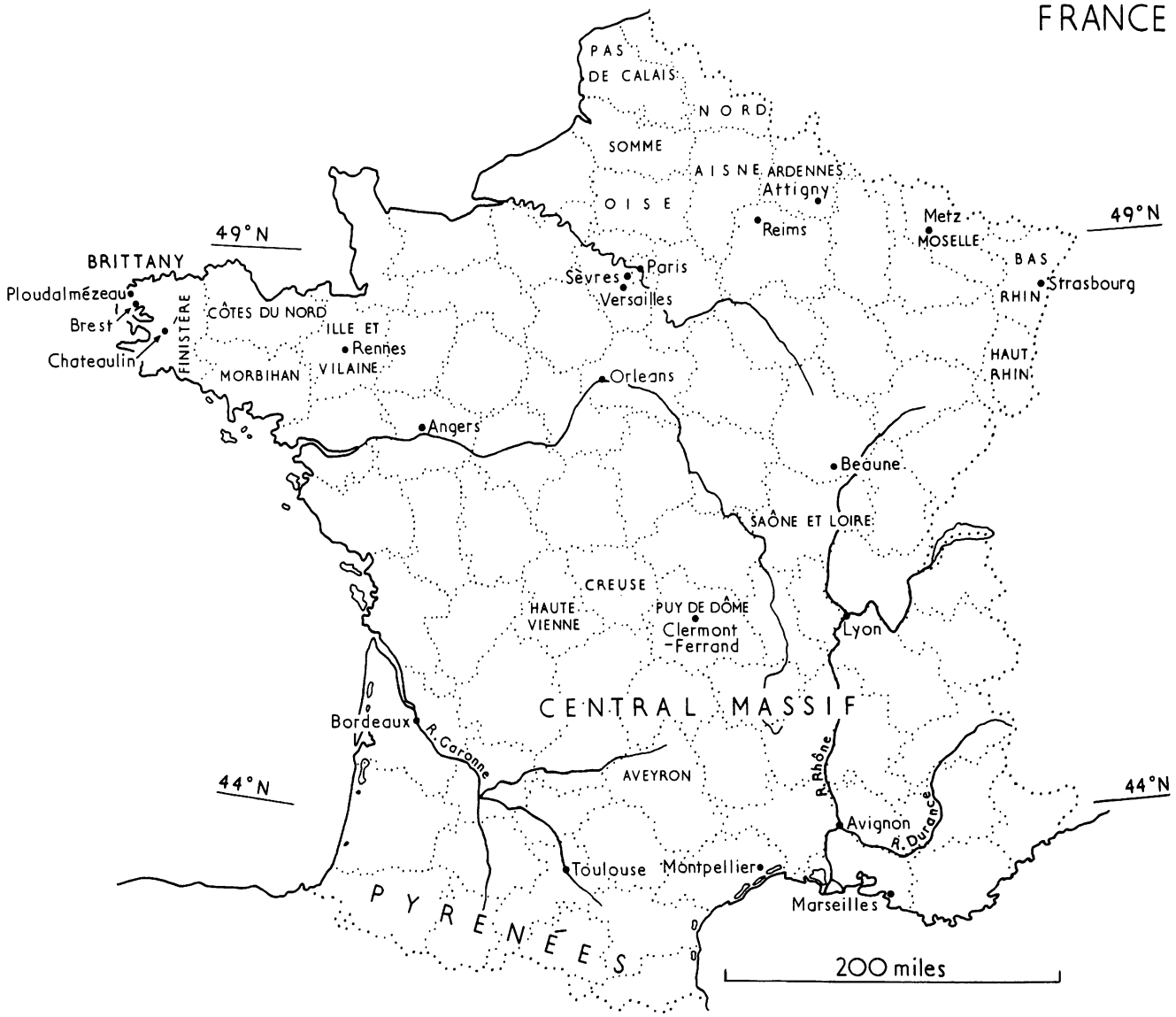


FIGURE 23.--Key map of France.

varieties are planted from 18 to 22 in. apart in the rows. The potatoes are almost always ridged up. Storage is in farm buildings or, where the winters are mild, in field clamps. A description of ware potato production methods has been given by Malmonté (1954).

FREQUENCY OF BLIGHT EPIDEMICS

The importance and incidence of blight vary considerably between the different areas. Broadly speaking, if a line is drawn across France from Strasbourg to Bordeaux, the disease is important north of the line. South of the line, blight is considerably less important, although in the intensively cultivated river valley areas (e.g., valleys of the Garonne and Durance) where some potatoes are grown under irrigation, heavy losses from blight may occur.

In the north of France, the four main potato-growing districts differ from each other in climatic and soil conditions and blight incidence. (1) In Brittany the disease occurs every year. (2) In north-central France, which includes the Paris basin, blight incidence appears to be fairly uniform, although there are climatic differences within this area. Severe attacks occur about 1 year in 3. (3) In eastern France blight is somewhat less important than in north-central France. (4) In the northern part of the Central Massif the disease is only occasionally severe.

Very little published survey data on the incidence of potato blight on a year-by-year basis exist for France. Ducomet and Foëx (1939) have summarized very briefly the attacks of the disease from 1919 to 1937. In 1953, short notes were given anonymously in the Annales des Epiphyties on attacks in 1951, and Barbotin (1953) has given an account of the progress of blight in 1952. Information on other recent years has been given to the authors by H. Darpoux and M. Guntz of the Station Centrale de Pathologie Végétale at Versailles, and by P. Dumas of the Service de la Protection des Végétaux. From this, it was possible to divide the 10 years 1947-56 into 3 categories; i.e., years in which the incidence of the disease was slight, moderate, or severe. Table 35 shows the results of this division:

TABLE 35.--Incidence of potato blight in France, 1947-56

Slight	Moderate	Severe
1947	1950	1948
1949	1953	1951
1952	1954	--
--	1955	--
--	1956	--

It is not very satisfactory to have to treat France as a single unit in this way, but it is not possible to give concise data for the separate growing regions, as the information is too fragmentary. In broad terms, the three categories used in table 35 can be defined as follows:

Slight: Blight attacks are either absent or very late throughout northern France.

Moderate: Blight attacks are important in only some parts of northern France, or the disease is late in appearance throughout the whole area.

Severe: Blight attacks occur early and are severe throughout northern France.

BLIGHT ON HAULM

The incidence of blight is usually considered to follow a fairly regular pattern from year to year. The disease is present every year in Brittany, where it starts about the middle of June; the tops of unsprayed potatoes are usually dead by mid-July. It is normally first reported in the Paris area about 2 weeks after its appearance in Brittany, but the course of the disease both there and in eastern France is much less certain than in Brittany, and its incidence is not so severe. In the Central Massif, blight is usually late and is rarely severe.

Since 1955, systematic observations on the development of blight on haulm in relation to weather conditions have been made at a number of centers throughout France by the Plant Protection Service in collaboration with M. Guntz. The aim is to use these data to improve the existing blight warning services. Progress curves supplied by M. Guntz for selected centers in the main growing regions of northern France during 1955 and 1956 are shown in figure 24.

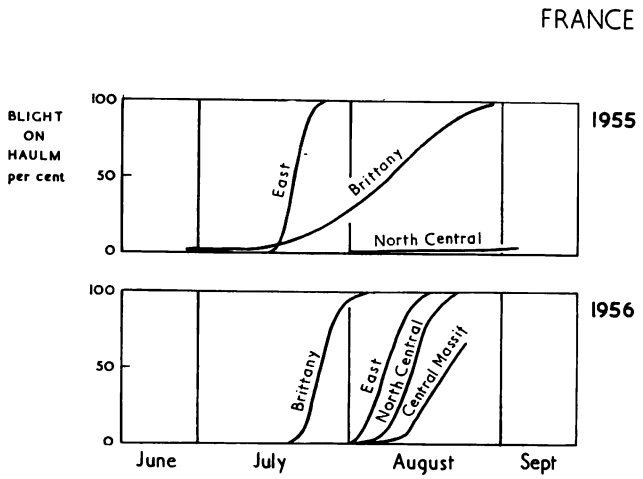


FIGURE 24.--Progress of blight on unsprayed haulm in principal potato growing regions of northern France in 1955 and 1956; variety, Bintje.

The year 1955 was exceptional for blight. It occurred first for a distance of about 50 km. round the coast of Brittany, but made slow progress in dry weather except on the coast. In north-central France, dry weather prevented the development of the disease, but there were heavy rains in eastern France, where blight is not usually bad, and these rains resulted in severe blight attacks. In 1956, blight appeared late, but made very rapid progress on the tops of potato plants throughout northern France.

LOSSES DUE TO PREMATURE DEFOLIATION

BRITTANY: Although the first generalized field outbreaks of blight in this region do not normally occur before mid-June, first reports in the area usually come in much earlier, sometimes by mid-April. The evidence so far available suggests that there are considerable variations in the incidence of blight between the coastal regions and inland Brittany. This is shown up in figure 25, which presents blight progress curves for unsprayed Bintje at three centers. Ploudalmézau is on the coast; Chateaulin is about 15 km. from the coast; and Rennes, which is a good deal farther east than the other centers, is at least 60 km. from the sea.

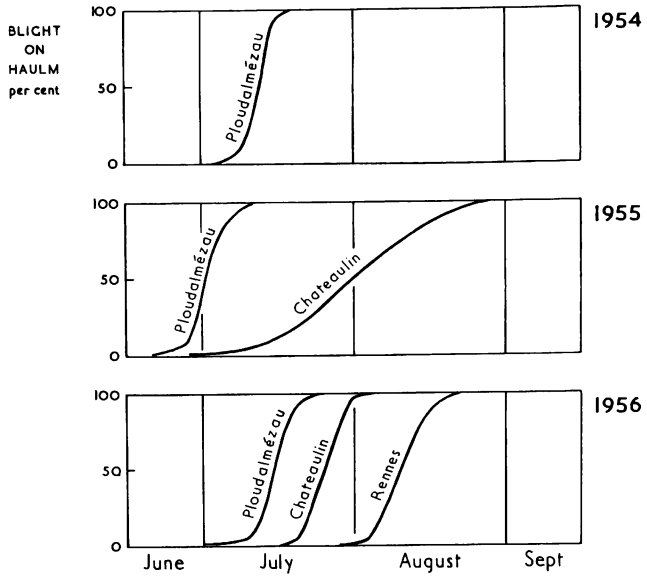


FIGURE 25.--Progress of blight on unsprayed haulm at centers in Brittany, France, 1954-56; variety, Bintje.

There are insufficient data on which to base yield loss estimates for this area, but some general statements can be made. The 75 percent blight stage on unsprayed crops is reached very early along the coast. Figure 25 shows that at Ploudalmézau, this stage was reached at or before mid-July during 1954-56. However, this early defoliation is unlikely to have a serious effect on potato yields, as the coastal strip is the early growing region and immature potato crops will be dug there from the end of May onward. Brittany is the principal seed-growing area, but blight is unlikely to affect the yields of these crops seriously, as, in any case, they have to be burned off in mid-July under compulsory regulations designed to prevent the spread of virus diseases. The seed crop, also, receives the greatest amount of protective spraying.

Despite the importance of early varieties and of seed-potato growing in the region, most of the potato acreage is planted with mid-season varieties (in particular, Bintje) for the ware market. It seems likely that relatively heavy yield losses due to premature defoliation following blight attacks will occur very frequently in crops of these ware varieties if they are unsprayed. In 1956, blight attacks were late, but figure 25 shows that at Chateaulin the 75 percent stage on unsprayed crops was reached before the end of July, and at Rennes the same stage was reached before the middle of August. The time of maturity of Bintje is roughly the middle to end of August, so that unsprayed crops of Bintje will have lost up to 4 weeks of growth.

NORTHERN FRANCE, outside Brittany: Differences in the incidence of blight between the remaining potato-growing areas of northern France occur, but precise data for comparative purposes are lacking. The disease is less important in these areas than it is in Brittany, and as a result there may be a tendency to minimize it.

The only information on which tentative loss estimates can be made for northern France, outside Brittany, comes from a series of spraying trials against blight carried out at Attigny (Ardennes), during the period 1948-55. The results of the 1948 trial have been reported by Raucourt, Lansade, and Ventura (1949), and figures for the remaining years have been given to us by E. Ventura. These trials were not designed to estimate losses but to compare the efficiency of a number of different spray materials by measuring their protective effect on the haulm, and to compare sprayed plots to an unsprayed control. In only 2 years out of 8 were the spray plots lifted and weighed. Table 36 shows the dates on which the 75 percent blight stage was reached on the unsprayed controls each year, and the increase in yield from spraying in the 2 years that the crop was weighed.

TABLE 36.--Date when 75 percent blight occurred on unsprayed Bintje potatoes and increase in yield 2 years when crop was sprayed, northern France, 1948-55

Year	Date 75 percent blight occurred on unsprayed plots	Increase in yield from spraying
		Percent
1948.....	Aug. 6	--
1949.....	9	--
1950.....	11	--
1951.....	16	--
1952.....	([1])	--
1953.....	July 17	33
1954.....	Aug. 14	--
1955.....	19	20

[1] No blight.

The variety grown was Bintje. Planting took place around the first week of May, which is rather late, except in 1953, when it was at the end of March. In only 1 year was blight absent. Of the 6 years when the 75 percent blight stage was reached in August, the latest date (Aug. 19) occurred in 1955, when there was a 20 percent net gain from spraying.

At this stage, the results presented in table 36 can only be used as an indication that blight losses due to premature defoliation in this part of France may be fairly consistently heavy. Weather conditions at Attigny are very similar to those in the potato-growing districts of eastern France, which is not looked upon as a bad blight area. The inconsistencies between the Attigny results and the general opinion about

blight in the area can only be cleared up by more detailed trial and survey work aimed at estimating losses.

BLIGHT IN TUBERS

H. Darpoux has told us that "the damage caused by blight is nearly always the result of premature destruction of the potato foliage, leading to a fall in crop yield. Tuber infection is usually of little importance except in summers with a particularly heavy rainfall." Both in 1954 and 1956, however, the rainfall in the latter part of the summer was high, and heavy losses from infection, while the tubers were still in the ground, were reported. Tuber infection is in general regarded as of small importance in view of the widespread growing of Bintje, which is a very susceptible variety. In 14 years of potato experiments carried out at high altitudes in the Central Pyrénées, Chouard (1949) reported that in no year did blight affect the keeping quality of the crop, despite the fact that no control measures were taken against the disease.

It is generally considered that the light soils in Brittany and the Central Massif are more favorable to tuber infection with blight than the more loamy soils in the north-central and eastern growing regions of northern France. The problem of tubers being infected at lifting time, by coming into contact with diseased haulm, does not usually arise in France, owing to the concentration on early-maturing varieties.

BLIGHT AND WEATHER DATA

The three main types of climate--maritime (Brittany); continental (eastern France); Mediterranean (southern France)--under which potatoes are grown are illustrated in figure 26. The climagrams give long-term average temperature and rainfall figures for three representative centers, together with planting and lifting times.

Brittany, which is the worst blight area in France, has a relatively low summer rainfall. Compared with eastern France the average rainfall is lower in Brittany in May, June, July, and August, although annual rainfall is considerably higher, due to the high autumn and winter precipitation. This points the fact that humidity and not rainfall is the more important factor affecting blight attacks. The importance of humidity is borne out from a consideration of the two blight curves for Brittany in 1955 shown in figure 25 above. In that year, rainfall during the growing season was greater at Chateaulin than at Ploudalmézau on the coast. But blight progress was very much quicker at Ploudalmézau, due to higher humidity conditions. Rainfall in the center of Brittany is higher than on the coast, since it is not until the clouds driven by a prevailing

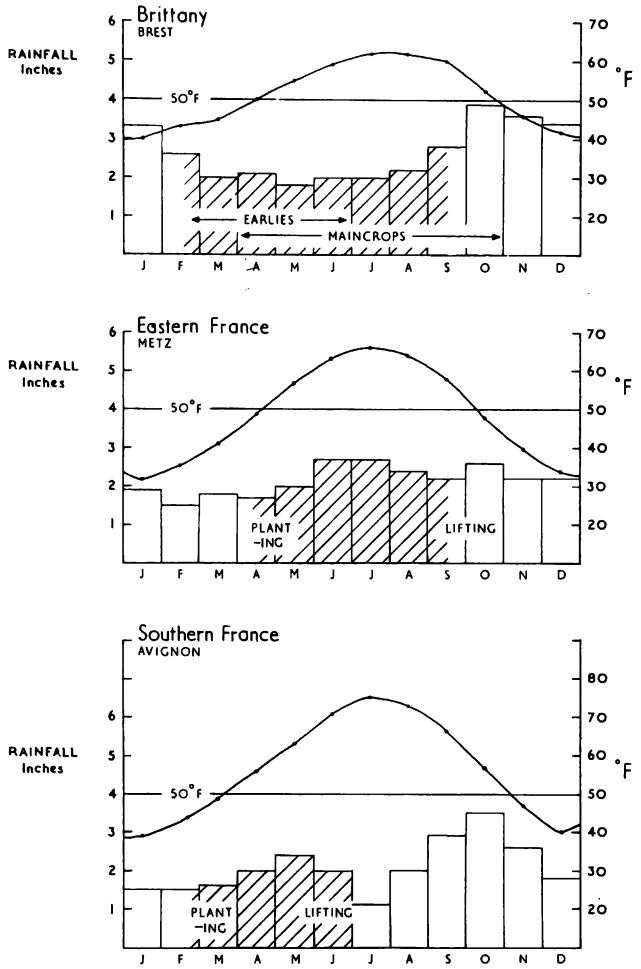


FIGURE 26.--Long-term average monthly rainfall and mean temperatures in relation to growing periods for three regions in France.

westerly wind reach the higher ground that the bulk of the rain is precipitated. Nontheless, the almost invariable story is for blight to be worse on the coast.

The high summer temperatures and generally dry conditions account for the minor importance of blight in southern France, and at the same time point the reason for the small interest in midseason and late varieties in the area.

CONTROL MEASURES

Most of the protective spraying against blight carried out in France goes on in the Brittany peninsula, and there, spraying is concentrated on the seed crop. Little or no spraying is done on the early crop. In the potato areas of north-central France, where the farms are large and highly mechanized, there is some protective spraying. In other areas, where much of the crop is grown on

small farms by peasant proprietors, little action is taken against the disease.

Spraying is most usually carried out at high-volume rates (about 1,000 liters per hectare, which is equivalent to 89 gallons per acre). Generally, 2 or 3 spray treatments are given to mid-season and late varieties. In Brittany and other areas where spraying against the Colorado beetle is compulsory, a combined treatment against blight and the beetle is often applied. DDT is the material most commonly used against the Colorado beetle, and the usual practice is to combine the second treatment against this pest with the first antiblight spray. Experiments with low-volume spraying against blight have been reported by Jouin, Hascoet, and Ventura (1954). E. Ventura has told us that in 1951, when blight was severe, application rates below 300 liters per hectare (27 gallons per acre) did not give an adequate control of the disease.

Sprays are more efficient and economical than dusts, and are far more widely used. Most protective spraying is still carried out with copper compounds, the most important of these being bordeaux mixture, copper oxychloride, and copper oxide. Experiments have been carried out by Raucourt, Lansade, and Ventura (1949) to compare the relative efficiency of bordeaux mixture containing 1 percent and 2 percent copper sulfate. In a bad blight year (1948), the 2 percent bordeaux mixture was found to be more efficient under conditions where only 2 or 3 sprayings were given. In another series of trials in northern France in 1954 reported by Guntz, Hascoet, and Ventura (1954), a depressive effect of copper on potato yields was noted when blight was absent or attacked the crop late in the growing season. Reduction in yield from the use of 2 percent bordeaux mixture in these trials was about 10 percent.

The organic fungicides are not used on any scale. It has been found that they do not reduce the crop in dry seasons, but when blight has been bad the organic materials have had to be applied more frequently than the copper compounds to give a comparable protection to the potato foliage. This finding does not accord well with one of the French farmer's main aims, which is to keep his number of sprays down to a minimum. Some recent spraying trials in France have compared the relative efficiency of copper and organic fungicides (Guntz and Ponchet, 1952; Ventura and Raucourt, 1953).

Haulm killing is not practiced to any extent outside the seed-growing districts, in particular Brittany. The tops of certified seed crops have to be destroyed within a certain period, as laid down by the seed inspectors, to prevent the late spread of virus diseases, and this practice also serves to prevent tuber blight infection. Materials used are sulfuric acid and sodium chlorate. Monot (1956) has described some of the different methods of haulm destruction practiced on seed crops, and at the same time he has compared the efficiency of a number of different chemicals used for this purpose.

One method that the French hope to use in order to reduce blight losses is to grow quickly maturing potato varieties that will escape most if not all the effects of blight attacks. To some extent, they already look upon the widespread growing of Bintje as a control method. Although very susceptible to blight, Bintje matures early (mid-August to end of August, when planted about the middle of April), and, except in Brittany, it usually escapes serious yield losses as a result of premature defoliation even when unsprayed. The Dutch variety Sirtema, which was put on the market in 1952, meets this need for very rapid maturity, but, unfortunately, it is a poor quality potato and is unlikely to have any commercial future. Work at La Station Génétique in Brittany aims to produce a good quality, quick maturing variety based on breeding with the old German variety, Erste von Nassengrunde. Some work on blight races is also being done at this station, but hope of producing blight-resistant varieties from Solanum demissum hybrids has been given up, owing to the ability of the fungus to produce new races.

POTATO BLIGHT FORECASTING

The whole of France is covered by a network of 14 regional Stations d'Avertissements (Agricultural Warning Stations) under the administration of the Plant Protection Service. A recent account of the working of these stations has been given by Journet (1955). In brief, advice on the correct timing of spray and dust treatments against a wide range of crop pests and diseases is sent out at regular intervals from the stations to cooperating growers in their regions.

For potato blight, growers are advised individually by post card when it is time to spray. The warnings are based on field observations of blight sent in by observers (agricultural advisers, farmers, etc.) plus a general consideration of past and present weather conditions in the region. No specific weather rules are used, and the stations do not provide a forecasting service in the strict sense of the term. Advice is also broadcast over the radio and put in the local newspapers.

Table 37, based on information given to the authors by P. Dumas, shows the dates on which advice was given to farmers to spray against blight by the stations during 1955.

France is thus well ahead of most other countries in offering a blight warning service to all growers. Full advantage of this service is not being taken at the present time, but interest in this type of advice is shown by

TABLE 37.--Dates of spray warnings in France, 1955

Station	May	June	July	August
Angers	--	9, 21	20	--
Avignon	[1] 27	6, 13, 28	--	--
Beaune	--	10, 28	[2] 18	--
Bordeaux	--	8, 22	6	--
Clermont-Ferrand	--	11	21	--
Lyon	[1] 24	7, 21	1, [2] 26	17
Montpellier	23	6, 20	4, 19	[2] 2
Orleans	--	11, 29	19	--
Paris	--	14, 30	21	--
Reims	--	15	4, 27	--
Rennes	[1] 18	3, 16	6	[2] 3
Strasbourg	--	20	9, [2] 21	--
Toulouse	--	8, 22	18	--

[1] Spray warning for early crops.
[2] Advice to kill the haulm of severely infected crops.

the progress of the scheme as a whole. According to Journet, membership is increasing by 25 to 30 percent each year.

SUMMARY: FRANCE

Blight is most serious in northern France, particularly in the Brittany area, where the climate is maritime. Information on defoliation and tuber blight losses is generally lacking, though surveys of blight on the haulm are now being made and there have been numerous spraying trials. Chemical control is concentrated on the valuable seed crop. The quick-maturing Bintje is the most widely grown variety and largely escapes the worst effects of blight epidemics. French breeders are trying to produce an even more rapidly maturing ware potato suitable for winter storage. There is a well organized plant disease and pest warning service.

BELGIUM

In Belgium potato yields are among the highest in the World. Some 250,000 acres of potatoes are grown each year, with an average yield of about 10 tons per acre (F.A.O., 1956). The greater part of the crop is used for human consumption, and only a small proportion is fed to livestock or used for manufacture. The estimated annual consumption of potatoes per head in 1947-48 was 315 lb. (F.A.O., 1948).

The breakup of the potato acreage by province and also into early, midseason, and late varieties, together with the acreage grown for seed is shown in table 38. The figures refer to the 1950 growing season (Belgium, Ministère des

TABLE 38.--Acreages of early, midseason, late, and seed potatoes in each province, Belgium, 1950

Province	Early potatoes	Midseason potatoes	Late potatoes	Seed potatoes	Total
	1,000 acres	1,000 acres	1,000 acres	1,000 acres	1,000 acres
Antwerp	9.3	7.3	13.7	0.1	30.4
Brabant	3.2	14.3	12.8	--	30.3
West Flanders	2.7	48.4	9.7	.6	61.4
East Flanders	2.0	41.6	19.2	.7	63.5
Hainaut	.9	10.3	7.6	--	18.8
Liège	.2	1.1	5.3	--	6.6
Limbourg	.3	3.0	7.9	--	11.2
Luxembourg	.2	3.0	11.6	.7	15.5
Namur	.4	1.7	5.4	--	7.5
Belgium (total)	19.2	130.7	93.2	2.1	245.2

Affaires Économiques, 1953). Belgium provinces and places named in the text are shown in the map (fig. 27).

The principal midseason and late ware-producing areas are in the belt of sandy soils running across the north of Belgium, with the heaviest concentration in West Flanders and East Flanders. Early potatoes are grown in the region of Duffel and Mechlin, which lie between Antwerp and Brussels. There is an early potato district near the coast, around Lombardsijde in West Flanders; elsewhere some early potatoes are grown in the region of large towns. Home seed production is concentrated in the polder region of West Flanders and East Flanders, and in the higher land in the province of Luxembourg. The varieties grown in Belgium are the same as those in the Netherlands. Andries (1953) has reviewed the importation and home production of seed potatoes. He shows that Bintje is the variety most widely grown and Eersteling is the most popular early potato. Of the midseason varieties, after Bintje, come Record, Eigenheimer, and IJsselster. The principal late varieties are Alpha and Voran.

Most of the potatoes are grown on light, sandy soils. These soils are inherently very poor, but with the favorable rainfall and a high level of management and manuring, they produce excellent crops. In the main potato-growing areas of northern Belgium, the annual rainfall is about 28 to 32 inches per annum, with a slight peak in the summer and autumn months. Winters are relatively mild and the summer is cool. (See climagram, figure 28.) The growing period for Bintje and other midseason varieties is from the middle or end of April to early September; late varieties planted in the middle of April are mature at the end of September.

Potatoes are grown chiefly on small farms. In Flanders, farms are very small, about 5 hectare ($12\frac{1}{2}$ acres) in size, and they suffer

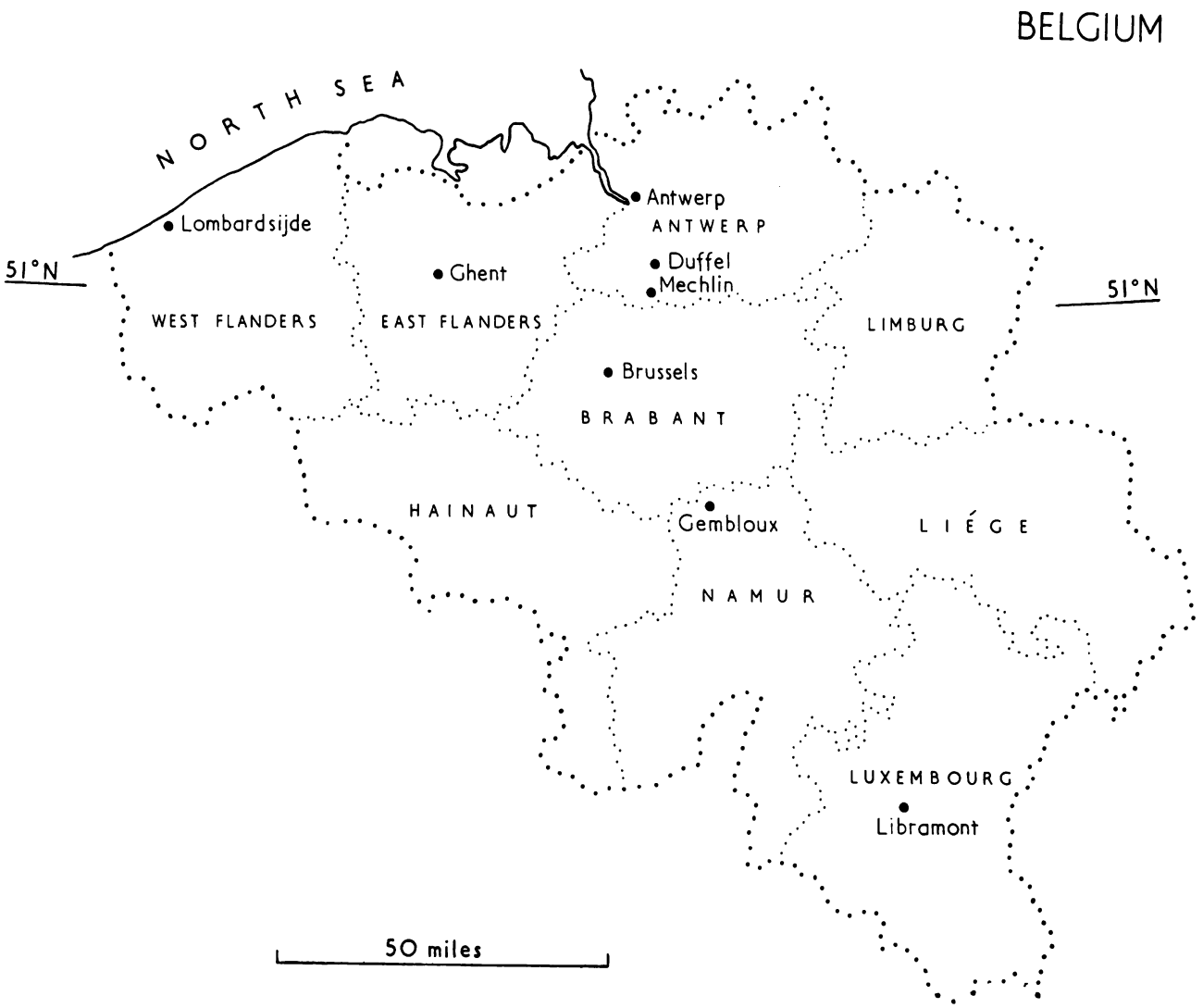


FIGURE 27.--Key map of Belgium.

further from the disadvantage of being carved up into small strips, very often widely scattered, which seriously hinders the efficiency of working. Despite their small size, they are farmed on intensive lines; i.e., the only way the farmers can get a living is by producing big crops. Their main crops are rye, oats, barley, and potatoes. Most of the work is done by hand and horse labor.

BLIGHT EPIDEMICS: FREQUENCY AND DISTRIBUTION

Since 1941, annual accounts of the blight epidemics on potatoes in Belgium have been given in the bulletins of the Agricultural Institute at Gembloux by R. Vanderwalle. These accounts, which are in very general terms, have been included in reports on the annual incidence of a large number of plant diseases (see Vanderwalle (1942)). From them, it is possible to group the different years into three categories: severe, moderate, or slight, according to the incidence of blight (table 39). In no year was the disease absent.

TABLE 39.--Incidence of blight in Belgium, 1941-55

Severe	Moderate	Slight
1941	1942	1944
1946	1943	1947
1951	1945	1948
1953	1950	1949
1954	1952	1955

No report was made for 1951, but indications are that this was a "severe" year. The reports for 1954 and 1955 have not yet been published, but W. Welvaert has provided information from which the authors have completed the table.

The relevance of the terms "severe," "moderate," and "slight" is best illustrated by quoting from Vanderwalle's accounts for three typical years. These are 1953, a "severe" year; 1945, a "moderate year"; and 1948, a "slight" year.

1953: Blight severe. "The disease caused heavy losses to potato growers, notably in the variety Bintje. It appeared early (July 1) and a large-scale outbreak developed during the next 8 days. On late varieties, the disease was less important and less damaging. Protective treatments were carried out frequently in July to counter the effect of the rains. Where this was done a good control of blight was obtained. There were also heavy tuber rot losses in this year."

1954: Blight moderate. "Climatic conditions did not favour the appearance of the disease until late in the growing season. The result was that early varieties, which are very susceptible to the disease, and frequently attacked, escaped infection. The disease appeared on mid-season and late varieties in an irregular fashion, according to area. In the south of the country, losses were small. In Flanders, Brabant and Antwerp, the potato fields were more heavily attacked. Crop yields were reduced, and losses were increased by storage rots, which in some cases reached 20-40 per cent of the crop."

1948: Blight slight. "In general, the disease appeared rather late, and as a result, it caused little damage, at any rate to the potato haulm. There was a certain amount of tuber blight in susceptible varieties."

From table 39 it would appear that the frequency of severe blight years is about 1 year in 3. Belgium is a small country (11,755 sq. miles), with fairly uniform weather conditions. Nevertheless, there is a marked tendency for blight to start earlier and be more severe in the northwest, which is the principal potato-growing area, than in the south and east. It seems likely that in the Flanders area the frequency of severe blight years is somewhat greater than 1 year in 3.

LOSSES FROM BLIGHT

There is no existing survey material in Belgium on which estimates of blight losses can be based. Rigot (1953) has suggested that the total of losses caused by potato blight is somewhere between 150 to 200 million francs per annum. This is equivalent to a loss of about half a ton of potatoes per acre over the whole potato acreage each year, and represents approximately 4 percent of the potential crop.

It is evident from the high average yield of potatoes that blight losses are to a large extent controlled. Even so, severe losses do occur. This is illustrated by what happened in Flanders in 1954, which was a bad blight year. The tops of Bintje, despite the fact that practically all crops of this variety are protectively sprayed in the region, were dead by mid-August. This means that from 2 to 3 weeks of growth were lost by these crops, representing between 10 to 15 percent loss of crop due to premature defoliation.

According to W. Welvaert, tuber infection is not a serious source of loss in the main potato-growing areas of northwestern Belgium. Infection before lifting is generally only slight, mainly because of the sandy soils. Infection

at harvest is avoided by delaying lifting until the potato tops are dead. This is made easier by the concentration on growing midseason varieties in the area and by the relatively great labor force (due to the small size of the holdings) available to deal with the harvest. Vanderwalle in his annual accounts of blight reported a number of years in which cases of severe tuber blight infection of Bintje occurred. It is not possible to tell from these accounts how widespread the trouble was, but it seems fair to infer that severe cases are relatively isolated. Tuber blight infection is not a serious problem for the country as a whole.

BLIGHT AND WEATHER DATA

Figure 28 shows the long-term average temperature and rainfall data, together with the main planting and lifting times for potatoes in Flanders. Temperature and rainfall conditions in 1954, when blight was severe, and in 1955, when it was slight, are compared. In 1954, the first field outbreaks of the disease occurred about mid-June, and the tops of midseason varieties were dead by mid-August. In 1955, blight appeared only at the extreme end of the summer.

The high July rainfall in 1954 appears to have been one of the main causes of the severe attack; August and September rainfalls were also above average, the mean temperatures were generally below average in that summer. By contrast, 1955 was a hot dry summer. June, July, and August rainfalls were all below average; July being a particularly dry month (0.9 inches of rain). July mean temperatures were 2° F. above average, and August temperatures 3° above average.

Vandenplas (1955) has explained the cooperation that exists between the meteorological service in Belgium and the agricultural advisory and research services. This has not so far included any detailed work on potato blight. Jaivenois and Beck (1956), however, have described a pilot experiment carried out in 1955 in Hainaut, in which protective spray applications were made to potatoes following Beaumont periods.

CONTROL MEASURES

In Flanders all the farmers apply a number of protective spray treatments each year. These are given to the midseason and late varieties; it is most unusual for early varieties to be sprayed. Normally 2 applications are given: The first, just before the crop meets in the rows, and the second 2 to 4 weeks later. Welvaert has said that many of the farmers do not spray sufficiently often in bad blight years, when a minimum of 3 applications should be given. Most of the spraying is done by the farmers themselves, very often with knapsack sprayers. There are also a number of spraying contractors at work, many of whom are local farmers who possess a tractor and sprayer and are only too glad to supplement their income in this way. Outside Flanders, less spraying is done.

The majority of the farmers use copper preparations, chiefly copper oxychloride but sometimes cuprous oxide or bordeaux mixture. A few farmers (not more than 5 percent) are using organic fungicides (zineb). To some extent, the antiblight treatments are combined with DDT or lead arsenate against the Colorado beetle. The contractors' charge for a course of 3 protective sprayings in 1956 was 1,200 to 1,500 francs per hectare--equivalent to £3 10s. to £4 10s. per acre. Haulm destruction is practiced only in seed crops. Bintje remains the most popular variety, despite its extreme susceptibility to blight. In 1941, Vanderwalle wrote: "Undoubtedly, Bintje possesses very great assets, both from a culinary point of view and also on account of its outstanding yield, but because of its great susceptibility to blight, it should be discouraged." Up to the present, however, no other variety has been capable of dislodging Bintje.

Some work on breeding blight resistant potato varieties has been carried out at the Station pour l'Amélioration de la Culture de la Pomme de Terre, at Libramont in southern Belgium (Rigot, 1953). So far, no commercial varieties have come from this station. Roland (1946) examined the foliage susceptibility to blight of a number of commercial varieties, which he classified as resistant (e.g., Aquila), slightly susceptible (Ackersegen), susceptible (Industrie), and very susceptible (Bintje).

Little or no research or experimental work is being done in Belgium at the present time on potato blight control. The last paper on this subject was that published by Vanderwalle and Roland (1948), which dealt mainly with a series of experiments covering the influence of certain cultural treatments, including

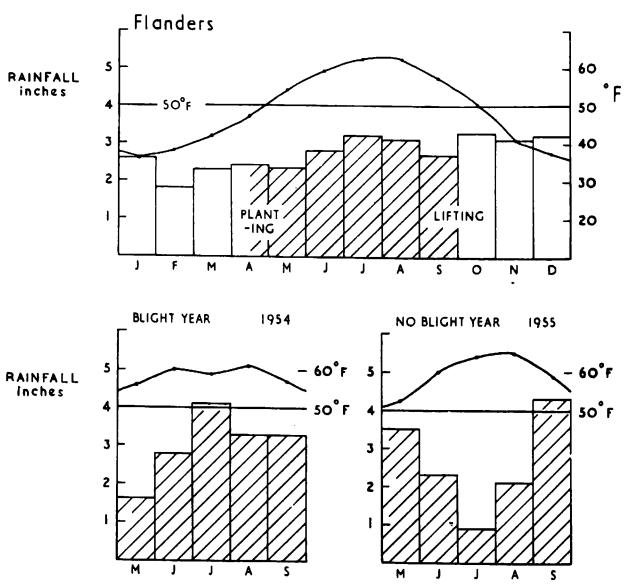


FIGURE 28.--Monthly rainfall and mean temperature for Flanders, Belgium: Above, long-term average; below, "blight" and "no blight" years.

manuring and date of planting, on the incidence and severity of the disease.

SUMMARY: BELGIUM

Most of the potatoes are grown on small farms, which produce excellent crops. Little precise data are available on the importance of blight or the losses that the disease causes, but in Flanders severe blight conditions appear to occur somewhat more frequently than 1 year in 3. The small size and awkward layout of the holdings has not prevented growers from following an annual spray program against blight. The system of farming is achieved only at the expense of a low standard of living to the growers.

THE NETHERLANDS

During the period 1951-55, approximately 400,000 acres of potatoes were grown each year in the Netherlands. The average yield of 10 tons per acre is among the highest of any country in the world (F.A.O., 1955). Only 30 percent of the crop is used for home ware consumption, which in Holland is about 240 lb. per head per annum. Of the rest of the crop, 25 percent is used for manufacture, principally into farina; 20 percent is fed to livestock; and the remainder is exported as ware potatoes or as seed, or used for seed at home. The export of seed to France, Belgium, and other European countries, as well as to South America and North Africa, is a most important branch of the potato industry (Netherlands Ministry of Agriculture, 1953).

POTATO DISTRIBUTION AND SOIL CONDITIONS

Potatoes are grown in all parts of the country, with a particularly heavy concentration in the "peat colonies" of Groningen and Drenthe in the northeast (fig. 29). The acreages of potatoes in the several provinces in 1955, as given in Nederlandse Rassenlijst (1956), were:

Province:	Thousand acres
Groningen	48.4
Friesland	22.0
Drenthe	70.9
Overijssel	51.4
Gelderland	30.6
Utrecht	3.0
North Holland	28.7
South Holland	29.4
Zeeland	26.2
North Brabant	45.9
Limburg	20.0
Total (Netherlands)	376.5

The soils of Holland can conveniently be divided into four main classes, each with its own well-defined type of potato production.

SEA CLAY soils occur in the north and west of the country. These soils are derived from the sea, and in texture they are fine sandy and silty loams. The land is low lying; a large proportion of it is below sea level, and the soil water table is controlled. The ample soil moisture and favorable temperatures induce rapid growth of the potato plants; the variety Bintje planted in mid-April is meeting in the drills by mid-June. The principal ware and seed potato areas of the Netherlands are on the sea clay soils. De Streek, the most important early district, is a sea clay area in the northeast part of the province of North Holland. Seed-potato production comes under the control of the N.A.K. (Nederlandse Algemene Keuringsdienst) with headquarters at Wageningen. The spread of virus diseases in the seed crops is controlled by the compulsory destruction of the potato haulm on a certain date each year, the so-called "E" date. This varies slightly from year to year and according to the grade of the seed, but destruction is about the middle of July.

RIVER CLAY soils are much less extensive than the sea clay soils and are generally less fertile. The Betuwe region in the south of Gelderland is the most important river clay area, and is a ware-producing district.

SAND soils are the principal soils of the south and east of the Netherlands. Rainfall is very similar to that of the sea clay areas, but late frosts during the last weeks of April and first part of May are more likely to occur, so that planting is delayed. Growth, too, is slower as the sands are not so well supplied with soil moisture. The sand soil regions are areas of mixed farms, and the potatoes grown are chiefly for fodder, but are also for ware. The demand for ware potatoes from the sand soils increases in years of low potato production, so that dual-purpose varieties suitable for both ware and fodder are widely grown.

RECLAIMED PEAT ("DALGRONDEN") soils are in the northeastern part of the country. The top layer of the soil in the "peat colonies" is manmade. Instead of leaving a sterile subsoil after the peat had been dug in these areas, the top layer of peat was used to cover the subsoil and this in turn was covered with sand excavated from canals and ditches and brought to the site by barge. These soils are devoted very largely to the production of potatoes for manufacture.

FIGURE 29.--Key map of the Netherlands.

TABLE 40.--Potato varieties listed for resistance to blight in the Netherlands, 1955

Variety	Percentage of Dutch potato acreage	Maturity group	Blight resistance[1]	
			Foliage	Tuber
	Percent			
Voran	30	Late	7	6.5
Bintje	16	Midseason	3	3
Eigenheimer	12	..do	5	3
Eersteling	5.5	Early	3	3
Noordeling	5	Late	7.5	8
IJsselster	5	Midseason	6	8
Other varieties	26.5		--	--

[1] Higher numbers indicate greater resistance to blight.

The distribution of the 1955 potato crop according to soil region was--

Soil region:	Thousand acres
Sea Clay	144.2
River Clay	16.8
Sand	131.2
Reclaimed Peat	84.3
Total	376.5

POTATO VARIETIES

A description of Dutch potato varieties is given by Hogen Esch, Nijdam, and Siebeneick (1955) and in the Nederlandse Rassenlijst (1956). This variety list, a new edition of which is published each year, covers all agricultural crops and includes much statistical information. Potato varieties are divided into four main groups--for ware, fodder, manufacture, and export. Many of the varieties fall into two or more of these groups. Thus Voran, which occupies the greatest acreage of any single variety, is grown for manufacture, fodder, and export as seed, although its chief use is for manufacture. Bintje, the next most important variety, is grown principally for export as seed and ware. The most popular variety for home ware consumption is Eigenheimer, and the most important early potato is Eersteling (synonymous with Duke of York). The Rassenlijst includes a table in which all potato varieties are given a value on a scale from 0 to 10 for a number of economic factors, including resistance to diseases. In table 40 the most important Dutch varieties are listed, together with their foliage and tuber resistance to blight, as assessed by this scale. The higher numbers represent the greater degree of resistance.

Early varieties are normally planted toward the end of March, and lifting starts at the end of May. The growing period of midseason potatoes (Bintje) is from mid-April to the end of August. Late varieties (Voran) are planted at the end of April or beginning of May for lifting at the end of September.

WEATHER AND CLIMATIC CONDITIONS

Although the types of soil and amounts of standing water in canals and ditches are very different in the sea clay areas to the west and the sand areas to the east of the Netherlands, there is no part of the country more than about 100 miles from the coast, and no high land to break the sweep of the prevailing southwesterly and northwesterly winds coming in over the North Sea. Even the highest parts of the sand areas are not more than 300 ft. above sea level. The summer rainfall and temperature conditions over the whole country are very uniform. This point is demonstrated clearly by the climagrams given in figure 30 for Groningen in the north; De Bilt on the border of the sand and clay areas in the middle; Flushing in the extreme south of the sea clay lands in Zeeland; and Gemert on the sand lands of eastern North Brabant, near the German border. At all these stations the long-term average temperatures are about 63° F. in July and August, and the corresponding mean rainfall for these months is between 2 and 3½ inches.

Although the winter temperatures in the Netherlands are much lower, the mean summer temperature and rainfall figures are very similar to those for Penzance in the southwest of England (compare fig. 6). With a macroclimate like that of Penzance and a topography like that of the English Fens, blight conditions in the low-lying parts of the Netherlands would certainly be expected to be severe.

An important consideration affecting the yields of potatoes and the incidence of blight in the Netherlands is that in the low-lying regions the crops are grown with a controlled water table, so that except in a few areas, notably on some of the sand lands to the east, the effects of drought do not so greatly affect the influence the annual level of potato yields as in England and Wales. Table 41 shows the mean monthly rainfall and temperature figures at De Bilt for each of the years 1950-55. The

TABLE 41.--Potato yields, with rainfall and temperatures at De Bilt, Netherlands, 1950-56

Year	Rainfall				Mean temperature and deviation				Yield	Mean 75 percent blight date (Bintje)
	June	July	Aug.	Sept.	June	July	Aug.	Sept.		
	In.	In.	In.	In.	°F.	°F.	°F.	°F.	Tons/ acre	
1911-50	2.4	2.9	3.2	1.7	60	63	63	58	--	--
1950	2.6	4.2	7.6	4.8	+3	0	0	-2	9.6	Aug. 1
1951	1.8	2.0	4.7	2.2	0	-1	-1	+2	9.7	Aug. 8
1952	2.6	3.9	3.6	2.2	-1	0	0	-5	10.9	Aug. 18
1953	3.2	3.0	4.5	1.5	0	0	-1	-1	9.8	July 25
1954	3.6	5.7	4.4	3.5	-1	-5	-2	-1	9.4	Aug. 8
1955	2.0	1.4	2.4	2.6	-2	0	+2	0	10.7	Aug. 18
1956	2.7	5.7	4.9	1.9	-5	-1	-5	+1	9.5	Aug. 5

average potato yields for the Netherlands are also given, together with the estimated mean 75 percent date for unsprayed Bintje.

In the Netherlands, the years of highest average national yield (1952 and 1955) were not the years in which the rainfall was highest. In 1954 and 1950, when the rainfall was markedly high, the yield was below average. Also, the high yields in 1952 and 1955 were in the years in which the blight attack was latest. Thus, it would appear that, with the relatively constant supplies of the water needed by the crops, blight has a far more direct effect on the annual level of potato yields in the Netherlands than in England and Wales, and is of greater importance in the national economy.

Although mean rainfall and temperature conditions are very similar throughout the Netherlands in the summer months, the humidity conditions, which chiefly affect the incidence of blight, are variable from area to area. A study of the critical weather periods shown in figures 31 and 32 reveals that the variation even between low-lying clay areas and the obviously drier sand areas is not so great as might be expected.

POTATO BLIGHT FORECASTING

The Netherland workers have been the pioneers in potato blight forecasting. Continuing the investigations of Löhnis (1924), Van Everdingen (1926) found that outbreaks of blight occurred after a period in which the weather satisfied the following conditions:

1. At least 4 hours of dew during the night.
2. Minimum temperature during the night: 50° F.
3. Mean cloudiness of the following day at least 0.8.
4. Precipitation on the same following day at least 0.1 mm.

At least 4 hours of dew during the night was assumed if the minimum night temperature was at least 1° C. (1.4° F.) lower than the dewpoint at 1900 hours on the preceding evening or 0800 hours on the following morning.

With the aid of these "Van Everdingen Rules" and readings from instruments placed 16 inches above ground level in potato fields, the issuing of blight warning reports was started in the Netherlands in 1927. The validity of the Van Everdingen rules under English conditions was studied by Wiltshire (1931) and Beaumont (1947). As a result of his studies year after year under the severe blight conditions of southwest England, Beaumont was able to propose a simplification of Van Everdingen rules. Beaumont's rule requires two meteorological measurements only, i.e. minimum temperature and relative humidity. The Beaumont rule (see section on England and Wales) was then very extensively tested in the Netherlands, as described by Post and Richel (1951), and it has been adopted since 1948 with the following modifications:

> For a critical period there must be two consecutive days on which the mean relative humidity does not fall below 82 per cent on one day and 79 per cent on the other. The mean relative humidity is taken as the average of readings made in standard screens at 2.2m (about 7 ft.) above ground level, at 0800, 1400 and 1900 hours. The minimum temperature on one of the two days must be at least 50° F.

Observations from a network of weather stations over the whole country are employed by the K.N.M.I. (Royal Netherlands Meteorological Institute) at De Bilt for determining the critical periods, and notifications of their occurrence in the several regions are issued to growers over the wireless. The use of synoptic maps sometimes enables the critical periods to be forecast a day or two before their occurrence, and this earlier notice gives the

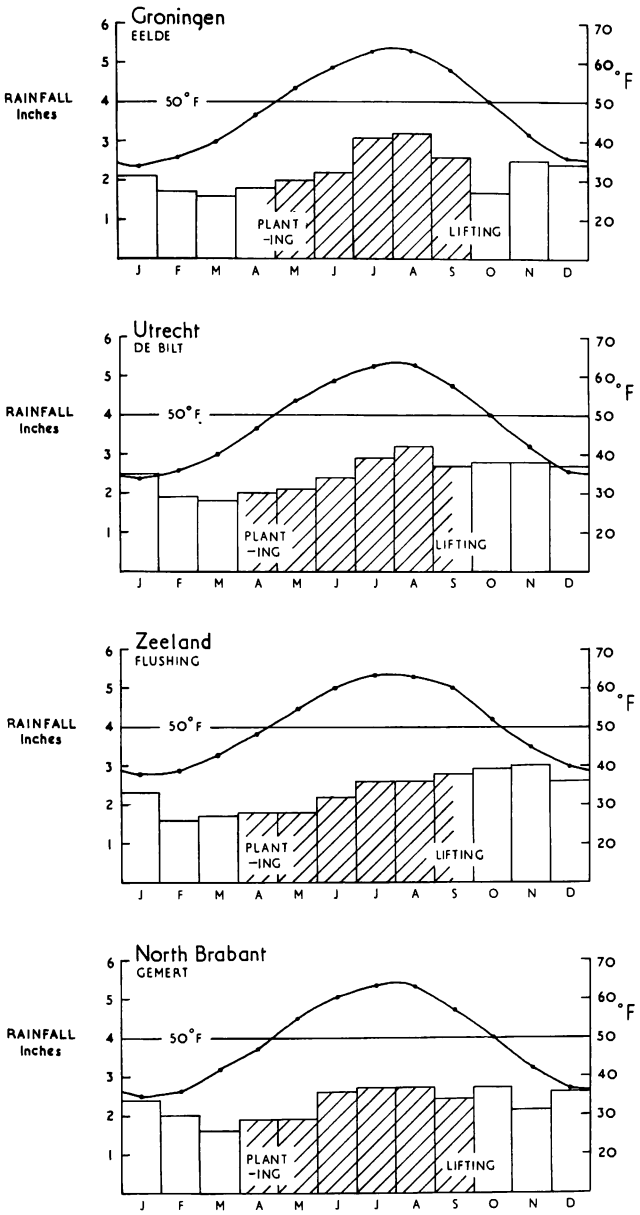


FIGURE 30.--Long-term average monthly rainfall and mean temperatures in relation to potato cropping for four centers in the Netherlands.

growers a little extra time between the warning and the outbreak in which to do their spraying.

In figures 31 and 32 the principal critical periods given for the years 1951-55 are shown in relation to the blight progress curves for two representative potato varieties. In general, a very good correspondence is shown between the first critical periods and the dates of blight outbreaks and between subsequent periods of blight weather and the rapid progress of the disease. This agreement is reached despite the fact that the Netherlands criteria, with humidity measurements at only 3 times during the day, are far less exacting than those employed for the forecasting in England and Wales, where the measurements are made every hour during both day and night and a break of only 2 hours at any time breaks the period. With outbreaks commonly occurring in the second half of June, critical periods in June, and indeed in late May, are certainly significant in the Netherlands, and, as in the southwest of England and Wales, there is no need for the postulation of a "zero date." Phenological observations on the state of forwardness of the crops are, however, taken into account in issuing spray warnings.

INITIATION OF BLIGHT EPIDEMICS IN THE SPRING

In his classical paper on the overwintering and epidemiology of Phytophthora infestans, Van der Zaag (1956) describes a very thorough search for the first appearance of infected plants in the spring. The district chosen for this work was De Streek, a region in the north of the province of North Holland where potatoes, chiefly of the early variety Eersteling, occupy about 80 percent of the total acreage and where potato blight is usually found earlier than anywhere else in the Netherlands. In 1953, when the most extensive search was made, 27 foci were found to be established in the Eersteling crops in De Streek between May 26 and June 18. Of these, 15 were scattered over an area of about 16 sq. km. (4,000 acres) and could be recognized with reasonable certainty as having arisen from diseased tubers planted. In one case, in which careful measurements of spread were made, it was found that where only about 40 plants in the immediate vicinity of the focal plant were infected by June 4; by June 23 ten percent of the plants at a distance of 100 yards to the northeast and 1 percent of those at a distance of 300 yards, were infected. From this and many other observations it was concluded that a single infected plant arising from an infected tuber planted could infect an area of at least 1 sq. km. (240 acres) within a month under weather conditions normal in De Streek, and that the attacks each year almost certainly originate in this way. Infection from volunteer plants on refuse heaps play little part in the story. Van der Zaag estimated that about 100 diseased tubers would have to be planted to obtain a single focus, and that these would be contained in about 1,600 kg. ($1\frac{1}{2}$ tons) of the Eersteling seed potatoes.

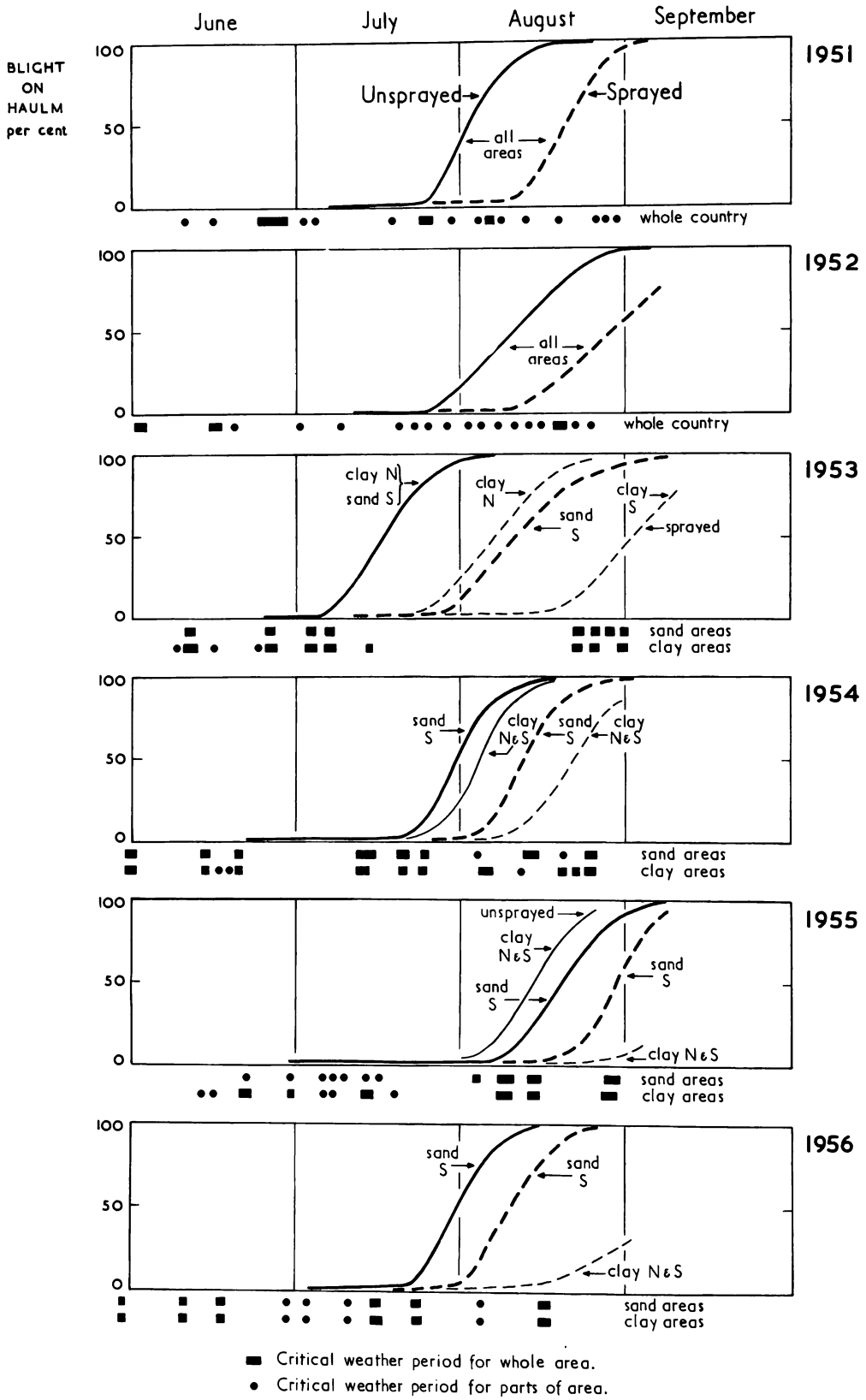


FIGURE 31.--Blight progress curves for Bintje variety in the Netherlands in 1951-56, with the critical weather periods for each year.

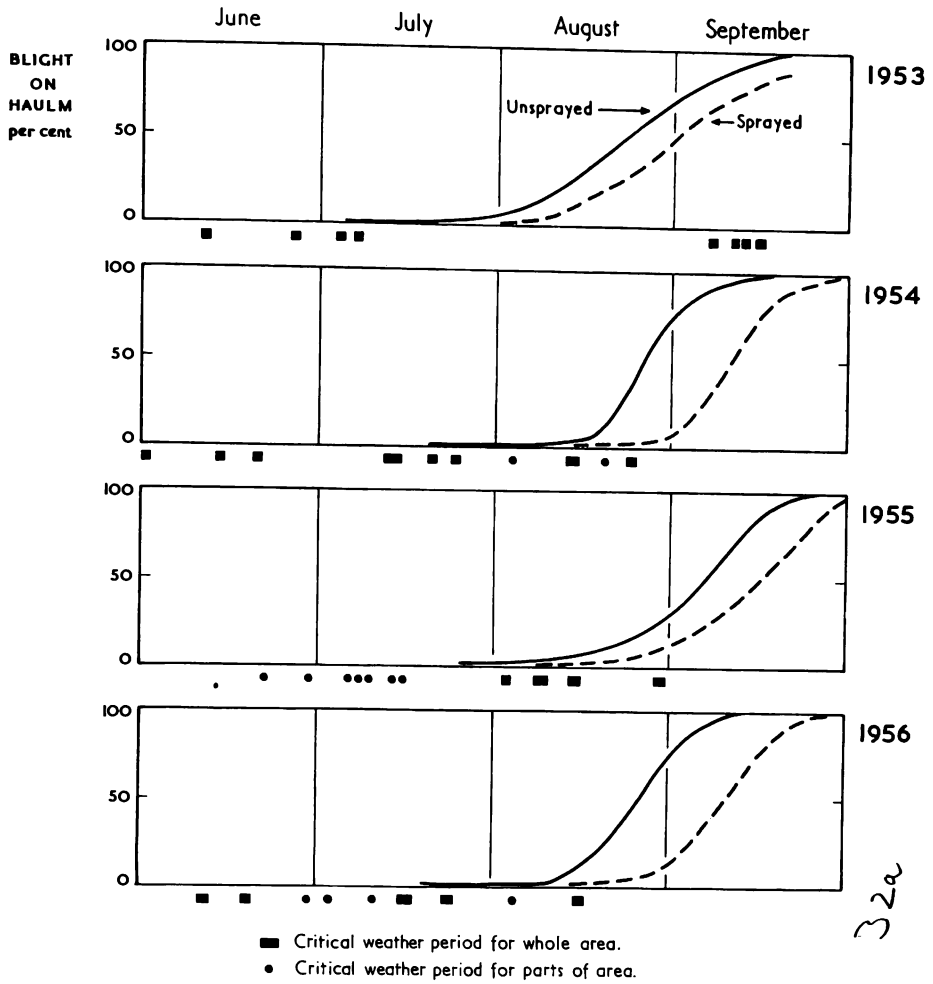


FIGURE 32.--Mean blight progress curves for Voran variety in the sand areas of the Netherlands, 1953-56, with the critical weather periods for each year.

In Van der Zaag's view, the development of an epidemic in any given district must depend upon (1) the number of primary foci, (2) the percentage of the land area occupied by potatoes, (3) the susceptibility of the varieties grown, and (4) the macro- and micro-climate. The effect of the degree of tuber susceptibility of the variety on the number of primary foci could be expected to be very great. In an experiment in which 200 to 300 inoculated tubers of several varieties were planted in soil at a mean temperature of 50° F. the percentage of emerged plants that produced shoots infected from the tuber was 10 in Eersteling, 4 in Eigenheimer, and none in Voran. Taking into account the factor of varietal susceptibility and the percentage of land occupied by potatoes, Van der Zaag surmised that the probable number of primary foci operative in starting the blight epidemics in various parts of the Netherlands would be about 1 per square kilometer in De Streek (as found by observation), 1 per 20 sq. km. in North Friesland and Zeeland, 1 per 70 sq. km. in North Brabant, and as few as 1 per 600 sq. km. in Utrecht--with an average of 1 per 60 sq. km. (about 15,000 acres) in the Netherlands as a whole.

An extremely interesting observation was made on the island of Rottumeroog, 11 km. north of the Groningen coast, in 1954. Here an area of a quarter of an acre was planted with tubers that were entirely healthy, and there were no groundkeepers. On a close inspection of the island on July 25 no diseased plants were found. When blight had spread throughout the province of Groningen, blight also appeared on the test crop on the island, indicating that the sporangia were carried by the wind over a distance of at least 11 km. (nearly 7 miles) without losing their viability.

NETHERLAND BLIGHT SURVEYS SINCE 1951

Since 1951 a countrywide survey of the incidence of blight has been conducted each year in the Netherlands by the Plant Protection Service in collaboration with advisory officers and farmers. The accounts of this work are given in the Yearbooks of the Service (Netherlands Plantenziektenkundige Dienst, Wageningen, 1953-55; Lint and Meijers, 1956 and 1957 (in press)). Some 400 to 600 observation fields have been included in the surveys each year, and a wealth of information has been obtained on the extent to which spraying is practiced, the dates of outbreak and progress of blight on the haulm, and the percentages of blighted tubers at lifting. Some information has also been obtained on the effect of the blight attack on yield, but the figures derived in various ways from sampling small areas have been incomplete and not always very reliable. However a limited number of spraying trials have been conducted in several districts each year for which good yield figures are available. Both the surveys and the trials have been carried out in relation to the warning service operated by the K.N.M.I. at De Bilt.

Throughout the work a standard key has been used for the assessment of blight on the haulm. Most of the definitions are the same as in the B.M.S. key (see section on England and Wales), but categories intermediate between 0.1 to 1.0 percent have been added, and the stages are designated by figures on an arbitrary 0 to 10 scale. Progress curves obtained by plotting according to this scale are reversed: The scale figures being in order, not to attack, but of freedom from attack (10 = no attack, 0 = completely dead). A typical curve is shown in figure 33, which also gives the B.M.S. equivalents of the scale. In figures 31 and 32 progress curves for the Netherlands are plotted according to the English method, using these equivalents, to facilitate comparison of the curves with those for other countries.

For the purposes of the survey, observations have been confined to the three principal maincrop varieties, Bintje, Eigenheimer, and Voran, and the results analyzed for these varieties. Seed crops, which are burned off prematurely, have been excluded. In 1951 and 1952 mean results were given for the Netherlands as a whole, but in 1953 and subsequent years the means have been broken down according to regions--defined as follows:

SEA CLAY
- South --Zeeland, western parts of North Brabant, and the South Holland Islands.
- Middle -The rest of South Holland, North Holland, and the North East Polder.
- North--Friesland and Groningen.

RIVER CLAY ----------Certain districts along the Maas, Waal, Ryn, and Ijssel.

SAND
- South----North Brabant and Limburg.
- Middle --Gelderland and Overijssel.
- North ---Friesland, Groningen, and Drenthe, including the villages on reclaimed peat land.

BLIGHT ON THE HAULM

In the review of the very detailed results of the Netherlands surveys over the 6 years, it is first necessary to consider how many crops of each variety were included in the survey for each region and what percentage of these crops were sprayed. This information, for 1953, is given in table 42.

In the sea clay areas the number of unsprayed crops has been too small for the extraction of mean figures for the unsprayed, so that for these important areas the survey provides information about the incidence of blight on the sprayed crops only. In the sand areas, where less than half the crops were sprayed, comparative figures are available for both sprayed and unsprayed potatoes. On average the sprayed Bintje and Eigenheimer crops received 4 to 5 spray applications each year in the sea clay areas, and 2 to 3 applications in the sand land area. The Voran crop, on the sand lands, received two applications. This matter of number of applications and of materials used is considered later in the section on spraying practice.

The information provided by the surveys concerning the variety Bintje is here chosen for the fullest study because of the importance of this variety, not only in the Netherlands

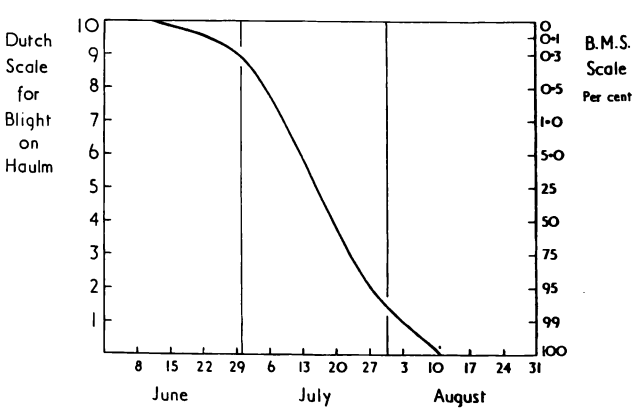


FIGURE 33.--Comparison of the Dutch scale for the assessment of blight on potato haulm with the B. M. S. scale for unsprayed Bintje variety on sand land, 1953.

TABLE 42.--Number of crops and percentage sprayed of Bintje, Eigenheimer, and Voran potatoes according to soil areas, Netherlands, 1953

Soil areas	Bintje		Eigenheimer		Voran	
	Crops	Sprayed	Crops	Sprayed	Crops	Sprayed
	Number	Percent	Number	Percent	Number	Percent
Sea clay.....	76	94	44	93	0	0
River clay.....	13	46	9	78	0	0
Sand lands.....	85	50	47	23	79	30

but throughout western Europe. The data for blight on the Bintje haulm in each of the 5 years are summarized graphically by the progress curves given in figure 31. The curves for 1951 and 1952 are for the country as a whole, but the "unsprayed" curves refer chiefly to the southern sand areas, where most of the unsprayed Bintje crops are situated, while the "sprayed" curves are the means for the sprayed crops in both the sand and the clay areas. For 1953 and subsequent years, when the survey results were analyzed according to region, "sprayed" and "unsprayed" curves are given for the southern sand regions, with "sprayed" curves for sea clay regions. The surveys did not provide data for the few unsprayed crops in the sea clay regions, but to complete the picture as far as possible, approximate "unsprayed" curves for these regions are added from a study of the blight assessments on the controls in a number of spraying trials.

The curves show that there was a good deal of variation in the course of the blight attack according to district in the 5 years (and especially in 1953), but the curves also give some indication (sufficient for this study) of the relative severity of blight on Bintje in the several years for the Netherlands as a whole. In all 5 years widespread outbreaks (0.1 percent stage) started on the unsprayed in the second half of June or in early July. The 75 percent stage ("3" on the Netherlands scale) was reached by the third week of July over a wide area in 1953 (the worst blight year); by about the end of the first week in August in 1951, 1954, and 1956; by mid-August in 1952; and in the second half of August in 1955. There are not sufficient data to establish a frequency of "blight years" over a long-term period, but it would perhaps be reasonable to say that the curves for 1951 strike a fair average for Bintje in the Netherlands over the 5 years. That is to say, the mean 75 percent date for the unsprayed crops was about August 7 and for the sprayed crops about August 24.

ESTIMATION OF LOSSES FROM PREMATURE DEFOLIATION

The method of estimating average losses from an average growth curve, as employed in England and Wales, has not yet been investigated in the Netherlands. From figures obtained in periodic liftings on Bintje in the North West Polder in 1952 and in the North East Polder in 1955 on crops free from blight or at most very little affected, it is, however, possible to draw up an approximate mean growth curve for Bintje in the Netherlands (fig. 34). Assuming, as in England and Wales, that further increase in the crop of tubers is arrested when blight reaches the 75 percent (or "3" stage) on the haulm, the mean percentages of the full potential crop obtained, as shown by this approximate curve and in the absence of additional damage from the passage of sprayer wheels, will be as shown in table 43.

So far these figures are very tentative, but they may now be tested by reference to the actual 75 percent dates and recorded yields in spray trials. This is done in table 44 for trials carried out in each of the 3 years,

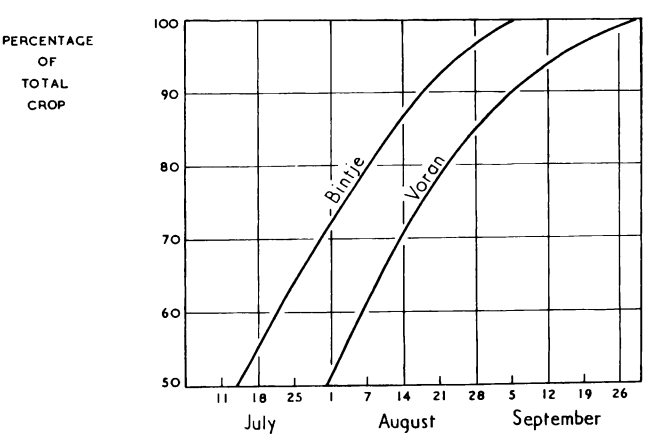


FIGURE 34.--Approximate mean growth curves for Bintje and Voran varieties in the Netherlands, showing percentage of the total crop of tubers produced by various dates.

TABLE 43.--Estimated percentage of the potential crop obtained when the 75 percent stage of blight on the haulm is reached by given dates, on Bintje, Netherlands

Date when blight on haulm reaches 75 percent stage	Estimated percentages of potential crop
July 18	55
25	64
Aug. 1	72
7	80
14	87
21	93
28	97
Sept. 5	100

1953, 1954 and 1955, at three centers, respectively, at Emmeloord on sandy clay in the North East Polder, at Terneuzen on the sea clay in Zeeland, and at Doetinchem on the sand in the east of Gelderland. The Plant Protection Service at Wageningen supplied the data on these trials. Where the original (total) yields were given in kilograms per acre they have been converted to equivalent tons per acre; where they were given in kilograms per 100 plants they have been left in that form. As the full potential yield (with complete control of blight) was not known, it has been assumed that the percentage of the potential crop obtained in the sprayed plots was in accordance with table 43, and the actual and estimated percentages in the unsprayed crops have then been compared.

Throughout these 9 trials, under widely differing conditions, there was a good practical

TABLE 44.--Checks of estimated against actual yields in 9 spraying trials on Bintje, Netherlands, 1953-55

Place and data	1953		1954		1955	
	Unsprayed	Sprayed	Unsprayed	Sprayed	Unsprayed	Sprayed
Emmeloord						
Date of 75 percent blight stage on haulm	July 15	Aug. 20	Aug. 3	Aug. 10	Aug. 16	Aug. 29
Estimated yield.....percent	50	92	75	83	87	97
Actual yield...tons per acre	69.2	[1] 121.8	67.2	[1] 79.6	17.8	20.5
Actual yield.....percent	53	92	74	83	85	97
Terneuzen						
Date of 75 percent blight stage on haulm	Aug. 9	Aug. 28	Aug. 6	Aug. 24	Aug. 30	Sept. 9
Estimated yield.....percent	82	97	78	94	97	100
Actual yield...tons per acre	87.7	[1] 99.0	17.0	19.4	12.7	13.1
Actual yield.....percent	86	97	82	94	96	100
Doetinchem						
Date of 75 percent blight stage on haulm	July 26	Aug. 8	Aug. 8	Aug. 17	Aug. 4	Aug. 27
Estimated yield.....percent	65	81	81	89	74	96
Actual yield...tons per acre	45.0	[1] 62.3	96	[1] 101	10.5	14.7
Actual yield.....percent	59	80	85	89	69	96

[1] Kilograms per 100 plants.

agreement between the percentage yield of the unsprayed crops as estimated from the 75 percent dates and as determined by actual lifting. Further investigation of the mean rate of bulking of Bintje in the Netherlands is obviously needed. It would appear that the tentative curve of table 43 and figure 34 fits the available evidence fairly well, and loss estimates based upon it are probably the best that can be given at the present stage.

The curves for 1951 (fig. 31), suggested as representing a general average for Bintje over the 6 years, indicate an average loss of 20 percent of the potential total crop in the unsprayed (75 percent date, Aug. 7) and 5 percent in the sprayed (75 percent date, Aug. 24). In commercial crops, however, where the spraying is done by tractor-drawn machines (and not by hand as in the trials) there is wheel damage also to be taken into account. The magnitude of this damage has been investigated by trials in the Netherlands (Plantenziektenkundige Dienst, Wageningen, 1955, pp. 48-49) and estimated at 3 percent of the total crop. This figure is in close agreement with that obtained in England and Wales with similar machines. Accepting this figure, the loss in the sprayed crops with 75 percent date of August 24 would be not 5 but 5 + 3, or 8 percent.

Thus, in ware crops of Bintje, with a potential yield (were there no blight) of $12\frac{1}{2}$ tons per acre, the average yield of the unsprayed would be 10 tons per acre and of the sprayed $11\frac{1}{2}$ tons per acre--a difference of $1\frac{1}{2}$ tons per acre or 3.75 tonnes per hectare. In 1954, which according to the progress curves was about an average year and similar to 1951, the mean gain from spraying as determined on 31 crops of Bintje in various parts of the Netherlands in the blight survey was 3.9 tonnes per hectare--again in very close agreement with the estimate figure. It must be stressed that all these estimates so far are of loss of total yield due to defoliation; they do not include losses due to tuber infection, which will be considered later.

The survey data and trial figures available do not permit a similar computation of average losses in the variety Eigenheimer, but it would appear that in general the 75 percent stage on both sprayed and unsprayed crops of this variety can be expected to be reached about a week later than in Bintje. The date of maturity is also somewhat later. This may counterbalance the slower progress of blight, so that in practice there may be no great difference in the defoliation losses with the two varieties.

For Voran, the variety predominantly grown in the sand areas, the surveys provided good data for both unsprayed and sprayed crops in each of the years 1953, 1954, 1955, and 1956. For this late variety, producing a full crop by about the end of September, the growth curve for the tubers is probably similar to that for Majestic in England and Wales, and indeed the results of one periodic lifting trial available for Voran in North East Polder in 1955 agreed almost point by point with the English Majestic curve.

Figure 32 shows that blight on the unsprayed Voran crops in the sand areas reached the 75 percent stage about the end of August in 1953 and 1954 and in the second or third week of September, according to district, in the dry year 1955; blight reached only the 25 percent stage by the end of September in 1956. The defoliation losses as determined by sample lifting of sprayed and unsprayed portions of a number of crops in the surveys were in good accordance with those to be expected from the growth curve for Voran (shown in figure 34). In 1954 with the 75 percent stage on the unsprayed occurring at the end of August and on the sprayed crop at mid-September, the gain from spraying was a little over 1 ton per acre; while in 1953, when the spraying appears to have been less effective and the 75 percent date occurred about September 7, the gain from spraying was only a little over $\frac{1}{2}$ ton per acre. In 1956, in five spraying trials, the mean 75 percent date for the unsprayed was the end of August, and for the sprayed, mid-September. The mean total yields were 13.6 tons per acre for the unsprayed and 15.2 for the sprayed, giving an increase of 1.6 tons for the sprayed plots--in exact accordance with the curve.

BLIGHT IN THE TUBERS

The surveys provided good data on the mean percentages of blighted tubers at lifting in the 3 years 1953-55, as shown in table 45. Each figure in this table is a mean for a good number of crops, in all cases at least 10, and sometimes 30 or more.

The figures indicate a high level of tuber infection in Bintje and Eigenheimer, particularly in the sea clay areas, in the wet seasons of 1954 and 1956, and fairly high infection in the sand areas in 1953, while in the dry season of 1955 the level of infection was low. Tuber infection in Voran in all 3 seasons was relatively low, though the infection is still considerably higher than for Majestic in England and Wales. Protective spraying gave some reduction of tuber infection in all 3 varieties.

CONTROL: MATERIALS AND METHODS

The amount of protective spraying against blight varies according to area and the potato variety grown. In general, the majority of growers in the sea clay regions spray, whereas in the sand regions growers spray occasionally. This is in part a reflection of the differing

TABLE 45. --Blighted tubers at lifting, as percentage of total crop, for Bintje, Eigenheimer, and Voran in 2 soil areas, Netherlands, 1953-56

Year and soil area	Blighted tubers					
	Bintje		Eigenheimer		Voran	
	Unsprayed	Sprayed	Unsprayed	Sprayed	Unsprayed	Sprayed
	Percent	Percent	Percent	Percent	Percent	Percent
1953:						
Sea clay	--	4.8	--	2.0	--	--
Sand	8.1	7.4	6.2	5.0	2.5	1.4
1954:						
Sea clay	--	11.4	--	9.4	--	--
Sand	9.4	5.5	4.3	3.4	2.7	1.0
1955:						
Sea clay	--	.5	--	1.4	--	--
Sand	3.9	.8	2.4	1.8	2.3	.8
1956:						
Sea clay	--	8.4	--	17.6	--	--
Sand	7.2	7.9	3.9	3.4	2.8	2.0

susceptibility to blight of the predominant varieties in the two areas: Bintje on the sea clay and Voran on the sand. Figures from the Netherlands surveys showing the proportion of potato crops sprayed illustrate this variation and are given in table 46.

Over 95 percent of the Bintje crops on sea clay have been sprayed during 1953-56. There has been a considerable difference from year to year in the amount of spraying done on Voran in the sand regions, but so far as can be seen this variation does not bear any clear relationship to the severity of the blight attack in the particular years. It would appear that under one-third of the Voran crops on sand are sprayed against blight. The number of spray applications given also varies. In the sea clay regions, Bintje for ware normally receives 4 or 5 applications, although seed crops of the same variety, which are killed prematurely in mid-July, are given only 2 or 3 sprayings. Voran on sand is usually given 2 applications.

The surveys provide very full information concerning the materials used in the Netherlands for protective spraying over the period 1951-56. Table 47 sets out these materials and shows their relative importance in the several years.

Table 47 brings out a number of important points. The use of bordeaux and burgundy mixture has been virtually abandoned in recent years. Copper oxychloride applied alone has steadily decreased in importance, although it is still the commonest fungicide. There has been a marked increase in the use of the organic fungicide zineb, which is applied principally in the form of a split treatment followed by copper. The most recent trend is in the use of stickers to increase the efficiency of application. The results of numerous spraying trials in which the use of zineb and copper compounds are compared have been reported in recent years (Ormel, 1954; Lint and Meijers, 1955). In the earlier trials, zineb was disappointing, but its performance was greatly improved by increasing the application rate from 2.7 to 4.5 lb. per acre (3 to 5 kg. per ha.). The general experience has been that with an equal number of spray treatments, zineb has given a greater increase in total yield than copper, but that on soils where tuber blight infection is a problem (the

TABLE 46. --Percentage of Bintje and Voran crops sprayed, Netherlands, 1953-56

Variety and soil area	1953	1954	1955	1956
	Percent	Percent	Percent	Percent
Bintje on sea clay	94	98	95	98
Voran on sand	30	45	22	17

TABLE 47.--Spraying materials and percentage of total sprayed area on which they were used, Netherlands, 1951-56

Material used	1951	1952	1953	1954	1955	1956
	Percent	Percent	Percent	Percent	Percent	Percent
Bordeaux or burgundy mixture	8	4	1	--	--	1
Copper oxychloride	88	81	79	69	52	42
Cuprous oxide	4	11	4	4	2	<1
Colloidal copper preparations	--	2	12	6	5	3
Zineb	--	2	2	7	9	2
Zineb followed by copper	--	--	2	14	26	31
Zineb followed by copper plus sticker	--	--	--	--	6	8
Copper plus sticker	--	--	--	--	--	12
Other materials	--	--	--	--	--	1

sea clay areas) a greater number of diseased potatoes has offset this effect. In other words, zineb has proved considerably less effective than copper in reducing tuber infection. This can be illustrated by the results of 5 trials on sea clay and 5 trials on sand in 1954, a year when tuber infection was very bad in the sea clay regions. Average results for these trials are given in table 48. The variety under trial was Bintje.

Table 48 shows that on both soil types the total yield of potatoes was highest with the zineb treatments. On the sand soils, net yield (total yield less diseased tubers) was 1.5 tons per acre greater with zineb than with copper, but on the sea clay, due to the very high percentage of blighted tubers in the zineb-treated plots, this result was almost exactly reversed. In the light of their experience the Dutch recommend that copper alone, or a split treatment (2 sprayings with zineb, followed by copper) should be used for protective spraying against blight in the sea clay areas. Zineb, alone, is considered satisfactory in the sand regions.

A high proportion of the spraying is carried out by contractors, and most of it is done by ground machines. Fixed-wing aircraft were used to spray 13,000 ha. of potatoes against blight in 1955, but expansion of air spraying is limited, owing to the small size of the majority of the potato fields. Recent developments in aircraft spraying have been reviewed by Maan (1954). He particularly mentions the research work in spraying against potato blight of Fransen and Kerssen of the Instituut voor Plantenziektenkundig Onderzoek, Wageningen. Ground spraying is carried out from the top only without the use of droplances. In recent years there has been a considerable development in spraying at low- and medium-volume rates. Figures, based on a sample of 293 sprayed fields, show that in 1956, 22 percent of the growers were spraying at less than 18 gallons per acre; 41 percent were spraying at 18 to 53 gallons; and the remaining 37 percent at over 53 gallons. To some extent spraying against blight is combined with DDT treatments for the control of the Colorado beetle.

ECONOMICS OF SPRAYING

Leeuwenburgh (1955) has considered whether blight control is justified on economic grounds. He states that the cost of one spraying is approximately 30 guilders per hectare (£1 4s. per acre), of which, 20 to 22 guilders is the cost of the material and 8 to 10 guilders the cost of application. The question of justification depends very much on the price obtained for the potatoes, and this varies considerably among the different sorts. For example, Leeuwenburgh quotes prices of 0.15 guilder per kilo for seed potatoes, 0.1 guilder per kilo for sea clay ware potatoes, and 0.06

TABLE 48.--Yield of tubers (over 1-3/8 in. diameter) from spraying trials with copper and zineb, Netherlands, 1954

Area	Total			Sound tubers		
	Unsprayed	Copper	Zineb	Unsprayed	Copper	Zineb
	Tons/acre	Tons/acre	Tons/acre	Tons/acre	Tons/acre	Tons/acre
Sea clay	14.7	15.1	16.2	10.4	12.9	11.6
Sand	12.1	11.5	13.2	11.8	11.2	12.7

guilder per kilo for ware and manufacturing potatoes from the sand regions. (These prices are equivalent to £15, £10, and £6 per ton, respectively.) Thus, the actual increase in potato yield required to meet the cost of one spraying is approximately 200 kg. per ha. for seed potatoes; 300 kg. per ha. for ware potatoes from sea clay areas; and 500 kg. per ha. for potatoes from sand areas. In terms of tons per acre, these yield increases become 0.08, 0.12, and 0.20 ton, respectively.

These figures, taken in conjunction with the greater resistance to blight of the sand land potato varieties, and also the smaller importance of tuber infection in the sand regions, go a long way toward explaining the markedly smaller amount of spraying that is done in these areas as opposed to that done in the sea clay areas.

FURTHER CONTROL MEASURES

A considerable amount of research work has been done in the Netherlands on the mechanical and chemical destruction of potato haulm. Most of this has been in connection with haulm destruction in seed crops (Lint and Crucq, 1956), where roto-beating, followed by one or two sprayings with a chemical such as sodium arsenite, has been found necessary to effect the complete killing of the vigorously growing haulm. In ware crops attacked by blight, destructive spraying of the potato tops is also recommended under certain circumstances. One spraying is sufficient. Chemicals used include sodium arsenite, the di-nitro compounds, and sodium chlorate. Growers, however, have been advised not to use sodium arsenite on sand soils, owing to the risk to succeeding crops of toxic residues remaining in the soil. Lint and Meijers (1955), reporting on trials in 1954, concluded that on sea clay soils it was an economic proposition to burn off the haulm of a blight-infected susceptible variety (Bintje) even when this was carried out at an early date, due to decreased tuber blight. On sand soils, where tuber infection is normally slight even in susceptible varieties, Lint and Meijers stated that haulm destruction in ware crops was unwarranted. Further trials in 1955 confirmed these conclusions.

Fundamental work on the genetics of blight resistance has been carried out by Mastenbroek (1953), and this worker has cooperated in the setting up of an international nomenclature for blight races (Black, Mastenbroek, Mills, and Peterson, 1953). Mastenbroek and Bruin (1955) have demonstrated that the present common field race in the Netherlands is race 4. This research on blight races follows earlier work by Bruyn (1951), which showed the alleged plasticity of the fungus. Since 1951, H. J. Toxopeus at the Instituut voor Veredeling van Landbouwgewassen at Wageningen has been concerned with the breeding of blight-resistant potatoes and the genetical analysis of immunity. In a recent paper (Toxopeus, 1956) he has discussed the present possibilities in breeding for blight resistance in potatoes. He notes the apparent breakdown of field resistance to blight of the Irish variety Champion and suggests that the same thing is happening to Voran in the Netherlands. He associates this breakdown with the ability of the fungus to adapt itself even to field-resistant varieties, particularly when these predominate over other varieties in the makeup of the country's potato acreage. Toxopeus considers that the incorporation of R-gene resistance into new varieties, where this is combined with a high degree of field resistance, may be very useful. This is because the effect of one group of genes is likely to prevent the establishment of races of the fungus pathogenic to the other genes. Up till now, no R-gene blight-resistant varieties of potato have been grown on a commercial scale in the Netherlands.

Van der Zaag (1956) (in connection with his work in De Streek) has discussed the possibility of a number of phytosanitary measures for blight control, including the destruction of primary foci. The main difficulty here lies in the detection of the foci at a sufficiently early stage to make destruction worthwhile. Some consideration has also been given in the Netherlands to the effect of storage conditions on the development of blight in tubers. Work of this kind is the responsibility of the Stichting voor Aardappelbewaring (Institute for Potato Storage) at Wageningen.

SUMMARY: NETHERLANDS

Countrywide blight surveys have been carried out in the Netherlands each year since 1951, using a modification of the B.M.S. key for the assessment of the disease on the haulm. Severe epidemics occur on Bintje and other midseason varieties in most years, particularly in the sea clay areas, where, if the ware crops were left unsprayed, there would be an average defoliation loss of about 20 percent of the potential crop, with a further loss of 4 to 10 percent for infection of the tubers. Losses in Voran, the principal variety grown on the sand lands, are similar to those in Majestic in the southern zone of England and Wales. The valuable seed and ware crops of Bintje and other susceptible varieties almost all receive intensive protective spraying. This spraying usually reduces defoliation losses to about 8 percent, and also gives some reduction of tuber infection. Much less spraying is done on Voran.

A marked increase in the use of organic fungicides for blight control has occurred in the Netherlands in recent years. The Dutch are pioneers in potato blight forecasting and have made many contributions of fundamental importance to breeding for blight resistance and to the understanding of the origins of blight epidemics.

DENMARK

Denmark grows annually about 250,000 acres of potatoes, which produce an average yield of about 8 tons per acre (Danish Agricultural Organizations, 1954). According to Russell (1954), human consumption of potatoes was 282 lb. per head in 1950. In addition, potatoes are grown for fodder and industrial use. There is an important export market for Danish seed potatoes, and to a lesser extent, ware potatoes. Thus the structure of the industry bears a very close relationship to that in the Netherlands.

Figure 35 shows the distribution of potato growing in Denmark. The main concentration is in Jutland, particularly the west, and there is a smaller concentration in north Zealand. Ware potatoes are grown throughout the country, but the fodder, industrial, and seed potatoes are produced principally in Jutland. There is a center for early potatoes on the island of Amager, immediately southeast of Copenhagen.

The most important variety is Bintje. This is a midseason potato, grown for the home ware market and also for export as ware

FIGURE 35.--Distribution of potato growing in Denmark, 1951.

and seed. Other varieties grown on a fairly large acreage, all of which can be classified as late-maturing, are Tylstrup Odin (industrial), Alpha (fodder and export), Dianella (industrial), and Up-to-Date (ware). The crop is grown principally on the lighter soils. The main planting takes place in early May and lifting is carried out in September and October. Summers are cool, and rainfall is generally adequate, with a peak in August. This is illustrated in figure 36.

BLIGHT EPIDEMICS: DISTRIBUTION AND FREQUENCY

Ernst Gram, who has contributed the information on which this section is based, finds that blight occurs throughout Denmark, wherever potatoes are grown, and there is no evidence to show that the disease is worse in one part of the country than in another. Attacks are most severe where susceptible varieties, in particular Bintje, are grown. The late varieties for feed and industry, with the exception of Dianella, show a high degree of blight resistance.

Annual reports on plant diseases, including potato blight, based on the observations of plant pathologists and also of agricultural and horticultural advisers, have been published since 1884. The present title of these reports, which include a summary in English, is Plantesygdomme I Danmark. An attempt has been made to establish a fixed terminology in describing the incidence of the various diseases, so that observations from all over the country can be easily correlated and an overall picture obtained. The following simple scale is used by all reporters:

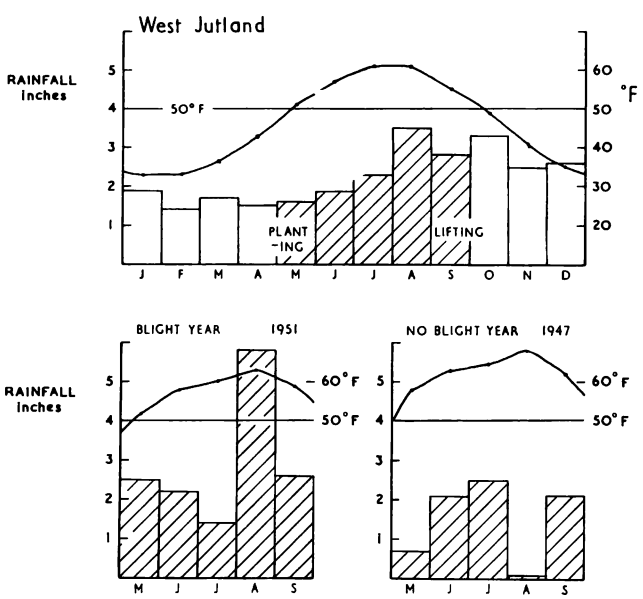


FIGURE 36.--Mean monthly rainfall and temperature for West Jutland, Denmark: Above, long-term average; below, "blight" and "no blight" years.

Incidence of disease	Description
1	Negligible
2	Slight
3	Moderate
4	Severe
5	Devastating

In table 49 blight attacks in Denmark are assessed according to this scale for the period 1945-55. The average yield of potatoes in the country for each of the years 1945-54 (F.A.O. statistics) are included in the table.

The average yield in the 6 "blight years" was 7.0 tons per acre, and in the 5 other years about 7.7 tons per acre. The slight evidence from this analysis tends to indicate that in Denmark, unlike England and Wales, the increase in potato yield resulting from increased rainfall in the blight years is not balancing or exceeding the losses caused by blight.

The number of "blight years" (scale 4-5) in the 11 years 1945-55 was 6, indicating a frequency of about 1 blight year in 2. This agrees very well with an analysis made by Gram (1935) of the years 1911-34. In 12 years out of this 24-year period, blight incidence was described as negligible to moderate (scale 1-3), and in the remaining 12 years, the disease was described as severe or devastating (scale 4-5).

Blight is reported first on early crops, usually in June. In 1949 (a "severe" year), the first observation of the disease in the field was made on June 9, although this was said to be unusually early. In 1947 (a "slight" year), first attacks were not reported until the middle of July. Little exact information on the progress of blight, after the initial outbreaks, is given in the annual reports of

TABLE 49.--Yield of potatoes and blight incidence, Denmark, 1945-55

Year	Incidence of blight	Average yield
Blight years:		
	Rating	Tons/acre
1945	4-4.5	6.0
1949	4-4.5	6.8
1950	4-4.5	7.0
1951	4-4.5	7.4
1953	4	7.0
1954	4	8.0
Other years:		
1946	3.5	7.0
1947	2	6.9
1948	2.5	8.5
1952	3.5	8.5
1955	1	--

Plantesygdomme I Danmark. It would appear, however, that in a severe blight year, the tops of midseason and early maincrop potato varieties are completely killed between the middle to the end of August; and those of late maincrop varieties between early to mid-September. In 1945 ("severe"), it was stated that the tops of midseason and early maincrop varieties were practically dead from blight as early as the end of July, but this seems to have been an exceptional season.

BLIGHT LOSSES

A very large number of spraying trials against blight have been carried out in all the potato-growing areas of Denmark during the present century. Figure 37, which has been adapted from data supplied by Dr. Gram, shows the average increase in yield (cwt. per acre) in the sprayed plots as compared with the untreated for each of the years 1934-53. These results are based on figures from 287 separate spraying trials carried out with bordeaux mixture.

If figure 37 is compared with table 49 it will be seen that there is a very close correspondence between the increased yield from spraying in any particular year and the intensity of the blight attacks in that year. Thus, in 1950 and 1953, attacks were severe and yield increases high; in 1947 and 1948, attacks were slight and yield increases from spraying small. Despite the fact that this correspondence may not hold exactly for every year, e.g., yield increases were greater in 1946 than in 1945, although 1945 was certainly the worse blight year, Gram (1935) has demonstrated that over a long-term period the spraying trials give a very good measure of blight incidence. Dealing with the period 1911-34, during which time 1,350 spraying trials were carried out, he expressed blight incidence (as measured by the cooperative plant disease recording scheme) against yield increase resulting from the spraying trials. This analysis for the 24 years is shown in table 50.

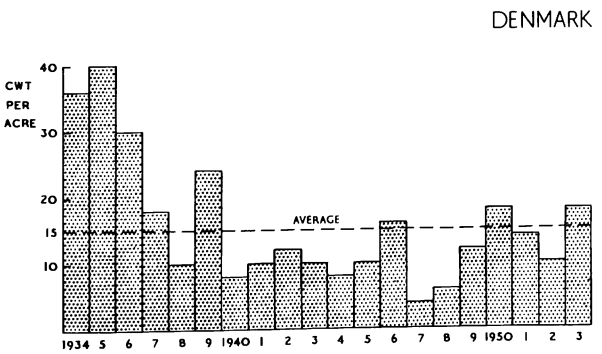


FIGURE 37.--Average annual increase in yield from spraying with bordeaux mixture, Denmark, 1934-53.

TABLE 50.--Increase in yield of potatoes by spraying as related to blight incidence, Denmark, 1911-34

Blight incidence (rating)	Years	Increase in yield by spraying
	Number	Percent
1..Negligible.....	2	1.5
2..Slight.....	6	10
3..Moderate.....	4	12
4..Severe.....	4	16
5..Devastating.....	8	21.5
Total years.....	24	--

Stapel (1953) has used the results of spraying trials from 1910 to estimate the average loss in Denmark caused by blight through premature defoliation of the potato plants. He concludes that the average loss, in the absence of spraying, is 15 percent of the crop ($1\frac{1}{2}$ tons on a 10-ton crop). This is just about double the average yield increase achieved in the spraying trials illustrated in figure 37. However, it seems a fair assumption that only 50 percent of the total loss due to blight was recovered in these trials, particularly as in the majority of them only one spraying was given.

There has been a marked tendency for yield increase in the spraying trials to be less during recent years, or to put it another way, for blight losses to be less severe. This point can be seen from figure 37, but it is further illustrated by data supplied by the Plant Production Office at Skanderborg in Jutland, and quoted by Stapel. These data show the average increase in yield for the four 10-year periods from 1910-50, and are given in table 51.

It is possible that the chemical situation in the war and postwar years influenced the position in 1940-50, but a change in the potato varieties grown is also, no doubt, having an effect. Acreages of Bintje have increased during recent years; and although this variety

TABLE 51.--Average yield increase for potatoes by spraying, in 10-year periods, Denmark, 1910-50

Period	Spraying trials	Increase in yield
	Number	Percent
1910-20.....	248	13
1920-30.....	105	12
1930-40.....	56	11
1940-50.....	57	6

is very susceptible to blight, it is very early maturing, and may often escape the full severity of the attacks.

Returning to Stapel's estimate that, on average, 15 percent of the potato crop will be lost in the absence of spraying, he develops his argument further to estimate an actual loss of 7 or 8 percent, basing this on the assumption that half the potato acreage in Denmark is sprayed. Clearly, this assumes that the spraying that is carried out is 100-percent efficient, which it cannot be, so that this final figure is probably low. In addition, it appears that 35 percent and not 50 percent of the acreage is sprayed. Assuming, however, that spraying is concentrated on the potatoes that need it most, the probable annual average loss caused through premature defoliation in Denmark is around 10 percent.

BLIGHT IN TUBERS

In view of this high loss figure, it is interesting to learn from Dr. Gram that "our main problem [in Denmark] is the tuber attack, owing to its influence on quality, on keeping in pits or houses, and on export values." This does not imply that the losses caused by tuber blight are greater than the losses brought about by premature defoliation. It would be most surprising if tuber blight losses were anything like so high as an average of 10 percent, though no figures exist on which to base an estimate. The statement does imply that tuber blight is a very real source of loss in Denmark, and that it is all the more important because of the export market in potatoes. The blight losses through premature defoliation are a more intangible quantity, and there is always a tendency for them to be balanced by a higher potential yield in the blight years.

BLIGHT AND WEATHER DATA

The climate of Denmark is under both maritime and continental influences. Throughout the country, the main rainfall comes in summer and autumn. Figure 36 shows the long-term average rainfall and temperature conditions for west Jutland, together with the main planting and lifting times for potatoes. In Jutland, the average annual rainfall is between 25 to 30 inches, and mean temperatures in July and August are around 61° F. In the Danish Islands, annual rainfall is somewhat lower, between 20 to 25 inches, and summer temperatures are a little higher than in Jutland. The whole country is low lying and exposed to strong winds blowing in from the west.

The relative frequency of severe blight years in Denmark (1 year in 2) would appear to be connected with the generally high August rainfall. In west Jutland, the long-term average rainfall for August is 3.5 inches. Weather conditions in a "no blight" year (1947) and a "blight" year (1951) are compared in figure 36. Summer temperatures in 1947 were exceptionally high, and this, with the very low August rainfall, will have prevented the development of blight. In 1951, the very high August rainfall, 5.8 inches, will have been one of the main causes of the severe attacks.

CONTROL MEASURES

Spraying is much more commonly practiced than dusting. The amount of spraying varies in different parts of the country. Experts judge that about 35 percent of the total potato area is sprayed. Copper compounds are principally used, of which copper oxychloride is the most popular. Experiments at Lyngby in 1941 and 1942, comparing the efficiency of a number of spray materials, including different formulations of bordeaux mixture, have been described by Stapel and Petersen (1943).

Under commercial conditions, it is normal to apply one or, at the most, two protective sprays, although Hammarlund (1956) has shown that in certain circumstances up to four can be applied economically. The need for correct timing of the spray application to obtain maximum protection of the potato haulm has long been realized in Denmark. An experiment to show how important it is to apply a protective spray as soon as the disease appears, and not to delay this application, was made at Lyngby in 1918, and is described by Gram (1924). This work appears to have been an anticipation of the recent use of blight progress curves. Because of its historic value, Gram's original diagram illustrating this experiment is reproduced in figure 38.

The diagram shows the development of blight on the sprayed plots and on the unsprayed plots (Ikke sprøjtet) according to a scale (0-10), where 10 equals complete haulm destruction. Blight first appeared in the plots on July 19, and the first set of plots was sprayed the next day, July 20. The heavy line shows the blight development on the haulm in plots sprayed on that date. Other sets of plots received a single spraying at intervals after this. The dates of spraying are all shown by arrows, and a blight progress curve is given for each set of plots. The columns at the top of the diagram give the date of spraying, and the yield per treatment in 100 kilograms per hectare. The plots which were sprayed on July 20 (the optimum time) gave a yield of 20 tonnes per ha. (7.9 tons per acre). The unsprayed plots gave 16.2 tonnes per ha. (6.4

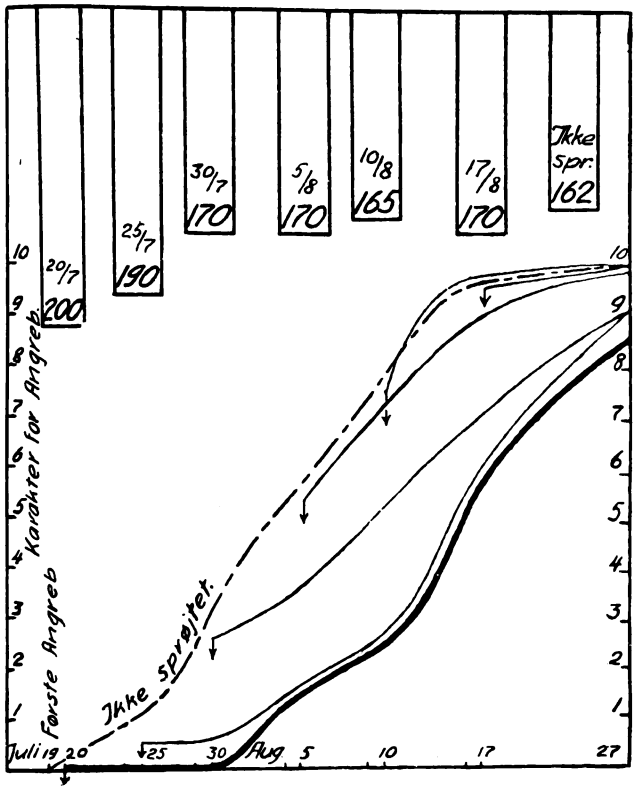


FIGURE 38.--Effect of date of spraying on yield, Lyngby, Denmark, 1918: Progress curves for blight on foliage are given on a scale of 0 to 10; yields in 100 kg. per hectare for dates of spraying (shown by arrows) are given in the columns above (Gram, 1924).

tons per acre). Thus, with optimum timing, a single spraying gave 14 days' prolongation of growth in early August, and increased the yields from 6.4 to 7.9 tons per acre. (Compare with figure 8 for England and Wales.)

Haulm destruction is not much used in Denmark. About 10 percent of the potato area is treated, mostly with sodium chlorate, which is not too satisfactory. Most of the killing is done on the late varieties, which have a very luxuriant haulm, but this is mainly to facilitate lifting rather than to protect the crop from blight. Roto-beaters are also in use.

SUMMARY: DENMARK

In Denmark, the results of numerous spraying trials carried out in all parts of the country have been used in assessing blight losses. These numerous spraying trials give a very good idea of the technical interest taken by Danish farmers in blight control over a long period of years. The average annual loss from blight through premature defoliation has been assessed at 15 percent, in the absence of spraying. Even so, only about one-third of the Danish potato growers take protective action against the disease. To a considerable extent, the growers appear to ignore this large invisible loss. The visible losses caused by tuber blight seem of more importance to them. Denmark has an important export trade in seed potatoes.

ICELAND

The occurrence of potato blight in Iceland is of special interest, as the temperature conditions are here at the lower limit for any epidemic development of the disease. The northern coast of Iceland touches the Arctic circle (fig. 39), and by far the greater part of the land area (some 40,500 sq. miles) is an uninhabited high tableland with vast snowfields and glaciers. Potatoes are grown on the lowlands to the southwest of the island about Reykjavik, and also on the coastal lowlands and in the glens to the south and east. The potato has been one of the main vegetable crops since it was introduced in 1759. About 2,000 acres are planted each year, and the yields, varying considerably with the severity of the season, are in general fairly high, giving a total annual production of 12,000 tons for a population of 154,000. All the potatoes are used for human consumption, and are all the more important in the food supplies because the climate is unsuited for grain crops. In addition to the Iceland production some potatoes are imported from Denmark, Holland, and Ireland.

ICELAND

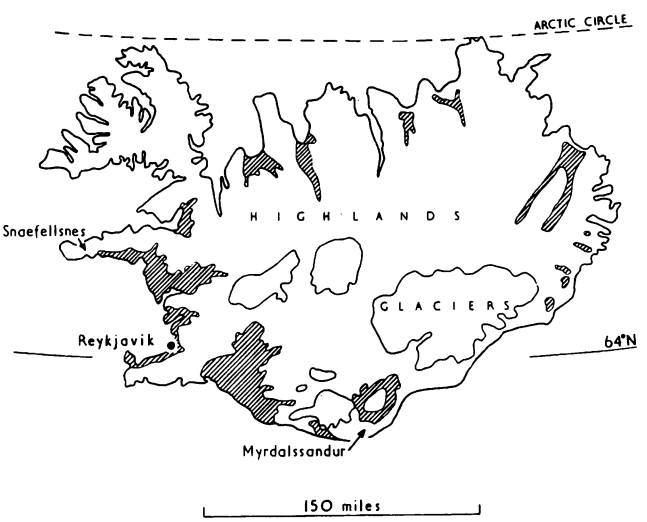


FIGURE 39.--Key map of Iceland. Shading indicates lowland agricultural areas.

An account of potato blight in Iceland has been published by Davidsson (1951). Sturla Fridriksson has carried out potato variety trials at the University Research Institute at Reykjavik over a number of years (Fridriksson, 1954) and has provided much supplementary information.

CLIMATIC AND CULTURAL CONDITIONS

Blight is known in Iceland wherever potatoes are grown, but it causes considerable losses only in the southwestern district from the southern part of the Snaefellsnes Peninsula south and east to Myrdalssandur. In figure 40 a climagram is therefore given for Reykjavik, as the center of this area. It will be seen that on a long-term average the mean temperatures in the summer are above 50° F. only in the months of July and August, and the growing period is short--at most, 120 days. But this growing season is increased, in effect, by pre-sprouting of the seed tubers, which are kept at temperatures of 50° to 57°, with some exposure to light, for 4 to 6 weeks before planting in mid-May. The lower temperatures over the growing period may also be offset to some extent by the long-day conditions, with over 20 hours of daylight in June and July. Sandy soils are preferred, and the planting is done by hand, with a rather close spacing (12 in. x 24 in.). The crop is lifted in mid-September to escape the severe autumn frosts. Kerr's Pink is perhaps the most commonly grown variety, but there are many others in cultivation, including the indigenous Icelandic varieties (the Red Potato, the Blue, and the Akranes), the Gullauga (an old Swedish variety), Early Rose, Great Scot, Up-to-Date, Eigenheimer, Alpha, and Ackersegen. Ability of the haulm to withstand some frost injury toward the end of the growing period is of great importance under Icelandic conditions. In trials of varieties from many parts of the world Fridriksson (1954) found only one indigenous variety, as well as Furore and the American variety, Sequoia, to equal Kerr's Pink in this respect.

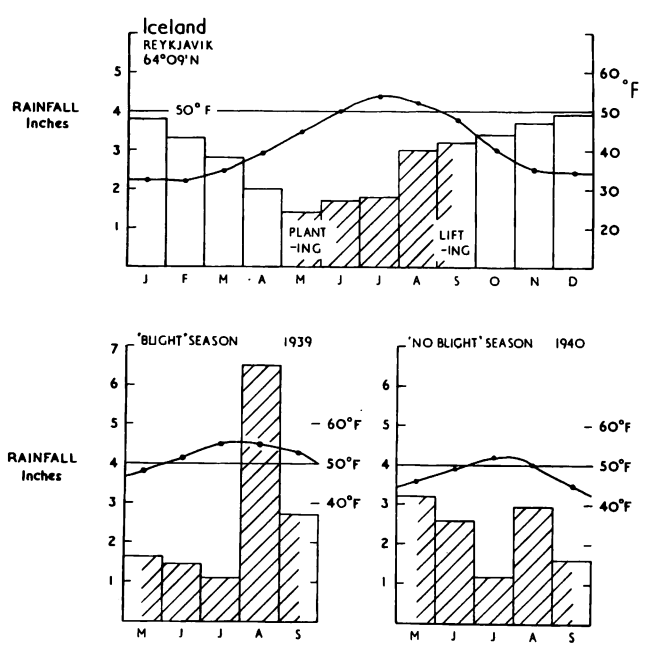


FIGURE 40.--Monthly rainfall and mean temperatures for Reykjavik, Iceland, in relation to potato cropping: Above, long-term average; below, "blight" and "no blight" seasons.

INCIDENCE OF BLIGHT

Blight appears so late in the season that the foliage does not suffer until the beginning of September. There is therefore little loss of total yield due to premature defoliation, but in some seasons there is considerable loss from infection of the tubers and consequent wastage in store (Davidsson, 1951). "Blight years" must here be taken to mean, therefore, years in which there is heavy infection in the tubers. Davidsson reported that severe losses (amounting to 20 to 40 percent of the crop) from this cause occurred in 11 of the 41 years from 1918 to 1950, and Fridriksson informs us that over the past 21 years the losses from tuber infection have been severe in 6 years (table 52).

TABLE 52.--Blight infections of tubers in Iceland, 1936-56

Severe	Slight	Negligible
1939	1948	1936
1941	1949	1937
1944	1950	1938
1945	1954	1940
1947	1955	1942
1953	--	1943
--	--	1946
--	--	1951
--	--	1952
--	--	1956

Climagrams for seasons in which blight was severe (1939) and negligible (1940) are given in figure 40. The severe blight season was characterized by mean temperatures of 55°, 54°, and 53° F. in the months of July, August, and September, respectively; while in the "no blight" season the corresponding temperatures were 52°, 50°, and 45°. With an average diurnal range from 5° above to 5° below the mean, it would appear that in such years as 1939 in Iceland, numerous spells may occur during these 3 months when the Beaumont minimum temperature requirement

of 50° is satisfied. The rainfall is abundant, and, occasionally, as in August 1939, very heavy. The southwest of Iceland is warmed by the Gulf stream, and humid conditions frequently occur. The long-term average mid-day (1400 hr.) relative humidity at Reykjavik over the months of June to September is about 72 percent--a figure rather less than that for Garvagh in Northern Ireland (78 percent) but much the same as that for Aberdeen. Low temperatures in July and August appear to be the factor checking the development of blight in the "no blight" seasons.

In trials at Reykjavik on the susceptible Gullauga variety, blight was first noted on the foliage during the third week of August, both in the "blight year" 1939 and in 1940. In 1939 it progressed to about 95 percent by September 20, just before lifting, while in 1940 the haulm at that time was almost free. In both years the total yield was about 10 tons per acre, but in 1939 4 tons of the potatoes were diseased.

CONTROL

It would appear that the infection of the tubers occurs in part before lifting and in part at lifting. The rather close spacing (24 inches between drills on maincrop varieties) may make it difficult to provide adequate soil cover in earthing up; and the necessity to lift before the frosts must result in many crops being harvested while the blighted haulm is still green. This would afford great opportunity for infection at lifting and probably accounts for most of the loss from blight developing in store. With a growing season already so short, haulm destruction at the beginning of September to reduce blight in tubers would involve too great a sacrifice of total crop.

Protective spraying of the haulm with burgundy mixture has been found to give good control of blight in the tubers, as indicated by the results of trials at Reykjavik in 1939, 1940, and 1941 (table 53).

TABLE 53.--Diseased tubers as a percentage of total yield, in sprayed and unsprayed plots, Iceland, 1939-41

Year and variety	Unsprayed	Sprayed with burgundy mixture		
		Once	Once	Twice
		July 18-27	August 1-7	July 18-25; August 7-14
	Percent	Percent	Percent	Percent
1939:				
Alpha	7	5	2	2
Gullauga	40	25	5	4
1940:				
Alpha	0	0	0	0
Gullauga	0	0	0	0
1941:				
Alpha	3	2	1	0
Gullauga	20	11	3	1/2

It is evident that spraying between July 18 and July 27 was too early for outbreaks not occurring until late in August; but that spraying in early August must have been very effective in keeping the disease off the haulm, so that opportunity for tuber infection both in the ground and at lifting was greatly reduced. The relatively low percentage of blighted tubers in the variety Alpha even without spraying points to the possibility of obtaining good practical control by the choice of varieties resistant to blight in the tubers.

Among the varieties found to be most susceptible to blight under Icelandic conditions are Early Rose, Arran Pilot, Gullauga, and Red Icelandic.

SUMMARY: ICELAND

Despite the low summer temperatures and short growing period, potatoes are an important crop in Iceland, and good yields are obtained. Blight occurs in the lowland areas to the southwest of the island, where it causes

severe losses by infection of the tubers from late attacks on the haulm in about 3 years out of 10. The blight attacks, under favorable humidity conditions, occur when the mean daily temperatures in July and August reach 54° to 55° F. but appear to be inhibited when these temperatures range about 50° to 52°, with a mean diurnal range of about 10° between the maxima and minima. Protective spraying of the haulm with burgundy mixture has been found to be effective in preventing blight in the tubers.

NORWAY

Norway forms the western part of the Scandinavian Peninsula, stretching from latitude 58° to 71° North, so that a large part of the country lies above the Arctic Circle (fig. 41). It is a mountainous country, and only in the southeastern parts and in the region of Trondheim Fjord are relatively large areas of level land to be found. The maritime climate of the west coast is associated with a high rainfall, in many places up to 80 inches per annum and more. In the southeast (Oslo) and in central Norway, the continental influence on the climate is felt, and this is associated with a summer rainfall peak. Annual rainfall is lower than in the west, and in parts of the interior may drop to an average of 12 inches. The modifying effect of the Gulf Stream on the temperature conditions of the country insures a reasonably long growing season in southern districts, but in the north the summer is necessarily much contracted, although the days are long. Climatic conditions at three centers in Norway are illustrated in figure 42.

About 140,000 acres of potatoes are grown annually and produce an average yield of 8 tons per acre (F.A.O., 1956). Human consumption of potatoes is about 224 lb. per person each year, and there are large quantities of potatoes used for stock feed, with small amounts for industrial purposes. The most commonly grown maincrop potato variety in Norway is Ås, which shows a fair degree of resistance to blight, but it is of poor quality for the ware market. Kerr's Pink, Prestkvern, Jøssing, and Up-to-Date (Grahm) are maincrop varieties widely grown for ware, all of which are susceptible or highly susceptible to blight. The growing season of maincrop varieties in southeast Norway is from May to September, with lifting continuing into October. Arran Pilot and Irish Cobbler are two of the principal early varieties. Early potatoes are grown mainly in southeastern Norway and in Rogaland County.

Four principal potato-growing regions can be distinguished, which, together, account for 70 percent of the total potato acreage. These are:

Region:	Thousand acres (1955)
Southeast Norway (Østfold, Vestfold, Akershus, Buskerud - - - -	35
Central Norway (Hedland, Opland) - - - - - - -	32
Rogaland - - - - - -	12
Trøndelag - - - - -	20
Other counties - -	41
Total - - - - - - -	140

These figures are from Erling Førsund of the Norges Landbrukshøgskoles Åkervekstforsøk at Vollebekk near Ås, who has also provided the information about blight epidemics in Norway on which this section is based.

DISTRIBUTION AND FREQUENCY OF BLIGHT EPIDEMICS

The importance of blight varies very much from district to district, but all farms in southern Norway, except those at the highest altitude, suffer from attacks at some time. The disease has been found as far north as Lyngen in southern Troms at latitude 69° 30' N.--probably the most northerly blight record in the world. It has also been recorded 550 m. above sea level at Kvikne.

Førsund has gathered together the available evidence on the incidence of blight over the period 1901 to 1951. The source of most of his information has been the annual reports of the Norwegian Ministry of Agriculture, together with data from the reports of some of the country's experimental farms. In table 54 the percentage of years during the 51-year period when blight attacks have been severe or medium, slight, and absent, are shown for each of the four main potato-growing regions.

Not a single year has been quite free from blight in all parts of the country. The variation between different years and different districts within a year has been considerable. The high percentage of years in which blight was absent in central Norway (1 in 4) and the low percentage of such years in Rogaland (1 in 50) is noteworthy. These two regions represent differing climatic conditions; Central Norway has a continental, and Rogaland a maritime (Atlantic) climate (see fig. 42 for Bergen, which lies just north of Rogaland county).

Since 1952, Førsund has been in charge of an investigation into the connection between weather conditions and blight epidemics to

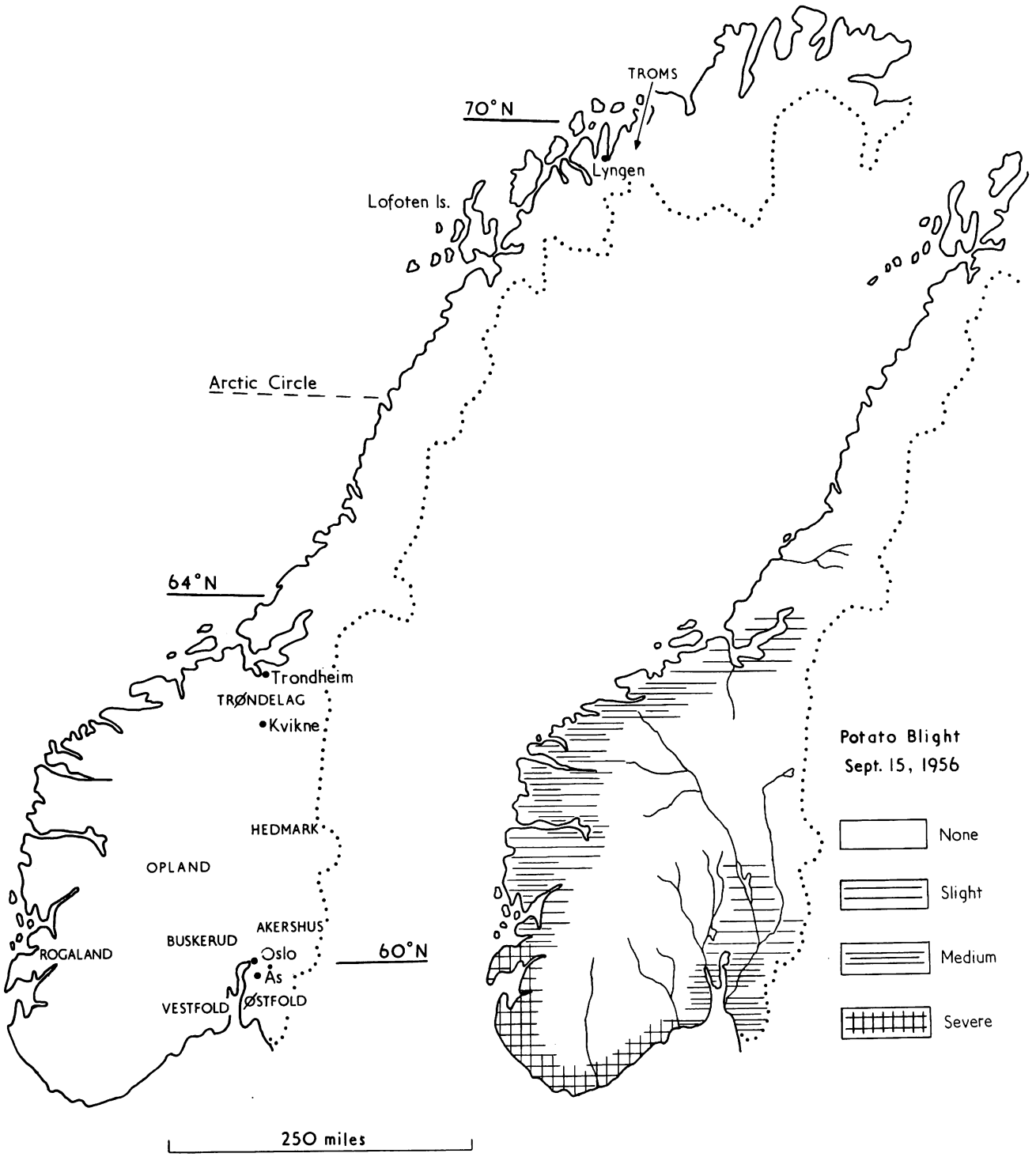


FIGURE 41.—Key map of Norway, and incidence of blight on September 15, 1956.

serve as a basis for a blight forecasting service in Norway. Somewhat more detailed records of blight have been kept over the country from that year, and the B.M.S. scale for the measurement of blight on haulm has been used since 1954. Maps to show the

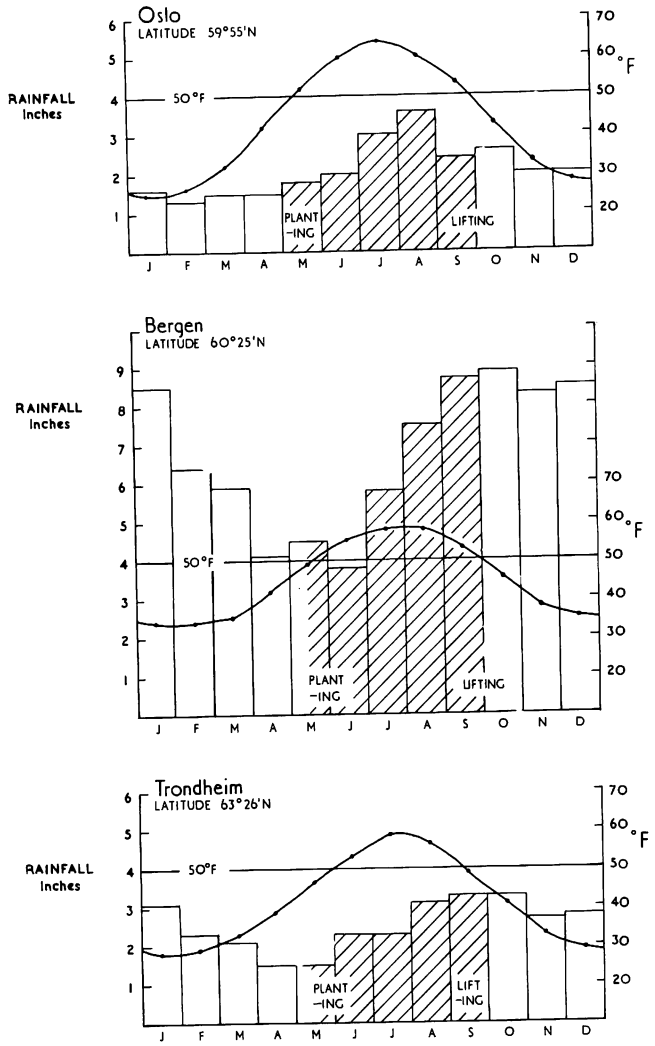


FIGURE 42.--Long-term average monthly rainfall and mean temperatures in relation to potato cropping at three centers in Norway.

TABLE 54.--Percentage of years when potato blight has been severe, slight, or absent in 4 regions, Norway, 1901-1951

Region	Severe or medium	Slight	Absent
	Percent	Percent	Percent
Southeast Norway.	55	35	10
Central Norway...	43	31	26
Rogaland.....	51	47	2
Trøndelag.....	45	47	8

incidence of blight at different times throughout the several years have been drawn, and one of these (for Sept. 15, 1956) is reproduced in figure 41. Blight attacks in Norway over the period 1952-56 are shown in table 55.

TABLE 55.--Incidence of blight in Norway, 1952-56

Region	Severe or medium	Slight	Absent
Southeast Norway.	1952	1956	1955
	1953	--	--
	1954	--	--
Central Norway...	1953	1952	1955
	1954	1956	--
Rogaland.....	1952	--	--
	1953	--	--
	1954	--	--
	1955	--	--
	1956	--	--
Trøndelag.....	1952	1955	--
	1953	1956	--
	1954	--	--

No great degree of precision is claimed for the terms used to describe the epidemics. Although a severe attack can generally be taken to mean a severe attack on the haulm with a resulting yield reduction due to premature defoliation, there has been no marked attempt to separate defoliation losses from tuber blight losses. The problem of tuber infection at harvest increases in the more northerly potato-growing areas where the growing seasons and harvest periods are short. Førsund gives as an example of a severe attack the data relating to a crop of Kerr's Pink under observation at the College of Agriculture at Ås in southeast Norway in 1953. Blight was first noted on July 21, and the crop was completely dead on September 10. Total yield was 7.4 tons per acre, of which 14 percent was blighted.

In general, blight is important in all the main potato-growing regions of Norway, and particularly severe in the southwestern part of the country. The biggest losses are caused in the varieties grown for ware, as most of these are highly susceptible to the disease.

CONTROL EXPERIMENTS

Roer (1957) has described a series of spraying trials made in southeastern Norway during the period 1945-54. The variety used during the first 9 years was Up-to-Date, which is very susceptible to blight. In 1954, this variety was replaced by Kerr's Pink, which is much more commonly grown in the area and is also less susceptible than Up-to-Date, particularly in the haulm. Fungicides were applied twice with a 2-week interval between applications. The percentage increases in total yield from this spraying were:

Year:	Increase in yield from spraying Percent
1945	23
1946	17
1947	1
1948	5
1949	8
1950	19
1951	22
1952	7
1953	7
1954	8
Average	12

The average yield of the unsprayed potatoes over the 10 years was 9.6 tons per acre, and of the sprayed, 10.8 tons per acre. This represents an average increase of 12 percent from 2 sprayings, or just over 1 ton per acre. Protective spraying had little effect on tuber blight infection, which was high, averaging 22 percent on the unsprayed plots. An economic analysis of these results showed that a routine control program against blight on Up-to-Date was profitable.

Similar results with Up-to-Date were obtained by Lunden (1947), who carried out trials in the same area during 1939-44. Again, two protective sprays were given. In these trials, however, the field-resistant variety Ås was also included. Average results for the 8-year period are shown in table 56. Bordeaux mixture was used throughout.

The difference between the field-resistant Ås and the blight-susceptible Up-to-Date is most striking. Protective spraying of Ås on a routine basis was not profitable. The much smaller percentage of blighted tubers in Ås should also be noted.

SUMMARY: NORWAY

Blight is important in all the main Norwegian potato-growing areas. Losses are principally in varieties grown for the ware market. The relatively small effect of the disease on Ås points the need for a field-resistant ware variety.

TABLE 56.--Results of spraying tests with bordeaux on yields of As and Up-to-Date potatoes, Norway, 1939-44

Test	Ås		Up-to-Date	
	Total yield	Blighted tubers	Total yield	Blighted tubers
	Tons per acre	Percent	Tons per acre	Percent
Unsprayed	11.6	1.6	8.8	11.0
Sprayed	12.0	.7	10.8	13.0

SWEDEN

Sweden extends in a narrow strip about 1,000 miles long between latitudes 55° and 69° N. Due mainly to the influence of the Gulf Stream, climatic conditions in the country are not so severe as might be expected from its northerly position. In the south, mean summer temperatures exceed 50° F. for about 4 1/2 months, but in the north for only about 2 months. Potatoes are grown throughout the country (fig. 43), principally on sandy soils, with the main concentration in the south: The three most southerly counties--Blekinge, Kristianstads, and Malmöhus--have, between them, a third of the total potato acreage. About 300,000 acres of potatoes are grown each year and produce an average yield of 5 1/2 tons per acre (F.A.O., 1955). Curiously enough, the potato yields in the most northerly provinces are as high, if not higher, than in the south, despite the shorter growing season. This must, in part, be a reflection of more intensive cultivation methods, but it would also appear that the long-day conditions of the near-Arctic summer suit the potato crop, provided that the right varieties are grown.

Approximately 40 percent of the crop is used for human consumption, giving an average annual intake of somewhat over 200 lb. per head of the population: Half the potatoes are used in animal feeding and the rest for manufacture (farina and alcohol). A very full account of the distribution of potato varieties in Sweden has been given by Hagberth (1951), from the results of a nationwide survey carried out between 1937 and 1943. The leading variety was then Magnum Bonum, and other maincrop varieties widely grown were Wohltmann, Up-to-Date, President, Birgitta, and Gloria. The principal early varieties were Early Puritan and Early Rose. In the south of Sweden the potato-growing season is from the beginning of May to early October. Northward the season is contracted; planting is later, and lifting earlier. (See climagrams, fig. 44.)

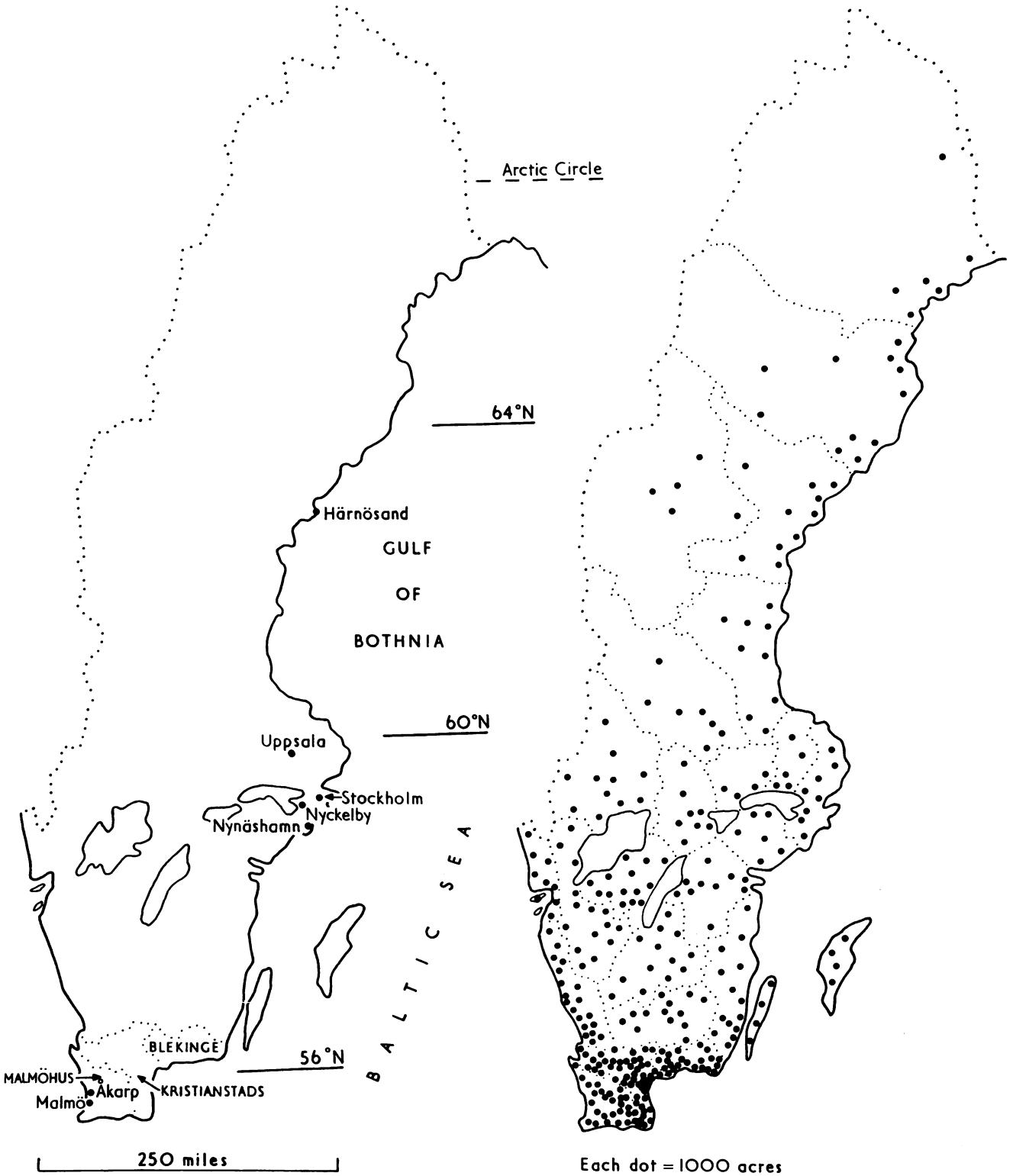


FIGURE 43.--Key map of Sweden, and distribution of potato growing, 1955. (After Jonasson, Höljer, and Björkman, 1938, and Sweden, Statistiska Centralbyran, 1956.)

BLIGHT EPIDEMICS: DISTRIBUTION AND FREQUENCY

Potato blight occurs throughout Sweden, but the disease is most important in the southern half of the country, particularly in the western coastal area. It is there that the first outbreaks of the season are usually recorded. In north Sweden, epidemics, when they occur, are usually late. No special survey work is in progress, but Dr. Lihnell of the Statens Växtskyddsanstalt, Stockholm, has provided his own appraisal of blight incidence in Sweden for the years 1946-55 (table 57), and other information for this section.

The classification of the epidemics shown in table 57 covers the losses caused both by premature defoliation and by tuber infection. Dr. Lihnell points out the difficulty of concentrating in a few words the truth about potato blight for a country the size of Sweden, where conditions vary considerably between the north and south. In some years, as in 1947, practically no blight occurred in any part of the country. But in 1955, for example, the northern parts of Sweden were almost entirely free from blight, while in the south one of the worst attacks of the whole 10-year period occurred, with heavy losses from tuber infection.

BLIGHT LOSSES

In the absence of survey data, the results of spraying trials give the best indication of blight losses. Figures have been published by Andrén and Pettersson (1956) and Andrén (1946-55) from trials held at two centers in Sweden during the period 1946-55. These centers were at Åkarp, near Malmö, in the extreme south of Sweden, and at Nyckelby, near Stockholm, in central Sweden. In addition to the yields of the unsprayed and sprayed plots, details of the progress of blight defoliation on the haulm have also been presented, measured by a 0 to 10 scale. From this information it has been possible for most years to estimate the time the 75 percent blight defoliation stage was reached on the unsprayed and sprayed plots. These estimates together with the plot yields and the gain from spraying (in tons per acre) are shown in table 58. In each year a number of different spray materials were used, and the results for the sprayed plots in the table refer to the most successful treatments. The variety was Up-to-Date in most of the trials, although in the earlier years it was Magnum Bonum at both centers.

TABLE 57.--Incidence of blight in Sweden, 1946-55

Severe	Slight	Negligible
1950	1946	1947
1951	1948	1955 (North)
1953	1949	--
1954	1952	--
1955 (South)	--	--

In the 7 years that trials were held at Åkarp, blight incidence for Sweden has been described by Lihnell (table 57) as severe in 3 years, slight in 3 years, and negligible to severe in 1 year. There does not therefore appear to be any particular bias toward "blight" or "no-blight" years in the series shown in table 58. Where no 75 percent blight date has been given for the sprayed plots in this table, it is because the 75 percent stage was not reached before lifting.

The figures in table 58 can be used, with some reservations, to estimate blight losses at the two centers. The losses can be estimated as the difference between the yields of the sprayed (S) and unsprayed (U) plots (the gain from spraying) expressed as a percentage of the "sprayed" yield. This is on the assumption that the "sprayed" yield is approximately equivalent to the full potential yield of the crop, and it is here that reservations need to be made. In those years when the 75 percent stage on the sprayed plots was reached before the end of September--1949, 1950, and 1954 at Åkarp--the "sprayed" yield will be lower than the potential yield. In all years, the yield on the sprayed plots will be somewhat lower than the potential yield due to damage caused while spraying. With this in mind, the estimated blight losses for the several years at the two centers, presented in table 59, can now be considered.

Losses due to premature defoliation are high and have occurred every year. This is partially explained by the evident late bulking of the crop at these two centers. For example, at Åkarp in 1955, the 75 percent blight stage was reached on the unsprayed potatoes on September 21, but there was still a gain of 2.5 tons per acre on the sprayed plots; at Nyckelby in 1948, the unsprayed plots were 75 percent defoliated on September 20, but the sprayed gained 2.8 tons per acre (table 58). Particularly in the area represented by this latter center, where the harvest period is relatively late and short, it seems likely that many crops will be lifted before they are fully mature, so that the trial figures tend to give a somewhat exaggerated picture of the benefits to the commercial grower of spraying against blight. Nonetheless, the disease is obviously very serious in Sweden, and this is borne out by farmers taking protective spraying as a matter of course.

Tuber blight figures have also been given for all the years of the trials at Nyckelby, and for some of the years at Åkarp. The

TABLE 58.--Yield, date when 75 percent blight stage occurred, and gain from spraying potatoes at 2 centers in Sweden, 1946-55

Location and year	Date of 75 percent blight stage		Total yield		Gain from spraying
	Unsprayed	Sprayed	Unsprayed	Sprayed	
ÅKARP:			Tons/acre	Tons/acre	Tons/acre
1946	Sept. 14	.....	6.4	7.9	1.5
1948	Sept. 10	.....	11.3	12.3	1.0
1949	Aug. 21	Sept. 18	9.1	11.4	2.3
1950	Aug. 10	Sept. 20	11.3	16.3	5.0
1953	Sept. 10	Sept. 30	15.2	21.0	5.8
1954	Aug. 22	Sept. 20	11.0	14.6	3.6
1955	Sept. 21	.....	14.4	16.9	2.5
NYCKELBY:					
1946	Sept. 15	.....	6.2	8.1	1.9
1948	Sept. 20	.....	8.2	11.0	2.8
1949	(1)	(1)	11.0	13.3	2.3
1950	Sept. 11	.....	10.1	14.2	4.1
1953	(1)	(1)	8.2	12.3	4.1
1954	Aug. 30	.....	8.8	12.8	4.0

[1] No data for date of 75 percent blight stage.

percentage of infected tubers in the unsprayed plots at both centers is shown in table 60. In all years the variety under trial was Up-to-Date, apart from 1946 at Nyckelby, when it was Magnum Bonum.

The average loss through tuber blight infection for the 6 years of trials at Nyckelby was just under 8 percent. At Åkarp the chief point of interest is the very heavy loss in 1955 (nearly 60 percent). It is not possible to say how accurately these figures reflect the position throughout Sweden, but it should be remembered that they are solely for tuber blight before lifting, and as such they are high. Tuber infection at harvesttime is also a problem in Sweden, which becomes more acute in the north, owing to the shorter growing season and shorter harvest period. The use of haulm killers should greatly reduce this source of loss.

TABLE 59.--Percentage loss of crop due to blight at 2 centers in Sweden, 1946-55[1]

Year	Åkarp	Nyckelby
	Percent	Percent
1946	19	23
1948	8	25
1949	20	17
1950	31	29
1953	28	33
1954	25	31
1955	15	(2)
Average	21	26

[1] Formula used to estimate loss: $(\frac{S-U}{S} \times 100)$, where S is yield of sprayed and U is yield of unsprayed plots.
[2] No trial.

BLIGHT AND WEATHER DATA

The climagrams (fig. 44) for three centers in Sweden show the strong continental influence affecting the country's climate. There is a

TABLE 60.--Percentage of blighted tubers at 2 centers in Sweden, 1946-55

Year	Åkarp	Nyckelby
	Percent	Percent
1946	--	0.1
1948	--	16.1
1949	--	8.3
1950	--	6.8
1953	10.0	12.7
1954	2.5	2.3
1955	57.8	(1)

[1] No trial.

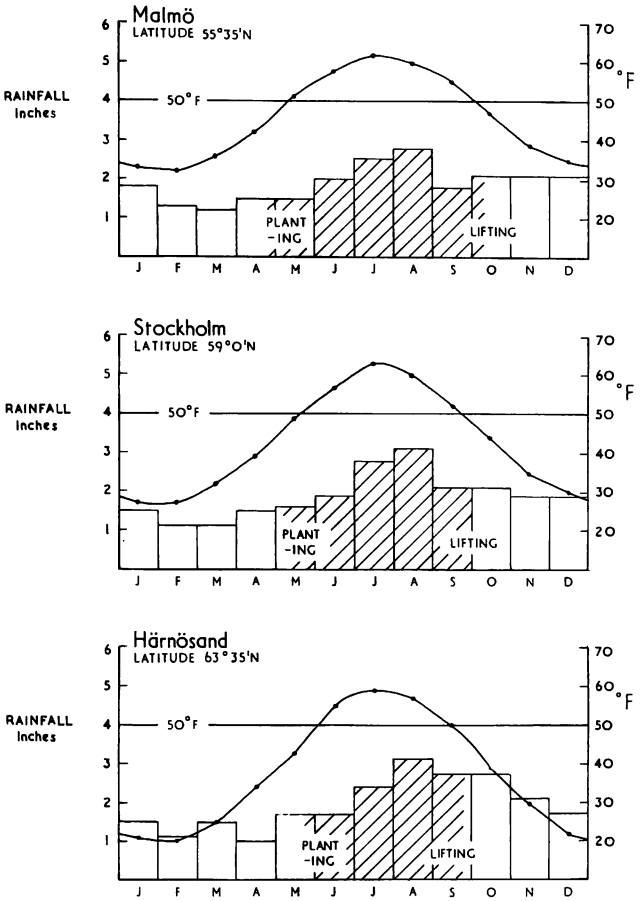


FIGURE 44.--Long-term average monthly rainfall and mean temperatures in relation to potato cropping at three centers in Sweden, showing shortening of growing period at higher latitudes.

marked summer rainfall peak and a wide difference between summer and winter temperatures. The wettest month of the year is August. Continental conditions are modified in the south by warm winds blowing across the land from the Atlantic, and in the north by the presence of the Baltic Sea and the Gulf of Bothnia. These various sea influences, resulting in high summer humidity conditions, appear to be one of the main factors leading to the relative frequency of severe blight years--approximately 1 year in 2. Combined with the high humidities in the southern parts of Sweden are summer temperatures generally favorable for blight. For example, long-term mean July and August temperatures at Malmö are 62° and 60° F., and at Stockholm 63° and 60°. The climagram for Härnösand shows the shortness of the growing season for potatoes (approximately 110 days), but a fairly large acreage of the crop is grown even farther north than this. Under these conditions, tuber infection at harvesttime has proved to be the major source of loss caused by blight.

CONTROL MEASURES

Dr. Lihnell has told the authors that practically all growers who produce potatoes on a commercial scale spray their crop once or twice, and growers that use better farming methods spray 3 or 4 times in the season. Haulm destruction has become popular in recent years. Investigations into the biology of Phytophthora infestans and on spraying techniques are carried out at the Royal Agricultural College, Uppsala. A recent paper from there by Björling and Sellgren (1955) has given an account of field experimental work on blight infections through the upper and lower surfaces of potato leaves. Although these workers found that by far the greater proportion of the infection took place through the upper surfaces, there was sufficient infection through the lower surfaces for them to state that both surfaces need to be sprayed to give efficient protection against blight. Work on protective spraying and potato haulm destruction is also being carried out at the Institutet for Växtforskning och Kyllagring, at Nynasham, by B. Emilsson and his colleagues.

SUMMARY: SWEDEN

Although survey information on blight incidence in Sweden is not available, the results of spraying trials lead to the conclusion that losses from the disease both by premature defoliation and tuber infection are potentially very heavy. Losses are, however, reduced by a universally applied annual spray program. Tuber infection at lifting--a direct result of the short growing and short harvest periods--is the main problem in northern Sweden. In the south, yield losses brought about by premature defoliation is the more important aspect of the disease.

WESTERN GERMANY

About 3 million acres of potatoes are grown annually in Western Germany, producing an average yield of just over 8 tons per acre (F.A.O., 1955). Total potato production is about 26 million tonnes per annum, and Van Hamelen (1955) states that this is used as follows:

Production for--	Million tonnes
Seed	2.9
Ware	8.2
Fodder	12.0
Starch manufacture	.2
Alcohol manufacture	.2
Shrinkage loss	2.5
Total	26.0

Human consumption accounts for less than half of the crop. Even so, consumption is very high, and in 1953 was 372 lb. per head per annum. Enough certified seed is produced to plant about one-third of the potato acreage, and in addition some seed is exported, principally to Switzerland, Italy, France, and Brazil. Fodder potatoes, grown mainly for pigs, account for about 50 percent of the total production.

POTATO DISTRIBUTION AND VARIETIES

Potato acreages, by province (fig. 45) for 1954, are shown in table 61. These figures were supplied by the Economist Intelligence Unit.

The principal areas producing potatoes for the ware market are in Lower Saxony, the south of Schleswig-Holstein, and the north of North Rhine. This region contains a high proportion of medium-sized farms, ranging from 50 to 300 acres. A very large acreage of potatoes is in Bavaria. The acreage is chiefly in small or very small farms, and the potatoes are for home consumption. Early potatoes are grown throughout the country, with the most important district centered on Dollbergen, between Hanover and Brunswick (Braunschweig). Seed potatoes, also, are grown in all areas, with a concentration of crops in Lower Saxony, which produces about half of all the certified potato seed grown in Western Germany. Much of this seed production goes on in the north of Lower Saxony in the area adjoining the North Sea. Stade is one of the main seed-producing centers.

FIGURE 45.--Key map of western and eastern Germany.

TABLE 61.--Potato acreage, by province, Western Germany, 1954

Province	Variety		
	Early	Mid-season and maincrop	Total
	1,000 acres	1,000 acres	1,000 acres
Schleswig-Holstein	9.5	128.0	137.5
Hamburg	.7	3.5	4.2
Lower Saxony	45.9	665.7	711.7
Bremen	.6	2.1	2.8
North Rhine Westphalia	38.9	389.6	428.7
Hesse	11.8	255.2	267.0
Rhineland Palatinate	14.1	244.5	258.6
Baden-Wurttemberg	13.3	322.1	335.4
Bavaria	30.4	762.2	792.6
Total	165.2	2,773.0	2,938.2

Most of the varieties grown originated in Germany. In a recent review, Hix (1955) has compared the importance of the different midseason and maincrop potato varieties from the results of a nationwide survey. His figures, showing the makeup of the Western German potato acreage in 1954, are shown in table 62.

Hix did not include first-early varieties in his survey. Erstling is the most important early potato, and most of the seed of this variety has to be imported. German early varieties grown on a fair-sized scale are Oberambacher Frühe, Sieglinde, and Vera.

Table 62 shows the preponderant part played by maincrop (late) varieties as opposed to midseason potatoes. This is a somewhat different state of affairs from that in France and Belgium, where a much higher percentage of the potato acreage is planted with midseason varieties. The three most important varieties are Ackersegen, Heida, and Bona. The part played by these potatoes varies in different parts of the country. Ackersegen is the most widely grown variety throughout almost the whole of Germany and is particularly important in south Germany. In Bavaria, it makes up half of the acreage; and in Hesse, about two-thirds. Heida is hardly grown at all in Bavaria and Hesse, but in the other provinces it occupies a tenth to a half of the potato acreage. The midseason variety Bona is concentrated in north Germany, particularly in Westphalia, where it is even ahead of Ackersegen and makes up almost a third of the potato crop.

The two main blight-resistant varieties derived from Solanum demissum hybrids, now grown in Germany, are Aquila and Maritta. Aquila does not occupy a large acreage, but Maritta is important, particularly in Bavaria. Recent descriptions of German potato varieties have been given by Snell (1952).

SOIL AND CLIMATIC CONDITIONS: CULTIVATIONS

Most of the potatoes are grown on light, sandy soils. The climate throughout the greater part of Germany is continental in type, with relatively severe winters and the rainfall peak coming in July and August. Summer temperatures are not high; in most places the mean temperatures in July and August do not exceed 65° F. In the north, true continental climatic conditions are modified by the presence of the North Sea and the Baltic; whereas in the south, the fact that most of the land is high leads to cool summer conditions.

There is a difference of 1 to 2 weeks in the time of planting potatoes between the north and south of Germany. The earlier plantings take place in the north of the country, from the beginning of April onward. Digging of early ware varieties starts from the middle to the end of June; and midseason and late varieties are lifted from mid-August to the end of September. Except in Schleswig-Holstein and parts of Lower Saxony, individual holdings are mostly small and subdivided into numerous strips, which may be widely scattered. This is a great hindrance to mechanization and, incidentally, to the blight control measures. Opitz (1949) describes potato cultivations in Germany in detail.

POTATO BLIGHT INVESTIGATIONS

Before the second World War, research and investigational work on the potato crop in Germany was concentrated in what is now the Eastern Zone, where the larger part of the crop was grown. Workers on potato diseases in Western Germany had a considerable amount of leeway to make up after the war, and are only now getting fully into their stride.

TABLE 62.--Potato varieties, use, and percentage of acreage in Western Germany, 1954

Varieties and use	Acreage
Midseason	
For ware:	
	Percent
Bona	9.4
Concordia	1.0
Flava	.2
Olympia	2.5
Others	.8
For ware, fodder, or industry:	
Augusta	1.2
Mittelfrühe	1.8
Total	16.9
Maincrop	
For ware:	
Agnes	3.6
Heida	12.6
Virginia	1.2
Others	1.9
For ware, fodder, or industry:	
Ackersegen	44.0
Aquila	1.1
Capella	1.0
Magna	1.0
Maritta	6.4
Voran	4.2
Others	5.3
For industry:	
Robusta	.8
Total	83.1

In the late 1920's and 1930's K. O. Müller (1928), with his W-races, and Schick, working at the Kaiser-Wilhelm Institute, were among the pioneers in the search for blight-resistant potato varieties. Since 1947, Rudorf and his colleagues have continued this line of research at the Max-Planck Institute, Voldagsen über Elze, in Hanover. Also, since the war, fundamental studies in connection with schemes for forecasting blight have been carried out in different parts of Western Germany, notably by Johannes (1953a), and Uhlig (1955).

The Plant Protection Service (Pflanzenschutzdienst) is organized on a provincial basis, and has been responsible for carrying out the majority of the trials on blight control in recent years. Individual Plant Protection Offices are also responsible for collecting information on the incidence of plant diseases from local observers, and data on potato blight from this source, presented on a national basis, have been published.

BLIGHT EPIDEMICS: DISTRIBUTION AND FREQUENCY

An attempt has been made by Voelkel (1954) to delimit those areas in Germany where potato blight is most important. His method embodies a conception of "pest or disease zones" (Schadgebiete), which he defines as "areas in which a pest or disease in most of the years in a particular period, is always more or less severe." Figure 46 is from Voelkel's map of the "Schadgebiete" for potato blight. The darkly shaded areas, which are most concentrated in Lower Saxony, are the real blight zones.

Voelkel based his zoning upon a combination of the total number and the frequency of "severe" blight reports received by the various Plant Protection Offices from the different districts during the period. The bad blight areas in Western Germany are thus shown as (1) the south of Schleswig-Holstein, (2) Lower Saxony (Oldenburg and Hanover), (3) the western half of North Rhine-Westphalia, and (4) a small area in southeastern Hesse. Areas 1 to 3 form a continuous zone, comprising practically the whole part of Western Germany on the great sandy plain that stretches across the north of Europe. In this northern blight zone, the disease is most serious in the districts near the coast.

Annual accounts of potato blight in Germany were published from 1920 to 1931 in the Mitteilungen aus der Biologischen Reichsanstalt für Land und Forstwirtschaft. From 1925 to 1931, these accounts included maps showing the distribution of the disease. Since 1948, general accounts of blight for most years have been compiled by Dr. Härle from the records of the Plant Protection Offices, and published in Nachrichtenblatt des Deutschen Pflanzenschutzdienstes, Braunschweig. (See Härle, 1951.) It is possible from this material, together with information supplied by Dr. Johannes, to divide the years 1948-55 into two categories--"moderate" and "severe"--according to blight incidence. This has been done in table 63, which also shows the average potato yields (F.A.O. statistics) in particular years.

In no year was blight absent, and although the incidence of the disease varied considerably between different areas of Western Germany over the period 1948-55, in each year there was at least some part of the country where blight was stated to be severe. The difference between a moderate and a severe blight

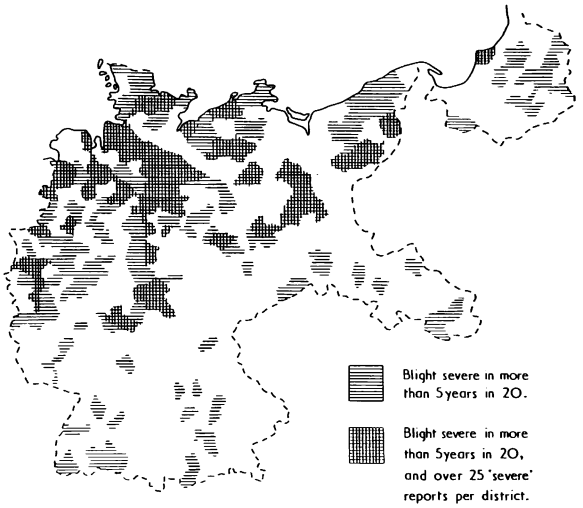


FIGURE 46.--Blight zones in Germany, 1925-44. (After Voelkel, 1954.)

year lies in the time of destruction of the potato haulm by the fungus. Generally, in a "severe" year, the haulm over a large part of the acreage is killed before the end of August, with a considerable resulting loss in yield. In a "moderate" year, the blight attack comes late and defoliation losses are generally small. This can, perhaps, best be seen from Härle's account for 1950, which appears to have been the worst year in the 8-year period; and for 1952, when blight was least damaging:

1950. Blight severe. "Blight on haulm, present in the Rhineland in May, was sporadic in June, and from July generally distributed and severe in the whole of Western Germany... The disease was especially severe in Schleswig-Holstein, Oldenburg and Westphalia. On some varieties, such as Bona (midseason), the foliage was completely killed within a few days. It appeared that the spraying against blight was often done too late. In Schleswig-Holstein and in part also in Oldenburg, blight in tubers, (especially on the lighter soils) was relatively slight despite the severe attacks on the haulm."

1952. Blight moderate. The summer in this year was dry and hot, and, up to the end of July, blight incidence was described as very slight. In August "although blight was long delayed with outbreaks only here and there in this month, the disease on haulm and tubers was in parts still very severe, especially in North Rhine Westphalia, Lower Saxony, Hamburg and Schleswig-Holstein. South Germany remained almost free of the disease."

The attempt that has been made in table 63 to define the incidence of blight in certain years for the whole of Germany, is, at best, unsatisfactory. Although the disease may be severe throughout the whole country in a particular year (as in 1950), the more general pattern is one of variation between different regions. The only satisfactory way of defining epidemics is on the basis of a number of relatively homogeneous potato-growing areas, and, unfortunately, the data are not available to do this. The highest yield (9.8 tons per acre) during the period 1948-54 was in 1950--the worst blight year. Without a clearer method of defining the epidemic in that year, it is impossible to explore fully the reasons for this, but it indicates that a high loss from the disease in a blight year may be amply offset by an actual increase over normal production.

BLIGHT ON HAULM AND LOSSES

Very few of the accounts of spraying trials in Western Germany include a description of the progress of the disease on the haulm. An exception is some recent work by Johannes (1953b), who used a scale from 0 to 5 to estimate the amount of defoliation, but this scale is rather lacking in precision. It thus becomes very difficult from published information to make statements on the timing of blight epidemics in the different regions of the country. However, Dr. Scheibe of the Pflanzenschutzamt at Hanover has given us a verbal account of blight progress on potato haulm in his area, which covers the eastern and larger half of Lower Saxony. From this account it is possible to get an idea of the effect of blight in one of the principal "Schadgebiete" of Western Germany. In this part of Lower Saxony blight occurs every year, most commonly appearing in July. In a bad blight year, it appears at the end of June and the tops of unsprayed maincrop (or late) varieties are dead by the middle to the end of August. The crop would normally ripen off by the middle to the end of September. The frequency of such blight years is about one in three.

Thus, in a bad blight year there may be a loss of 6 or 7 weeks' growth on unsprayed maincrops. By analogy with England and Wales, where the length of the growing season is very similar, this will involve a loss of about 30 percent of the potential yield. But this is putting the picture at its blackest. Even in the bad blight year, the yield loss is unlikely to average 30 percent on the unsprayed maincrops, and it will be reduced in the area as a whole by protective spraying. Moreover, the earlier maturing potato varieties are unlikely to suffer so severely from the effects of premature defoliation.

The results of large numbers of spraying trials in many of the potato-growing regions of Western Germany have been reported in the literature since 1946. These trials have varied from properly replicated experiments to simple demonstrations with one sprayed and one unsprayed plot. It might be possible, as

has been done in Denmark, to use the results of these trials, expressed as yield increases from spraying, to estimate blight losses on a countrywide basis. To the outsider, however, they present many difficulties of interpretation. Some of the most important of these difficulties are: (1) Very often the results for a number of years and/or a number of varieties of differing maturity groups have been averaged; (2) far too little precise information on the progress of blight on the haulm is given, and even general notes on the severity of blight in the year of the trial may be lacking; and (3) the results of the trials are often expressed as percentage increases in yield from spraying, without quoting the actual yields of the sprayed and control plots.

An idea of the scale of the yield increases in some recent trials can be gained by quoting representative figures. Johannes (1953b) has given the results of experiments carried out in 1949 and 1950 at a number of centers in Western Germany, where the main object was to test the relative efficiency of different rates of copper application and amounts of water in low-volume spraying. In 1950, which was a severe blight year, trial centers were at Uelzen and Ebersdorf in Lower Saxony, at Sandrup and Bonn in North Rhine Westphalia, and at Darmstadt in Hesse. The average increase in yield (all varieties) over the 2 years for the optimum treatment was 26 percent. This figure corresponds very closely to an average increase of 23 percent of the unsprayed yield, which was the result of trials by Ext (1950) during 1950 in Schleswig-Holstein. Two sprayings with a copper compound were given to a number of different varieties. The variation in yield increase between some of the varieties in Ext's trials are shown in table 64, and the figures illustrate some of the difficulties of interpreting results of this kind.

In southern Germany, Malmus (1954) has reported on 412 spraying trials in different parts of Bavaria during 1949, when blight was severe in the province. Of these trials 72 percent gave a yield increase as a result of spraying, and this increase averaged over 13 percent. To what extent the yield increases quoted above for the three sets of trials reflect the level of losses caused by blight during severe blight years in parts of Germany is a matter of conjecture. The efficiency of the spraying is a most important factor, and it is most unlikely that full blight loss was prevented.

Malmus (1949) has made some overall blight loss estimates for the German potato crop. He estimated that 33 percent of the crop was lost by blight in 1916, and 25 percent in 1926. In years of less severe attack than these, Malmus suggests that the loss is about 10 percent. It seems most unlikely that the average annual loss by premature defoliation in Western Germany will exceed 10 percent of the potato crop. This is on the basis of the careful analysis by Stapel (1953) of blight losses in Denmark, where losses were estimated to be of this order. The weather and other growing conditions in the blight zones of Western Germany are very similar to the general conditions in Denmark. Outside the blight zones, where half the total crop is grown, blight losses are likely to be less than in Denmark. It is important to see this loss of potential crop in its proper perspective. An analysis of West German potato yields in moderate and severe blight years (table 63) shows that in the years of moderate attack, the average potato yield was 8.2 tons per acre; in the years of severe attack it was 8.8 tons per acre.

Little data exist on the extent of tuber infection, either in the soil before lifting or at harvesttime. Dr. Johannes has said that in Western Germany, as a whole, tuber blight is not a very important problem, and this he associates with the generally sandy soils on which potatoes are grown and the relatively long growing season. Speaking of Lower Saxony, Dr. Scheibe stated that although trouble may be caused in a wet harvest year, tuber blight is not usually a problem.

TABLE 63.--Incidence of potato blight and average yield of potatoes in Western Germany, 1948-55

"Moderate" blight years	Average yield	"Severe" blight years	Average yield
	Tons/acre		Tons/acre
1949	7.4	1948	8.2
1952	8.3	1950	9.8
1954	9.0	1951	8.6
1955	--	1953	8.4
Average	8.2	Average	8.8

TABLE 64.--Increases in yield of certain potato varieties from copper spraying, Schleswig-Holstein, Western Germany, 1950

Variety	Maturity	Average increase in yield from spraying	Range of increase
		Percent	Percent
Flava	Midseason	17	5 to 29
Bona	..do	36	-2 to 66
Heida	Maincrop	27	8 to 45

BLIGHT AND WEATHER DATA

Uhlig (1955) has pointed out that the main blight zones in Western Germany (Voelkel's "Schadgebiete") lie predominantly in those parts of the country where the mean relative humidities in July and August are over 75 percent. But so far no detailed studies of blight conditions in relation to macro-climate have been made. The long-term rainfall and mean temperature data shown in figure 47 for three centers in different potato growing areas reveal a very similar pattern, and no very great difference in the average monthly rainfall and temperature figures between the centers occurs. A greater annual and summer rainfall is found in the higher parts of Germany; at Freudenstadt (2,395 ft.), for example, the average yearly rainfall is 58 inches, but these wetter districts lie outside the main potato-growing regions. The higher summer humidities due to sea influences, which occur in the north, are not correlated with a higher rainfall in these regions; and there is no simple relationship between blight and rainfall. Summer temperatures throughout the country are generally favorable to the disease.

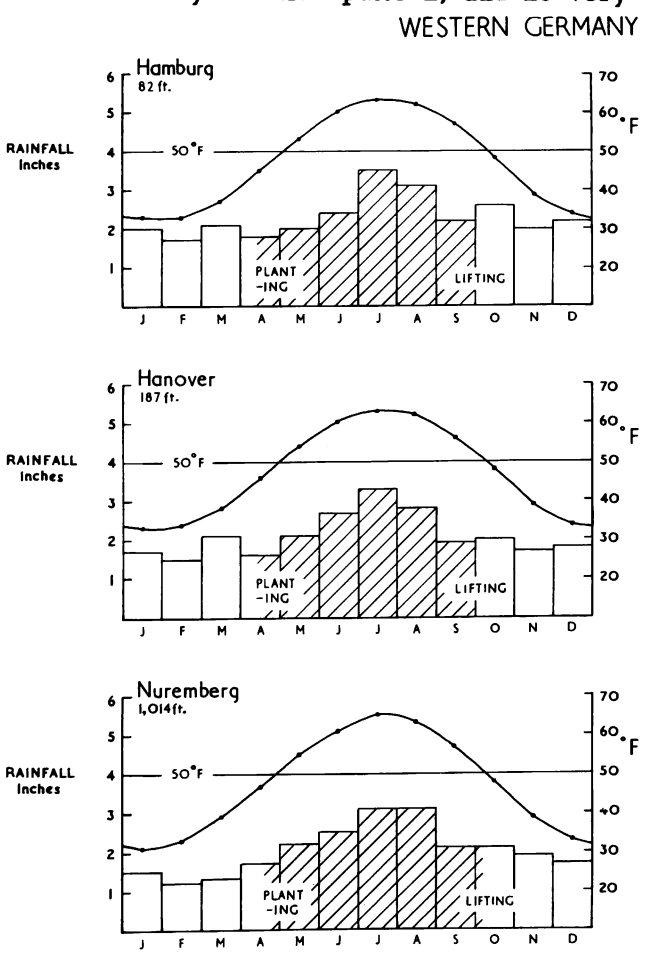


FIGURE 47.--Long-term average monthly rainfall and mean temperatures in relation to potato cropping for three centers in Western Germany.

A study of blight incidence in relation to weather at Braunschweig (Brunswick) over a period of 3 years (1952-54) has been made and is given in table 65. Climate at this center is very similar to that at Hanover, and may be considered as reasonably typical of weather conditions in the great sandy plain of northern Germany. In this table the descriptions of the blight attack in the several years have been given by Dr. Johannes.

During both the "slight" and the "severe" attacks in 1952 and 1953, respectively, rainfall was below average, although low rainfall was most marked in the "slight" year. The most unusual year of the 3 from the point of view of relationships between blight and weather was 1954. Despite extremely wet conditions in the summer (July rainfall: 7.8 inches), the very low temperatures in July (5° F. below average) delayed the onset of blight, and the attack was late.

CONTROL MEASURES

Dr. Johannes has given a general account of chemical control measures against blight in Western Germany. In the north of the country, protective spraying is commonly practiced. Seed potato growers (export and home consumption) are obliged by their contracts to use protective sprays on their crops; also, there are a number of organizations of large growers that insist on protective spraying as a necessary operation if the organization is to buy the member's potatoes. In most cases the work is done by the farmer himself; for the small farmers, communal machines are

available. Spraying against blight is much less common in the south of Germany.

An estimate of the amount of spraying done in the area covered by the Pflanzenschutzamt at Hanover has been supplied by Dr. Scheibe, and his figures illustrate some of the factors at work. The area falls into three main divisions. In the seed and ware-growing district in the northwest, about 50 percent of all growers spray each year; the growers of early varieties for seed usually spray three times, and the growers of maincrop varieties for seed usually only once. In the central ware-growing district, 20 to 30 percent of the growers spray once or twice. In the early ware-growing district centered on Dollbergen, no spraying is done.

The most commonly used spray materials in Western Germany are, in order of importance: Copper oxychloride (45 percent Cu); copper oxides (35 or 70 percent Cu); and organic fungicides, in particular, zineb. Dr. Scheibe has said that in Lower Saxony about 90 percent of the spraying is with copper materials, and about 10 percent with organic fungicides. Most of the spraying is done at high volume, but the low-volume rate is increasing in popularity. From the results of trials in 1949 and 1950 at centers in different parts of northern and central Germany, Johannes (1953b) concluded that the best low-volume results were obtained by an application of 4 to 6 lb. of 50 percent Cu in 40 gallons of water per acre. Sommer (1951) has given details of the spraying techniques employed in the important seed-growing region around Stade in Lower Saxony. Throughout Germany, spraying against blight is to some extent combined with spraying against the Colorado beetle, but in most years the first two applications against the beetle are given too early for it to be worthwhile to combine them with an antiblight treatment.

Haulm destruction is not practiced on any scale, even in seed crops. Where it is used, the chemicals most commonly employed are D. N. O. C. and D. N. B. P.

Over 80 percent of the West German potato acreage is planted with maincrop or late varieties (table 61), most of which, and notably Ackersegen, show a high degree of field resistance to blight. Schaper (1950) has described the blight susceptibility of most of the commonly grown German varieties. An interesting conclusion that he came to was that there is no correlation between the foliage and the tuber resistance of potato varieties. The same worker at the Max-Planck Institute is engaged on research into the biotypes of the fungus. Western Germany is one of the few countries in the World where named S. demissum x S. tuberosum hybrids, in this case Maritta and Aquila, have become accepted into commercial practice on an appreciable scale, although these two varieties have not retained their original blight resistance. Recent West German work on the resistance of numerous wild Solanum species and on the incorporation of this resistance into commercially acceptable potatoes, has been reviewed by Rudorf, Schaper, Ross, Baerecke, and Torka (1950) and Rudorf (1950).

Much attention has been paid in recent years to the development of weather rules by which to forecast the appearance of blight epidemics.[5] The operation of a blight forecasting service to growers is the responsibility of the individual provincial plant protection offices, and it is unlikely that a centralized system of issuing warnings will be developed. At the present time, the plant protection office at Oldenburg (W. Holz) is the only center in Western Germany issuing regular blight forecasts based on meteorological data, although other offices send out advice on spraying against blight when first reports of the disease in their areas come in. The main centers for research into forecasting methods are at Braunschweig and Bad Kissingen. Johannes (1953a) and Uhlig (1955) have both tested the Beaumont criteria and also the vapor pressure rule of Thran (1952), which was developed in Schleswig-Holstein. They considered that both these methods give insufficiently accurate forecasts under West German conditions, and have formulated more complicated rules based on crop humidity

[5] At an international conference on forecasting (Ullrich, 1957) held at Brunswick in December 1956, Uhlig explained that according to the "field-humidity rules" employed in a trial warning service in 1954-56, a critical period was one in which the relative humidity, measured in screens 2 m. ($6\frac{1}{2}$ ft.) above ground level, was over 88 percent for 15 hours in the absence of rain, and for 12 hours following rain, with minimum night temperatures falling during the period to 12°-16° C. (53°-61° F.) but not below, and the maximum day temperature rising to 20° C. (68° F.) or over, either during the period or within the following 12 hours. The rule was used in conjunction with 3 hourly weather telegrams. The critical periods from a network of stations were plotted on an operations chart to reveal the areas affected; and epidemic spread of blight was not anticipated until three critical periods had occurred.

At the same conference Thran explained that according to the "air-mass and accumulated temperature rule" employed in Schleswig-Holstein, a critical period is one of 2 consecutive days with vapor pressure 12 mm. or more, minimum night temperature 10°-17° C. (50°-63° F.), cloud five-tenths or more, and maximum temperature on at least one of the days reaching 23° C. (73° F.) or more, the readings being taken in screens at 2 m. above ground level. It was found that potatoes were attacked by blight following such a critical period only when certain accumulated temperatures had been reached. Figures for these (which ranged between 600 for chitted first-early varieties and 1,650 for very late varieties) could be obtained approximately by multiplying the number of days from April 1 by the mean day temperatures in $^{\circ}$C. (With long-term mean temperatures for Hamburg, this would indicate early June as a zero date for first earlies and early August for the very late varieties.)

In his very detailed microclimatic investigations, Johannes (1953a) found that a critical period for the spread of the fungus occurred when the relative humidity, measured in the upper third of the crop, exceeded 90 percent for a period of at least 33 hours, with temperatures between 10° and 20° C. (50°-68° F). A fall in humidity to not less than 82 percent for $4\frac{1}{2}$ hours did not break the period; but $2\frac{1}{2}$ hours at a minimum of 72 percent did. Two critical periods were found necessary for epidemic spread. Johannes' critical period refers to conditions in the crop; its relation to conditions in screens has not yet been determined.

TABLE 65.--Blight incidence in relation to weather at Braunschweig, Western Germany, 1952-54

Average and year	Rainfall				Temperature				Blight attack
	June	July	Aug.	Sept.	June	July	Aug.	Sept.	
	In.	In.	In.	In.	°F.	°F.	°F.	°F.	
Long-term average....	2.4	3.3	2.9	2.2	61	64	63	57	--
Difference from average for--									
1952.....	-.2	-2.3	-1.4	+.2	-2	+1	+2	-4	Slight.
1953.....	+.2	-1.1	-1.0	-.7	+2	+1	0	0	Severe.
1954.....	-1.0	+4.5	+1.7	+1.1	0	-5	-1	+1	Late.

periods. One of the main troubles with these new rules, however, is that they are very difficult to apply at the practical level of a large-scale warning service to farmers. Dr. Ullrich is continuing with the work on this problem that was started by Johannes at Braunschweig. The need for blight forecasts varies in the different parts of the country. In the north of Germany (Schleswig-Holstein and the north of Lower Saxony) a routine annual spray program is the general rule, so that there is little need for a blight forecasting service. In mid-Germany, it is usually a problem to know whether to spray or not, and blight forecasts would be most valuable. Blight occurs infrequently in southern Germany, and a service is less necessary.

SUMMARY: WESTERN GERMANY

It is possible to define fairly well the bad blight areas in Western Germany. These lie principally in the north of the country, where air humidities in July and August are highest. But the present system of blight surveying is not sufficiently precise to define epidemics in particular years satisfactorily. It is also very difficult on the basis of present data to estimate blight losses, but there is strong evidence that in recent years these losses have been outbalanced by increased potato yields due to the additional rainfall in the blight years. Chemical methods of control are generally employed in the north, but to a much less extent in southern Germany. Apart from the smaller need to spray in the south, the mechanization of spraying is greatly hindered by the small size and awkward layout of the holdings. Potato varieties showing a high degree of field resistance to blight occupy a large part of the West German potato acreage. The acceptance of Solanum demissum hybrids into commercial practice reflects pioneering German work in the search for blight-resistant potato varieties.

AUSTRIA

The greater part of Austria is mountainous (fig. 48) and includes the eastern extension of the Alps. Arable farming is carried on mainly in the lower land of the east of the country, which is also the driest area (fig. 49). Climatic conditions vary considerably over short distances, according to altitude, but in the east the climate is typically continental. About 400,000 acres of potatoes are grown annually. Acreage figures by province in 1952 (Austria, Statisches Zentralamt, 1953) were:

Province:	1,000 acres
Vienna.....	12.4
Lower Austria.....	198.3
Upper Austria.....	82.3
Burgenland.....	29.9
Styria.....	48.4
Carinthia.....	28.4
Salzburg.....	7.2
Tirol.....	9.6
Vorarlberg.....	3.5
Total.....	420.0

Average yield is about 6 tons per acre (F.A.O., 1955). Human consumption at somewhat over 200 lb. per head each year accounts for less than half the total potato production, and there is a large usage for fodder and the manufacturing industry.

Short notes on the occurrence of blight are included in an annual account of plant diseases and pests given in Pflanzenschutz Berichte. For the year 1951 and those following, a shorthand notation of describing blight epidemics according to their severity and distribution has been adopted (see Schreier, 1957). There is a 1 to 4 scale for severity (1, negligible; 2, medium; 3, severe; 4, very severe) and a 1 to 3 scale for distribution (1, local; 2, fairly extensive; 3, general). Table 66 shows the description by this method of blight epidemics in Austria during the period 1951-56.

Thus, the epidemic in 1956 was severe and fairly extensive. No measure of the epidemics in 1952 and 1954 was given. Dr. Beran, to whom we are indebted for the following notes, has told us that no special blight investigations

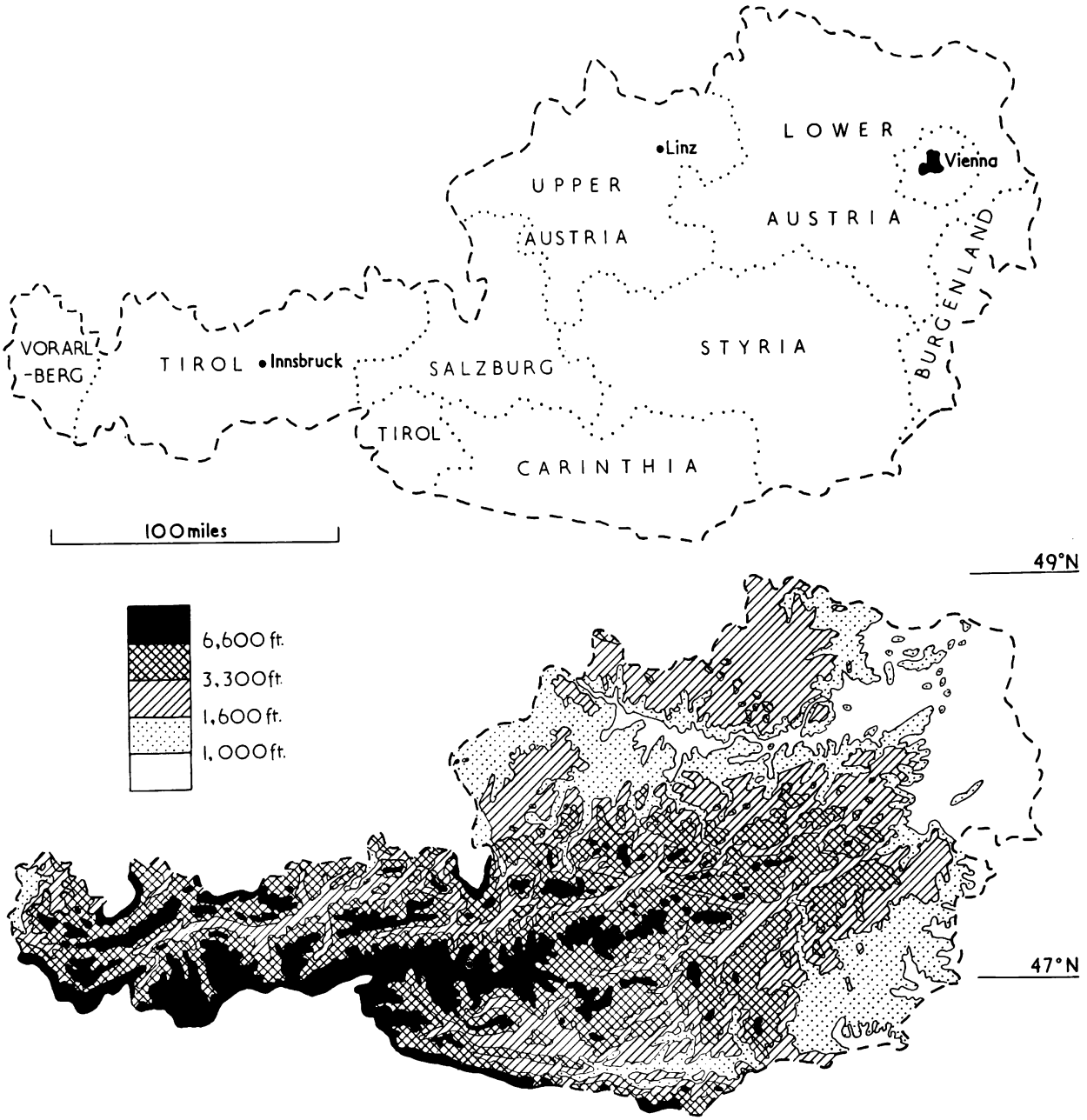


FIGURE 48.--Key map of Austria and altitudes.

are in progress at the present time. The special problems of the disease under alpine conditions have, however, been extensively investigated in the neighboring country of Switzerland, notably by Hänni (1949) and by Aebi (1956), who has employed progress curves and used Beaumont criteria in forecasting.

Blight is of economic importance in the whole of Austria, but in the eastern parts, which are the principal potato-growing areas, it is only serious in years of above-average rainfall. The attack varies greatly, according to variety. Early and midseason varieties are most severely attacked, those commonly grown being Erstling, Sieglinde, Saskia, Oberambacher Frühe, Bintje, and Bona. American varieties introduced after 1946 proved to be very susceptible, and this was one of the main reasons why they quickly went out of cultivation. Under normal weather conditions, loss in yield in the

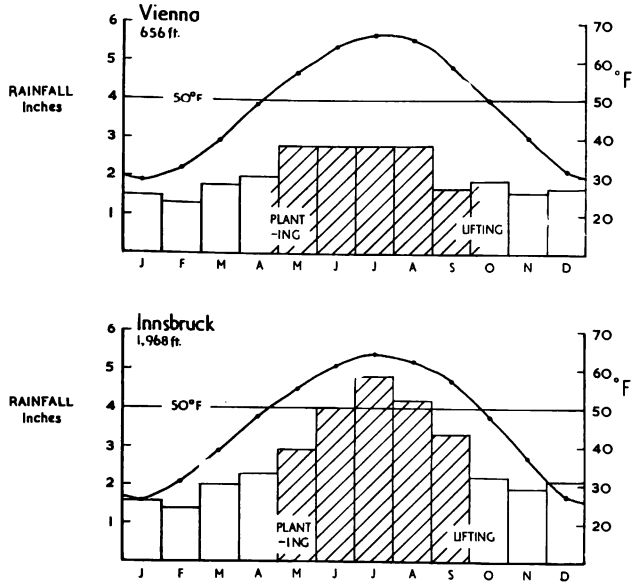


FIGURE 49.--Long-term average monthly rainfall and mean temperatures in relation to potato cropping for two centers in Austria.

blight areas ranges from 5 to 20 percent, according to variety.

The proportion of growers spraying against the disease is greater in the west than the east.

TABLE 66.--Blight incidence in Austria, 1951-56

Year	Blight epidemic[1]
1951	3/3
1952	--
1953	3/3
1954	--
1955	3/3
1956	3/2

[1] First figure indicates severity and second figure distribution of disease. (See p. 107.)

In the west, it has been necessary for some years to spray against the Colorado beetle, and between 10 to 20 percent of the potato area is also sprayed against blight. Spraying against the beetle has only recently become necessary in the east; there, not more than 5 percent of the growers take action against blight. It is principally the earlier varieties and valuable seed crops that are sprayed. Haulm killing is not practiced as a control measure against tuber infection.

POLAND

Although relatively small in total area, Poland comes third among the countries of the world in order of potato production. (The U.S.S.R. comes first, and Germany second.) Nearly 7-1/2 million acres of potatoes were grown each year over the period 1948-52, and these produced a yield of about 5 tons per acre (F.A.O., 1955). Potatoes are grown throughout the country; they form a major item of human diet and are also grown extensively for industrial purposes and animal fodder.

About 70 percent of the potato area is planted with varieties showing a high degree of field resistance to blight. Examples of these are Ackersegen, which occupies about half of the total potato acreage, Wohltmann, Switez Dolkowski, Silesia, and Lenino. About 10 percent of the area is made up of varieties that are highly susceptible to blight, such as Early Rose, Alma, and Flava, but these are principally early or midseason varieties and so normally escape the worst effects of blight epidemics. The remaining 20 percent of the potato acreage is occupied by varieties showing an intermediate degree of resistance, e.g., Mittelfrühe. The potato-growing season is generally from early May to the end of September.

The climate of Poland is predominantly continental in type, though the maritime influence of the Baltic Sea is felt in the north of the country. Average annual rainfall throughout Poland is relatively low; at Warsaw, it is 22.3 inches, but there is a marked summer rainfall peak, and the wettest months of the year are July and August. The mean temperature at Warsaw in July, the hottest month, is 65 °F. (fig. 50). According to an analysis of survey data on blight incidence dating back to 1926, sent to us by H. Dubniak of the Polish Ministry of Agriculture, the areas of Poland where blight attacks are most frequent and severe are those where the average August rainfall is 80 mm. (3.2 inches) or over. These "blight" areas can be divided into three main regions: (1) A mountainous region in the south of the country; (2) the center of Poland, where blight occurs along the river valleys; and (3) the northern region, which is subdivided into an eastern and western zone. The map (fig. 51) shows the approximate boundaries of these different regions. The losses caused by blight vary in the three regions. The greatest losses occur in the north, where blight attacks are earliest and most frequent; in the southern mountainous region, the attacks are generally late.

During recent years, the worst attacks have been in 1930, 1931, 1934, 1942, 1949, 1952, and 1954. This gives a frequency of "severe" blight years of about 1 year in 4. In such years, the disease is present throughout the whole country. From the point of view of blight epidemics, 1955 was an exceptional year, owing to an abnormal distribution of rainfall. In that year, the attack was relatively slight in the north, but severe damage was caused

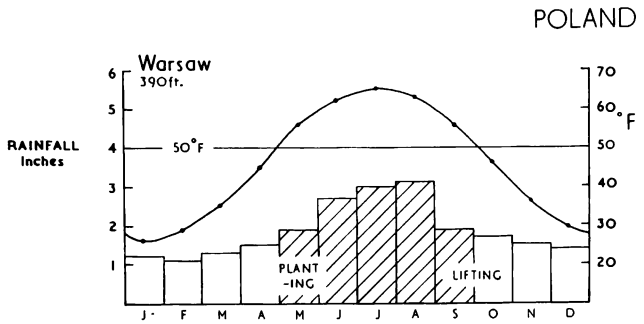


FIGURE 50.--Long-term average monthly rainfall and mean temperatures in relation to potato cropping for Warsaw, Poland.

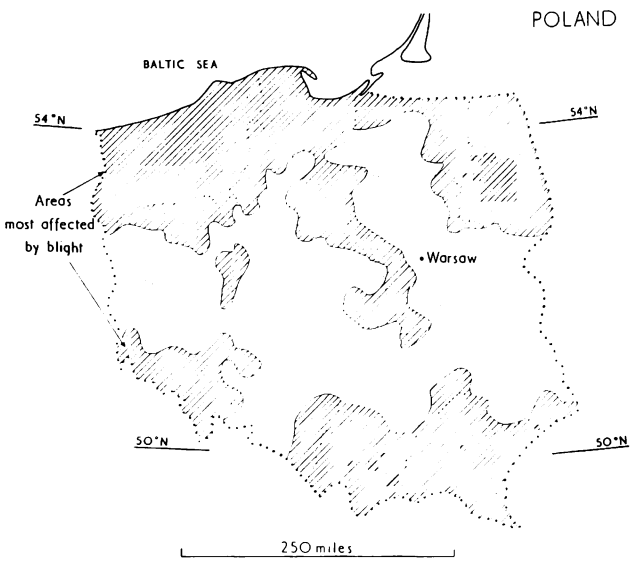


FIGURE 51.--Blight areas of Poland, according to survey data for 1926-55.

through the center of the country, in areas where it normally has little effect. Figure 52 shows the zoning for blight damage in 1955. The damage was measured by the amount of defoliation caused by blight on the variety Ackersegen toward the end of the growing season (the exact time is not specified). It is of particular interest that the survey information is available to enable the Polish Ministry of Agriculture to produce a map of the type shown for 1955, which can form the basic material for the assessment of countrywide blight losses.

The normal time for the development of epidemics is during the second half of August. Widespread attacks of the disease earlier or later than this are out of the ordinary. A very rough comparison of the amount of defoliation caused by the disease on Ackersegen in a "blight" year (1954) and in a year when the disease was slight (1956) can be made from figures provided by H. Dubniak. These are shown in table 67.

In 1954, the 50 percent blight defoliation stage was reached in general at the end of August. The normal time of maturity for this

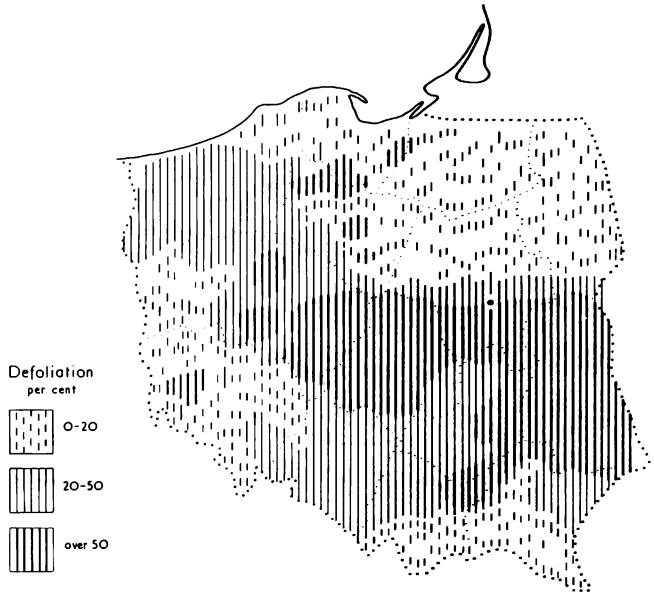


FIGURE 52.--Extent of defoliation by blight at end of growing period on Ackersegen, Poland, 1955.

TABLE 67.--Defoliation of Ackersegen at end of August, 1954 and 1956, Poland

Percentage of defoliation by blight at end of August	Ackersegen crop	
	1954	1956
	Percent	Percent
None.....	--	78.6
0-10.....	--	15.6
10-40.....	--	5.8
50.....	100	--

variety is around the end of September, so that approximately 3 to 4 weeks growth will have been lost. On the other hand, in 1956, over three-quarters of all Ackersegen potatoes were still unaffected by blight at the end of August. The relationship between premature defoliation and loss of crop yield has not yet been worked out, but it has been estimated that in "blight" years, crop loss from this cause falls between the limits of 10 to 30 percent. Dubniak points out the difficulty of using average potato growth figures to estimate blight losses in particular years. Thus, in 1955, when planting was late because of a cold wet spring, losses due to blight would tend to be overestimated. Blight seldom causes widespread or heavy losses in Poland due to tuber infection.

Research on Phytophthora infestans is carried out at the Laboratory of the Institute of Cultivation and Acclimatisation of Plants at Gdansk Wrzeszcz. This includes work on the biology of infection, the aggressiveness of particular biotypes, the length of the incubation period, and the relation of time of infection by the fungus to the chemical composition of potato leaves. Breeding of new potato varieties resistant to blight is also in progress at this Institute.

With an area of over 8-1/2 million square miles, the Soviet Union is the largest connected land mass under one central government in the world. The estimated population in 1954 was about 215 million (F.A.O., 1956). Potatoes are one of the country's principal crops and over the period 1948-50, 31 percent of the total world production of potatoes was in the U.S.S.R. This compares to 5 percent of the total world production in the U.S.A.

Apart from ware and animal feed, potatoes are grown extensively as an industrial crop, particularly for the manufacture of alcohol, much of which is used in the synthetic rubber industry. Figures relating to human consumption of potatoes are not published, but the crop forms a large part of the diet. From 1934 to 1938, the average area under potatoes was about 7 million hectares (17-1/2 million acres) with an annual average production of about 74 million tons. This means that the average yield of potatoes was around 4 tons per acre and it has continued to remain at about this figure. The potato-growing area has been considerably enlarged since the Second World War, owing to the incorporation of the Baltic Republics into the Soviet Union, and also the eastward and northward extension of potato growing. Under the fifth Five-Year Plan, the potato area was to reach 10 million hectares by 1955 (Oxford Economic Atlas, 1956).

DISTRIBUTION OF POTATO-GROWING AND CLIMATIC CONDITIONS

The principal potato-growing areas are in European Russia, west of the Urals. Large acreages are grown in the Baltic Republics, White Russia (Belorussia), and the Moscow Province. The northern Ukraine is an important potato region. Roughly speaking, the 70°F. isotherm for July (fig. 53), which divides the Ukraine and continues in a northeasterly direction across European Russia, marks the southern limit of intensive potato production. In the north, latitude 60° N., which passes through Leningrad, fixes the approximate northern limit of intensive potato culture, although small quantities of potatoes are grown above this, even as far north as the Arctic Circle (fig. 54).

East of the Urals, the most important potato areas are in western Siberia, and a scattered acreage of the crop is grown through the Siberian Plain, and eastwards as far as the vicinity of Lake Baykal. Relatively small acreages of the crop are grown in the far east of the Soviet Union, with some potatoes in the area north of Vladivostock, and in the island of Sakhalin.

Rainfall is generally low in Russia. In few parts of the country does it exceed 25 inches per annum, and over vast areas it is below 10

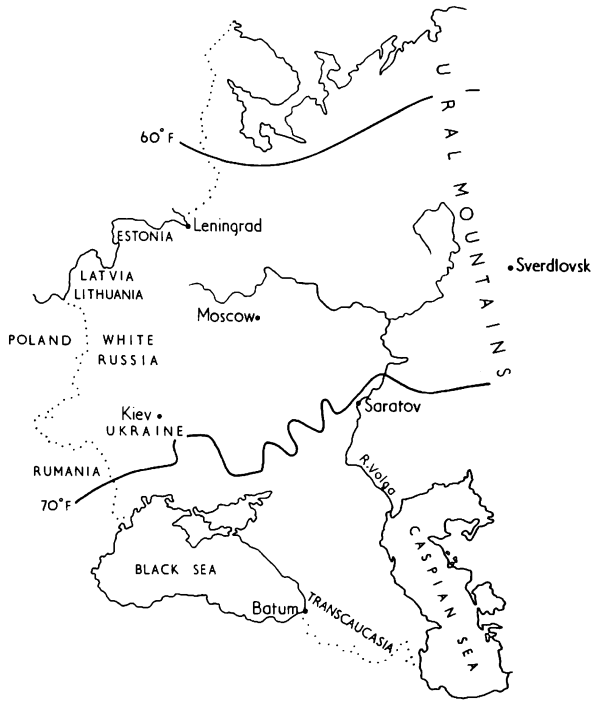


FIGURE 53.--Key map for European Russia, showing July isotherms.

inches. The wettest parts of the country are in Transcaucasia, adjoining the eastern seaboard of the Black Sea (at Batum, average rainfall is 93 inches per annum), and parts of far eastern Russia, where areas are influenced by the summer monsoon winds. Over most of the country winters are severe and the length of the winter in the more northerly areas sets a limit to successful potato cultivation.

In the main potato-growing areas of European Russia, annual rainfall is between 18 to 25 inches per annum. At the upper limits, rainfall is generally adequate, as there is a marked summer rainfall peak and the months of maximum rainfall are July and August. This is shown in the climagrams for Leningrad and Moscow (fig. 55). Long droughts however, do occur. At the lower rainfall limits, the crop may frequently suffer from drought. The lower rainfall areas are toward the south and have higher summer temperatures, so that the rate of evaporation of soil water is increased. Russell (1942) says "In the black soil region (of the Ukraine) potatoes are grown on the flat, not on ridges; this would cause too much loss of water by evaporation, and also loss of soil by wind erosion." Despite the trend for rainfall to decrease and temperature to increase in a southerly direction, there is a remarkable general uniformity in the weather conditions of European Russia, due to the topography, which is that of a great undulating plain with no mountains except at the edges.

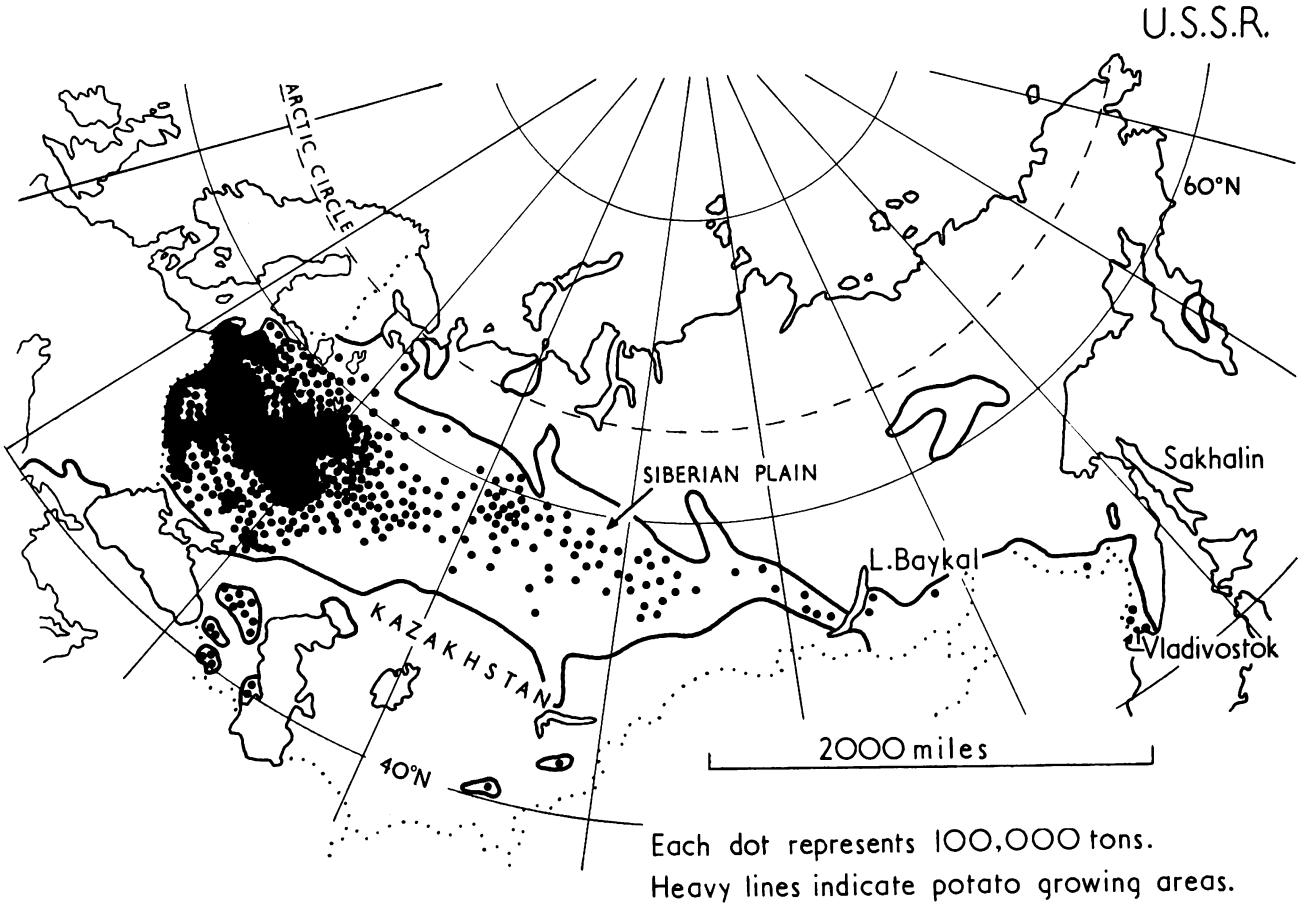


FIGURE 54.--Potato production in the U. S. S. R. Data are based on the Oxford Regional Economic Atlas: U.S.S.R. and Eastern Europe, 1956. (By special permission, Oxford University Press.)

Lorkh (1945) has given data for the length of the potato-growing season (May to September) in the Moscow Province, over the 8-year period, 1934-41. This averaged 147 days from the time of planting till the first killing frost in the autumn, with a range in time of 126 to 176 days. Thus, there is normally ample time for the maximum crop of potatoes to be formed. In areas north of Moscow, the decreasing length of the growing season begins to be a limiting factor to potato yields. Outside European Russia, the generally low rainfall and the usually short growing season for potatoes are unfavorable to the crop. In all regions, potatoes are grown for early summer, autumn, and winter use. In the main regions of cultivation, they are used for ware, animal feed, and industrial purposes; in the remaining areas, they are used mainly for ware. Seed potatoes are grown in all potato-producing regions.

POTATO VARIETIES, SOIL CONDITIONS, AND CULTIVATIONS

Both Russian and foreign potato varieties are grown. Common early varieties are Epron, Epicure, and Early Rose. Berlichingen is a widely grown midseason potato, and Lorkh is one of the most important maincrop (or medium-late) varieties; Wohltmann (late) is grown for industrial use and animal fodder. While the early varieties are normally highly susceptible to blight, the late varieties generally show a fair degree of field resistance. A number of Solanum demissum hybrids have been put on the market. These include Kameraz, Hybrid 42, and Phytophthora-Resistant. Details of the principal potato varieties grown in the U.S.S.R. have been given by Zaitsev (1950 and 1953). Most of the potatoes in the more northerly parts of European Russia are grown on sandy soils, while in the Ukraine, they are grown on black organic soils. A feature of Russian farming is the large amount of hand labor that is still employed, and this applies to potato growing, including planting and lifting. A recent development has been the planting of potato crops on the square, with from 24 to 28 inches between rows and plants. Before this, most of the crop was grown in 24 inch ridges, with approximately 18 inches between plants.

DISTRIBUTION, FREQUENCY, AND TIMING OF BLIGHT EPIDEMICS

Potato blight is most damaging in those parts of European Russia where conditions are most favorable to potato growing, i.e., in the

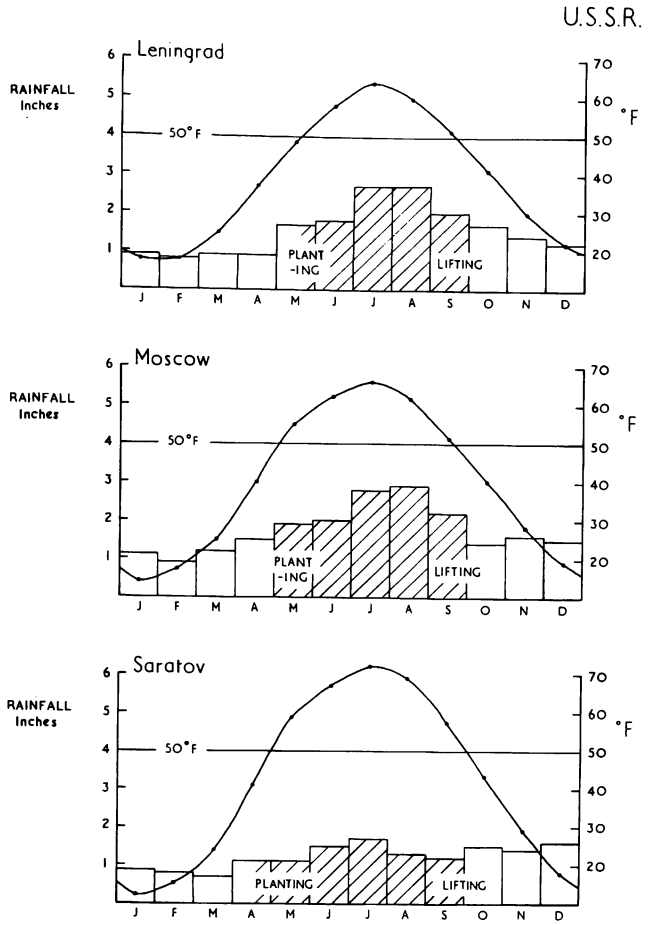


FIGURE 55.--Long-term average monthly rainfall and mean temperatures in relation to potato cropping for three centers in the U. S. S. R.

Baltic Republics, White Russia, the Moscow and Leningrad Provinces. In a southerly and easterly direction from this region, the importance of the disease diminishes, although outbreaks continue to occur as far east as western Siberia. In the southern parts of the U.S.S.R., attacks are infrequent, and in the Central Asian republics and southern Kazakhstan they do not occur at all. In some of the potato-growing areas in the far east of the Soviet Union, as on the Island of Sakahlin, blight occurs regularly every year.

Some idea of the frequency of severe blight years in the Moscow Province can be obtained from data given by the Research Institute of Potato Growing (Kartofelnoe Khozyaistvo, 1946) for the 17-year period 1918-34, during which time there were 7 "blight" years. This is a frequency of 1 in 2-1/2 years. In this area, blight appears about the end of July to early August in "severe" years, but information on the subsequent development of epidemics is lacking. Table 68 sets out data on the incidence of blight in the Leningrad Province during the 10 years 1946-55. This and much other information for the U.S.S.R. has been provided by I. Polykov of the All-Union Research Institute of Plant Protection at Leningrad.

TABLE 68.--Incidence of blight in the Leningrad Province, 1946-55

Severe	Slight	Negligible
1946[1]	1950	1947
1948[2]	1955	1951
1949[2]	--	1952
1953[1]	--	--
1954[2]	--	--

[1] First appearance of disease: Early August.
[2] First appearance of disease: End of July.

In the severe blight years (1 year out of 2) in the Leningrad area, the disease normally appears at the end of July or early August, although it may sometimes occur earlier than this. Dr. Polykov mentions that in 1954 (a severe blight year), early varieties were completely defoliated by the disease at the end of August, and midseason varieties were dead by the middle of September. This is unlikely to have resulted in a large loss of yield through premature defoliation, as the times mentioned coincide fairly closely with the normal ripening times of the two classes of potato in the area. But there is evidence that destruction of the potato haulms by blight does occur earlier than this. Kameraz (1954) has stated that in 1953, on many farms in the Leningrad Province the tops of maincrop as well as early varieties had been destroyed by mid-August. This will have resulted in about 4 to 6 weeks' loss of growth in maincrops with a consequent heavy fall in crop yield. Data on the progress of blight, other than in 1953 and 1954, are not available.

BLIGHT LOSSES

Rozhestvenski (1934) estimated the average annual loss of potatoes in the Soviet Union as 10 percent of the crop, due to attack by blight. This figure included losses from premature defoliation, together with tuber blight losses. The same worker also gave estimates of the variation in losses from blight between different potato-growing regions, and his map, setting out these variations, is reproduced here as figure 56. Although Rozhestvenski's estimates should be treated with reserve, as they were not based on systematic survey information, the estimated varying losses between regions appear to reflect, with reasonable accuracy, the differing importance of blight in the main potato-growing areas of Russia. Thus the disease is most damaging in the regions immediately south and southeast of Leningrad. The Baltic Republics were not then part of the Soviet Union, so are not zoned on the map.

It is not possible to state with any accuracy the relative importance of premature defoliation and tuber blight losses, although Dr. Polykov has told us that, for the Soviet Union

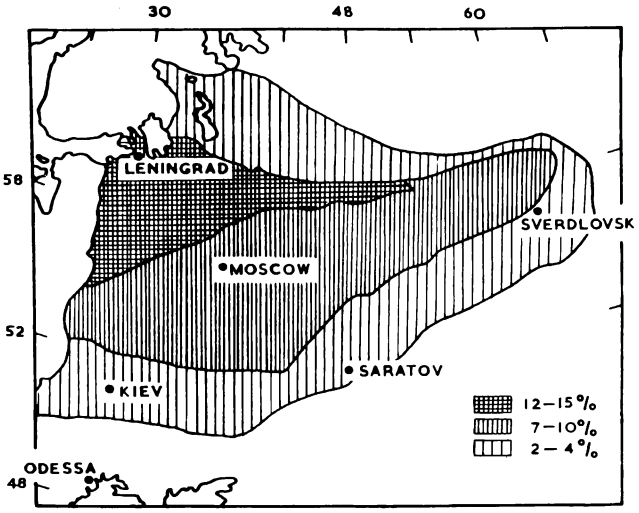


FIGURE 56.--Average annual losses from potato blight in U.S.S.R. (After Rozhestvenski, 1934.)

as a whole, the two problems are of about equal importance. That heavy losses brought about by early defoliation of the potato plants do occur has been shown for the Leningrad Province in 1953, but how frequently this happens is not known. The available literature also gives little help in deciding to what extent tuber infection with blight prior to lifting is a a problem; but the indications are that infection at lifting is a more serious source of loss. In most of the potato-growing regions of the U.S.S.R the harvest period is short. Over large areas, e.g., Leningrad region and western Siberia, the short harvest period will be combined with a relatively short growing period, so that in many years there will be a considerable likelihood of tuber blight infection occurring at harvesttime, unless steps are taken to deal with blighted haulms.

BLIGHT AND WEATHER DATA

The climagrams for Leningrad, Moscow, and Saratov (fig. 55) should be considered in relation to figure 56. The general similarity in the weather conditions of the several areas of European Russia is brought out by the three climagrams. Summer temperatures increase from north to south; in the south low summer rainfall and a high rate of evaporation often limit potato yields, and the crop very frequently suffers from drought. Even in the higher rainfall potato regions of European Russia, drought is a problem in some years, and the average rainfall figures conceal a considerable variation in rainfall from year to year.

It has been estimated that losses from blight are highest in the Leningrad region. This does not have the highest summer rainfall, but summer humidity conditions are higher there than in the Moscow region, and summer temperatures are lower. Also, tuber blight infection at harvesttime is a greater potential threat in the Leningrad region than in areas farther south, owing to the shorter growing period for potatoes. Although the long-term average temperature and rainfall figures for Moscow might lead to the supposition that blight attacks are unlikely to be serious very often in this area, such an interpretation is too superficial. Apart from other considerations, it ignores the variation in rainfall from year to year, which is illustrated by figures for the Moscow province during 1935 and 1938, shown in table 69. These data have been given by Lorkh (1945).

The survey information is not available to link the progress of blight epidemics in particular years with weather conditions in the Moscow Province. However, it seems likely from the rainfall figures alone, that in 1935 early defoliation by blight in the area will have caused heavy yield losses; whereas in 1938, the potatoes will have suffered severely from drought. How frequently a year like 1935 occurs is not known. In the potato-growing regions to the south of Moscow, represented by the climagram for Saratov, blight losses are estimated as being relatively small. Apart from the low rainfall of these regions, mean summer temperatures are high, with a large diurnal range, and the long growing season minimizes the risk of tuber infection at harvest. In general it would appear that, throughout European Russia, the problem of drought to the potato grower is very much greater than the problem of blight.

CONTROL MEASURES

It is characteristic of the Russian approach to agricultural problems that in the control of blight strong emphasis is placed on the sprouting of seed tubers before planting. A main aim

TABLE 69.--Average rainfall for Moscow Province, 1935 and 1938

Year and average	July	August	September	Total
	Inches	Inches	Inches	Inches
1935	5.6	3.9	4.8	14.3
1938	.6	.3	1.0	1.9
Long-term average	2.8	2.9	2.2	7.9

behind this is to speed up the growth cycle of the potato crop so as to avoid or minimize the effects of blight attacks. The process is usually referred to as "vernalization," and normally requires the provision of heated and lighted buildings. This is a major obstacle to the widespread adoption of vernalization, particularly when regarded in relation to the severe Russian winter. Arnautov and Novikov (1946) have described a method of sprouting potatoes in open trenches, which has been successfully employed at the Research Institute for Potato Growing at Korenevo in the Moscow Province. The potatoes were placed in the trenches during the second half of April. At night and during daytime frosts, the potatoes were covered with straw or mats. Whether this method is at all widespread in commercial practice is not known. It obviously requires a large amount of hand labor, but this is not likely to be a limiting factor to its adoption in the U.S.S.R. at present. The advantages of drying tubers immediately after harvest as a prophylactic measure in the control of blight has been discussed by Bordukova (1947). She places considerable emphasis on the large quantities of potatoes that could be saved by adopting this measure, and this suggested practice indicates that a good deal of tuber infection must occur at lifting. The development of chemical or mechanical methods of haulm destruction might be a valuable alternative approach to the problem. At the present time the chief method is hand cutting.

According to Dr. Polykov, spraying and dusting against blight as protective measures are not widely practiced in the U.S.S.R. The potato crops most commonly sprayed are early and midseason varieties grown for seed. Bordeaux mixture is mainly used, although some copper oxychloride is used. Dusting is done with "AB," a powder containing chalk, gypsum, and approximately 36 percent copper carbonate.

The Russians were the pioneers in sending expeditions to Central America and South America to collect potato species possessing disease resistance and other valuable economic properties for use in their breeding work. The principle applied in this case was the geographical method of N. I. Vavilov, then director of the Institute of Plant Industry at Leningrad. This method is based on the fact that the number, range, and variety of forms of a particular plant increase toward the locality in which it has originated. Between 1925 to 1932, Vavilov, Bukasov (1933), and Juzepczuk made extensive collections of wild Solanum species and, as early as 1931, the variety, Phytophthora-Resistant, a Solanum demissum hybrid that is still being grown, had been produced. In their breeding for blight resistance, the Russian workers up to the present time have relied mainly on S. demissum x S. tuberosum hybrids. To what extent they are still hopeful of tackling blight control through breeding is not clear. A recent account of potato breeding, including blight resistance work in the U.S.S.R., has been given by Hawkes (1957).

Little is known of methods used in the U.S.S.R. for the forecasting of blight and the issue of blight warnings to growers. Reference, however, should be made to a paper by Naumova (1935), in which the author states that field observations and controlled experiments carried out during 1933 and 1934 in the Leningrad area confirmed the rules of Van Everdingen (1926) relating to the appearance of blight epidemics. Further experiments were conducted by Naumova to ascertain the effect of temperature on the incubation period of the blight fungus. These experiments took into account diurnal variation of temperature. The results were used to construct a nomogram from which the incubation period could be obtained for various minimum, mean, and maximum temperatures during the days following infection.

SUMMARY: U.S.S.R.

Potato blight is most serious in those parts of European Russia where summer rainfall is highest. Even in these areas, however, drought is a more serious actual and potential menace to the potato crop. There is an almost complete lack of evidence on which to base reliable loss estimates, but the shortness of the growing season for potatoes in some areas has made tuber infection a serious problem. In control, emphasis has been on an "escape" method (vernalization) as opposed to chemical methods. The use of chemicals is largely confined to the valuable seed crop. The Russians were the first to realize the potentialities of wild Solanum species in breeding for blight resistance.

CYPRUS

Potato growing in Cyprus exemplifies conditions under a Mediterranean climate. This is characterized by a summer drought period with high temperatures. The pattern of potato growing in the countries bordering the northern, southern, and eastern shores of the Mediterranean, which include Greece, Israel, Egypt, Morocco, parts of Spain, and southern Italy, is a very similar one. Two crops of potatoes are grown in the year, both under irrigation. The first crop is grown during the spring and early summer months; the second during the late summer, autumn, and winter. The period during the middle of the summer is unsuitable for

potatoes owing to the high temperatures, and in most of the countries, particularly in the north of the area, there is a period in the winter when conditions are too cold for potatoes.

Cyprus is the third largest island in the Mediterranean Sea and has an area of 3,572 square miles (fig. 57). About 13,000 acres of potatoes are grown each year, and the greater part of this crop (about 60 percent) is exported,

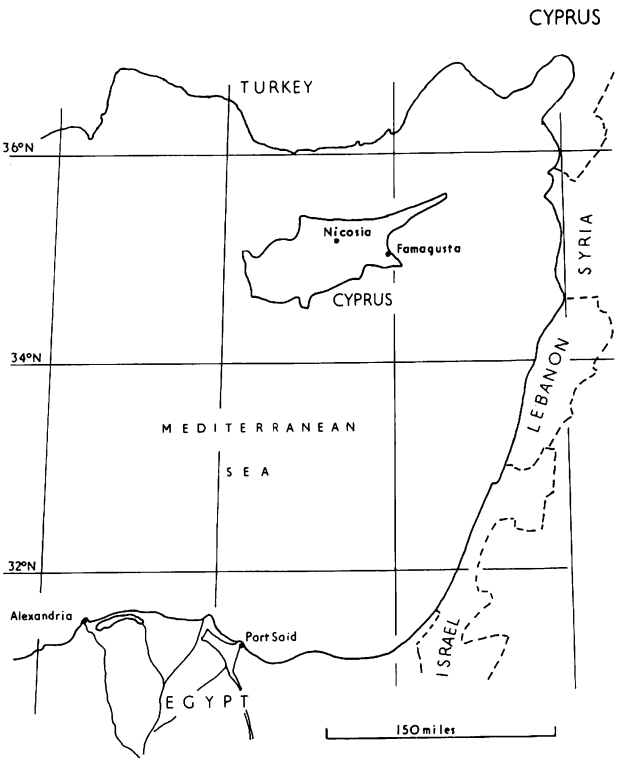


FIGURE 57.--Cyprus, in relation to eastern Mediterranean.

principally to the United Kingdom. The average yield per acre is approximately 4 tons (F.A.O., 1955). The most important potato-growing areas are in the plains (up to 750 ft.) in the Famagusta and Nicosia districts, where there is a light red soil (terra rossa). Figure 58 shows the two cropping periods during the year, and these are of about equal importance. The first crop is planted in February and lifted principally in May and June; this is the spring or summer crop. The second--the winter crop--is planted in August and matures about the end of November. Larger yields are generally obtained from the spring crop, as more irrigation water is available at this time. About 50 percent of the spring crop is planted with certified Irish seed, whereas the winter crop is planted with once-grown seed from the spring crop of the same year. Dormancy troubles do not appear to arise at this time, no doubt due to the high tempera-

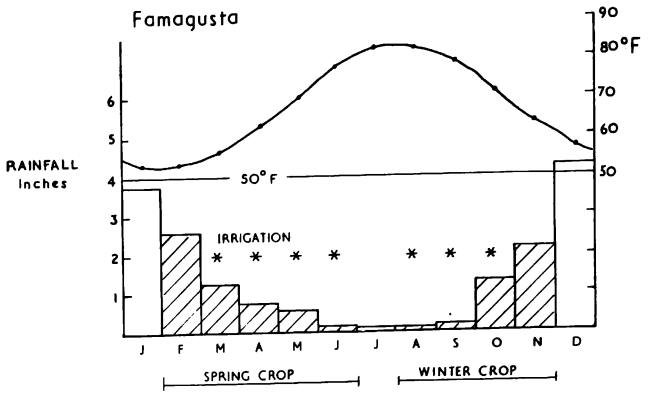


FIGURE 58.--Long-term average monthly rainfall and mean temperatures in relation to potato cropping at Famagusta, Cyprus.

tures. Only two potato varieties are grown commercially: Up-to-Date and Arran Banner, of which Up-to-Date is the more important. Both these varieties are very susceptible to blight. Accounts of potato growing in the island are available (Cyprus, Department of Agriculture, 1939; and Littlejohn, 1947). A feature of farming in Cyprus is the small size and fragmentation of the holdings. According to Allan (1956), the 1946 census of the island showed that the average farm consisted of 13 plots of an average size of 1.4 acres. These plots are often widely scattered and are commonly many miles apart. This is a great hindrance to improved farming methods, including blight control measures.

IMPORTANCE OF POTATO BLIGHT

Nattrass (1937) records that blight was first found in Cyprus on a potato crop near Famagusta in April 1931. The disease was believed to have been introduced in Irish seed. G. P. Georghiou has informed us that blight appears more frequently and is usually more severe in the main potato-growing areas in the southeast of the island. He says that it is worse on the spring crop of potatoes. Over the 7-year period 1950-56, blight was recorded as "severe" on the spring crops in 1952, 1955, and 1956, and on the winter crop in 1951. Heavy yield losses sometimes occur in the spring crop, which may be reduced by up to 25 percent. In blight years the disease usually appears when the plants are about 8 inches high, and there may be 75 to 90 percent defoliation about 1 month before the normal lifting time. Tuber infection is not much of a problem and is believed to occur mainly at lifting. An analysis of recent severe blight years in relation to average annual potato yields in Cyprus appears to show up a connection between low yields and blight years (table 70). Without further analysis, however, any such relationship should be

TABLE 70.--Average yield and blight occurrence in Cyprus, 1950-56

Year	Average yield	Blight
	Tons/acre	
1950.....	4.1	--
1951.....	3.6	Severe, winter.
1952.....	3.5	Severe, spring.
1953.....	5.4	--
1954.....	5.4	--
1955.....	4.3	Severe, spring.
1956.....	3.7	Severe, spring.

viewed with extreme caution. Both potato crops in Cyprus are grown under irrigation, and the amount of irrigation water available is likely to have a far greater effect on yield than the presence or absence of blight. In addition, time of lifting has a pronounced effect on yield, and in Cyprus this is very much under the influence of a varying export demand for potatoes.

A study of the long-term average weather data in relation to the growing periods of the two potato crops at Famagusta (fig. 58) explains the greater importance of blight in the spring crop. Temperature appears to be an important controlling factor. In the spring crop, temperatures are favorable to the disease until about the end of April; after this, conditions begin to get too hot. Thus premature defoliation is the main problem, with tuber infection of little importance. In the winter crop, temperatures are generally too high for blight until the last month of growth (November). Chambers (1952) records that in 1951 an attack of late blight occurred at the end of the autumn growing season and caused tuber infections, which resulted in severe losses.

No work has been done on the humidity conditions associated with blight attacks on the spring crop. There is no evidence that the channel-type irrigation practiced has any effect on blight. Table 71 shows blight incidence in relation to spring rainfall at Famagusta during 1950-55. The figures have been obtained from the island's Annual Reports, which unfortunately do not include temperature data.

In 1952 and 1955, the blight years, March rainfall was about twice the average for that month, but in 1950, when blight was of little or no importance, March rainfall was even higher. The high rainfall in April 1953 did not lead to severe blight. On the basis of table 71, there does not appear to be any very close connection between total rainfall during the spring and blight attacks for this important potato growing center in Cyprus.

TABLE 71.--Monthly spring rainfall and occurrence of blight at Famagusta, Cyprus, 1950-55

Year	Rainfall				Blight
	January	February	March	April	
	In.	In.	In.	In.	
1950.....	2.4	0.3	3.0	0.5	--
1951.....	3.7	3.2	.4	1.9	--
1952.....	4.4	3.1	2.7	.2	Severe.
1953.....	1.8	1.6	1.8	3.3	--
1954.....	1.3	2.2	1.3	1.0	--
1955.....	.7	.2	2.7	.3	Severe.
Long-term average.....	3.8	2.6	1.3	.8	--

G. P. Georghiou has told us that control measures against blight are rather limited. Copper and dithane fungicides are used, but only by about 5 percent of the commercial growers. Applications are made by knapsack sprayers. In the spring potato crop, control appears to resolve itself mainly into protecting the crop over a relatively limited period, after which temperature conditions are likely to become unfavorable to the fungus. The problem in the winter crop seems to be tuber infection at lifting, which could be prevented by removal of the potato haulms before harvest. The growing of varieties showing a high degree of field resistance instead of the blight-susceptible Up-to-Date and Arran Banner might go a long way toward control. However, finding the right variety is not easy. Commenting on the performance of Majestic (the principal maincrop variety in England and Wales) in variety trials held in Cyprus, Littlejohn (1947) says, "Majestic, which gave consistently high yields, always developed a serious fault in that the tubers cracked badly and tended to deteriorate very rapidly in storage."

NORTH AMERICA

UNITED STATES OF AMERICA

The potato acreage in the United States was just short of $1\frac{1}{2}$ million acres in 1953. This is less than half the area that was grown in 1930. Although there has been this marked decline in the acreage, total potato production has remained at about the same level, owing to increased efficiency in cultural practices. Production has not kept pace with increasing population, and a marked feature of the American potato industry is the falling demand for potatoes in competition with other vegetables.

At the present time the total production of potatoes is between 350 to 400 million bushels (approximately 10 million tons) per annum, and consumption is around 345 million bushels. Demand for potatoes is relatively inelastic, and almost all the crop is sold for human consumption. According to Smith (1956), the annual consumption of potatoes per head in the United States is about 104 lb.

The average yield for the whole country over the period 1942-51 is given as 190 bushels (5.1 tons) per acre. (1 U. S. bushel of potatoes weighs approximately 60 lb.). There are considerable differences between the average yields for the different States; the highest being around 360 bushels (10 tons) per acre in Maine (United States Department of Agriculture, 1954).

POTATO DISTRIBUTION

Figure 59 shows the distribution of potato growing in the United States. A relatively few States produce the bulk of the crop, and of these, the most important, in order, are Maine, Idaho, California, and New York. The greater part of the early crop comes from the Southern States and California. Some certified seed potatoes are produced in over half the States, but the chief seed-growing States are Maine, North Dakota, and Minnesota. Maine is by far the most important of these; half the total U. S. seed production comes from this State alone. The acreages of potatoes grown in some of the leading States in 1953 are shown in table 72.

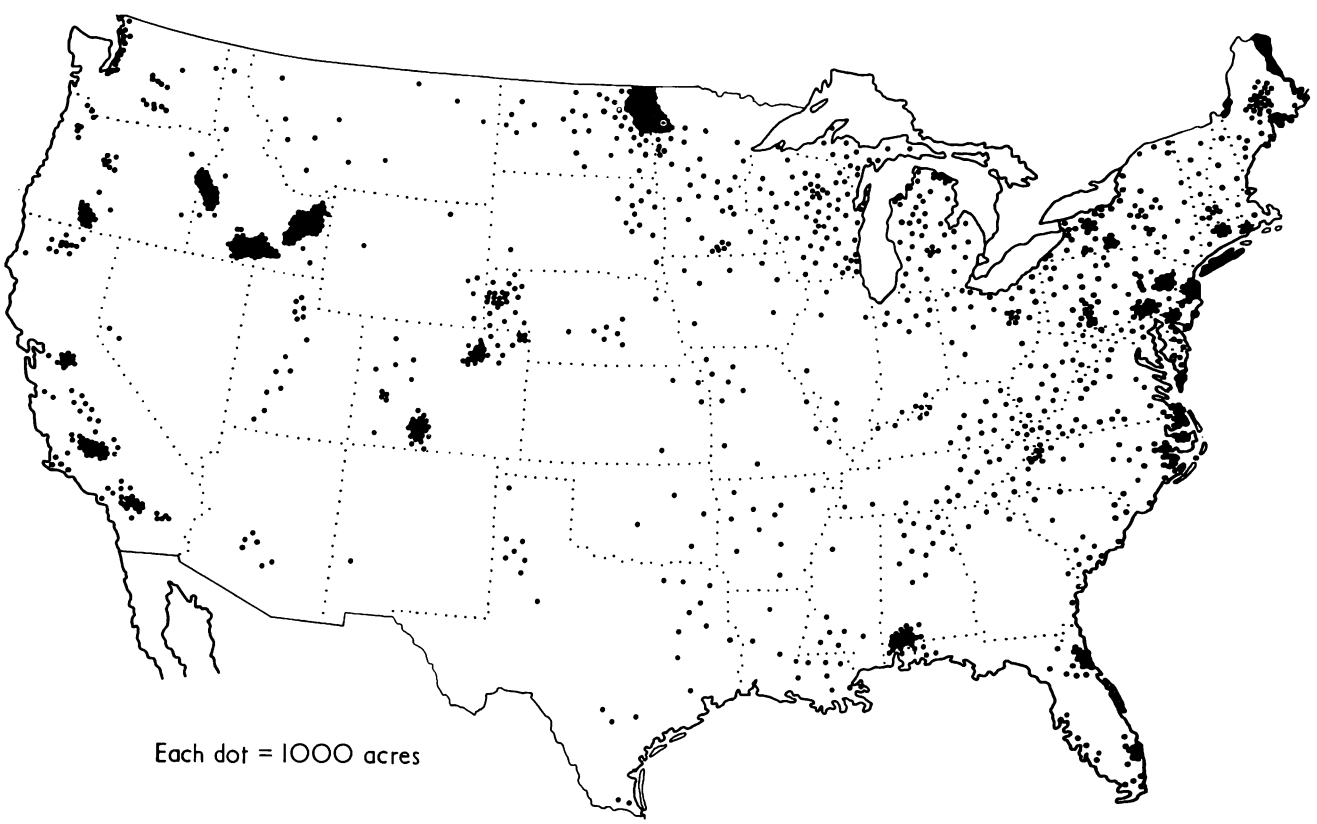


FIGURE 59.--Distribution of potato growing in the U. S. A., 1953. (Based on Neg. U. S. D. A. 46360 and U. S. D.A. Agricultural Statistics, 1954.)

TABLE 72.--Acreages of potatoes in leading States, U.S.A., 1953

State	Potatoes
	1,000 acres
Maine	156
Idaho	153
California	124
New York	106
North Dakota	94
Minnesota	78
Pennsylvania	62
Wisconsin	61
Michigan	58
Colorado	54
North Carolina	46
Florida	42

Despite the very large area over which potatoes are grown, production within States tends to be concentrated in relatively small growing centers. Examples of these are the eastern part of Aroostook County, Maine; Long Island in New York State; the Red River Valley in parts of Minnesota and North Dakota; and Kern County, Calif.

POTATO VARIETIES

American potato varieties are usually classified as early or late. The early varieties, such as Irish Cobbler, correspond to the long-day types of temperate regions; the late varieties are day-neutral or short-day types. Stevenson (1949) stated that 13 varieties (7 old and 6 new) constitute about 96 percent of the total U. S. potato acreage. These varieties are shown in table 73.

Since 1949, there has been a decline in the popularity of some of the older varieties, notably in Green Mountain. The acreage of Red Pontiac has increased, and Kennebec, a late, blight-resistant variety, has become considerably more important.

Some varieties are grown in relatively restricted areas. An example of this is Red McClure, which is grown principally in the San Luis Valley of Colorado. Again, there may be a preference for white-skinned or red-skinned varieties. Thus, in Maine, where white-skinned varieties are favored, the acreage is made up largely of Katahdin; but in North Dakota the predominant varieties are the red-skinned Red Pontiac and Triumph. A full description of American potato varieties has been given by Clark and Lombard (1951).

SOIL AND CLIMATE

Potatoes are grown principally on mineral soils and to some extent on muck soils (reclaimed peats) and other organic soils, such as the prairie soils in the Red River Valley. Climatic conditions vary considerably in the different growing areas. In the South the winters are relatively mild. In Florida, for example, the main planting of potatoes takes place in December and January. These crops are lifted by the end of May; during the height of the summer, temperatures are too high for potato growing. Moving northward up the eastern side of the United States, winters become progressively more severe and planting of the potato crop correspondingly later. In the Northeastern States, average winter temperatures are well below freezing, and planting cannot take place before the middle of May. Summer temperatures are relatively low and rainfall is high, providing ideal growing conditions for potatoes, but the growing season is short, as frosts start to occur from about the middle of September onward. In the North Central States, winters are severe, and the growing season is about the same length as in the Northeastern States. Summer temperatures are considerably higher, however, and rainfall is generally adequate. In the Western States, lack of rainfall is the principal factor limiting potato production, and most crops are grown under irrigation. In parts of California, potatoes can be grown all the year round, but in the States farther inland low winter temperatures occur, and it is possible to produce a summer crop only.

An account of potato growing conditions and methods in the major growing areas of the United States has been given by Dykstra and Reid (1956) for the South; by Lombard, Brown, and Dykstra (1948) for the Northeastern and

TABLE 73.--Most important potato varieties and percentage of total U. S. potato acreage, 1949

Early varieties	Percent	Late varieties	Percent	Late varieties	Percent
Irish Cobbler	15	Katahdin	28	Red McClure	2
Triumph	13	Russet Burbank	7	Pontiac	2
White Rose	9	Chippewa	7	Red Pontiac	1
Red Warba	1	Green Mountain	7	Russet Rural	1
		Sebago	3		

North Central States; and by Edmundson, Schaal, and Landis (1951) for the Western States. An important feature of potato growing is the short growing season, which in most districts does not exceed 120 days.

POTATO CULTIVATIONS

Generally speaking, potato growers in the U. S. A. tend to be specialists, and as such are well equipped technically and mechanically to deal with the crop. Much greater emphasis is placed on the mechanization of every job to do with potato growing than in European countries. For example, the table stock (ware) crop is universally planted by machine.

The potato seed is cut prior to planting. The rows are wide (36 inches), and the seed pieces are planted closely in them (10 to 12 inches), although there is variation from these figures, depending on variety, soil, or climatic conditions. Almost all crops are grown on the ridge. The wide rows enable interrow cultivations and spraying to be carried out with less damage to the plants. Particularly is this so in the case of spraying; also guards are fitted to the tractor and sprayer wheels to lift the haulm. A wide range of potato pests, including flea beetle, leafhopper, and Colorado beetle, have to be dealt with by spraying or dusting in most potato areas. Farmers are much more aware of the need for spraying and spray very much more frequently than in Europe.

Large storage houses, very often built partially into the ground, are used over a great part of the United States to keep the potatoes during the winter months.

POTATO BLIGHT: REGIONS CHOSEN FOR STUDY

A great deal of work on many aspects of the epidemiology and control of potato blight has been carried out in the United States under a wide range of growing conditions for the potato crop. An intensive study has been made of the effects of the disease in four widely separated potato growing areas, among which there are marked variations in the incidence of blight and in the problems that the disease poses. The areas chosen were, Aroostook County, Me; Hastings Section, Fla.; Red River Valley, Minn. and N. Dak.; and South Fork, Long Island, N. Y.

Following the discussion on these particular areas, an account is given for the United States as a whole. The location of places named in the text is shown on the key map (fig. 60).

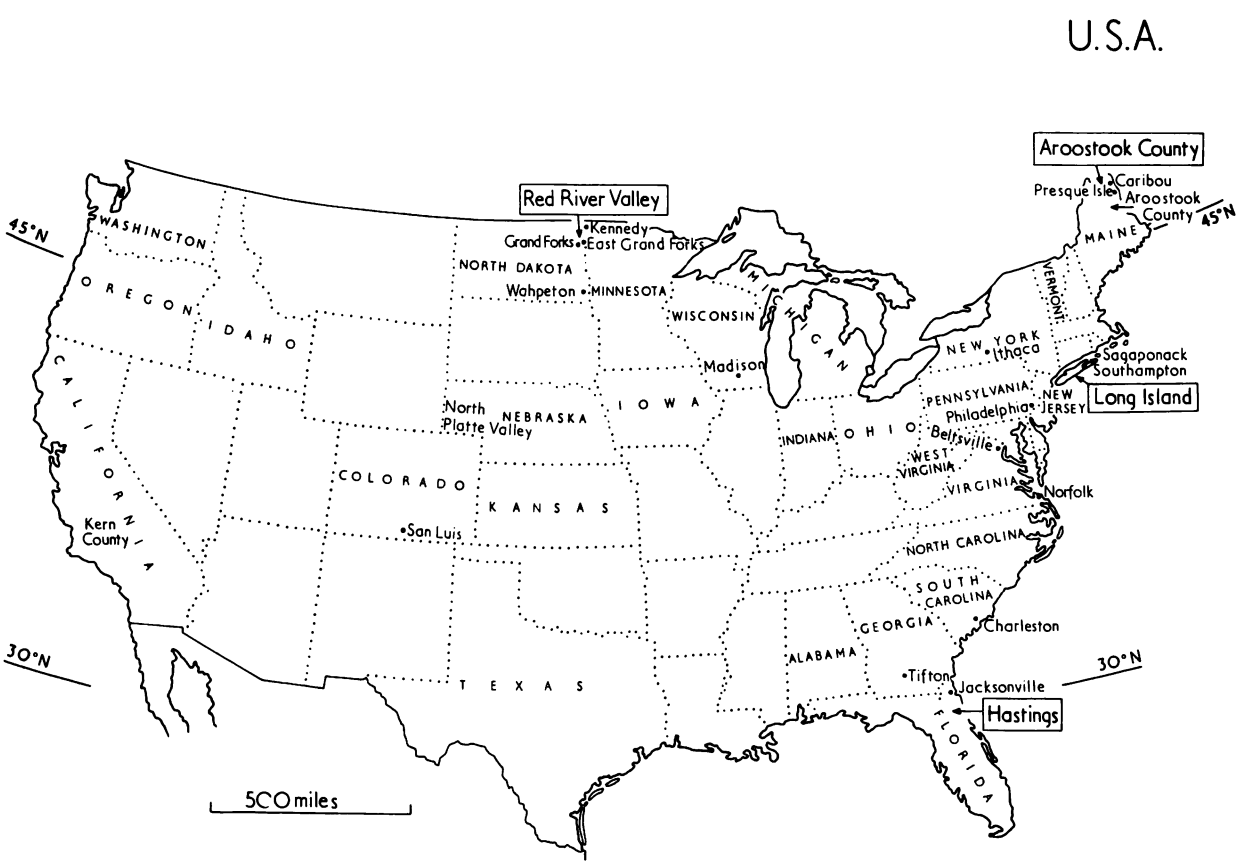


FIGURE 60.--Key map of United States of America.

Aroostook County, Maine

According to Simpson and Shands (1949), 12 to 15 percent of the total potato production of the United States is grown in Maine, and of this 85 to 90 percent comes from Aroostook County. The farming land in Aroostook County lies in a narrow belt along the eastern and northeastern part of the State, adjoining the Canadian border. For the past 30 years, Aroostook has led the United States in potato production. About 130,000 acres of potatoes are grown annually, producing average yields of around 10 tons per acre.

Aroostook is principally a late ware-producing area, and only a few early varieties (5 to 10 percent) are grown, some of these for seed. About 25 percent of the total acreage is planted for certified seed production. Schrumpf (1953) states that the chief variety grown is Katahdin, which over the last 15 years has largely replaced Green Mountain. Katahdin shows some resistance to blight, whereas Green Mountain is highly susceptible, both in the foliage and the tubers. The variety Kennebec, which has the R_1 gene for blight resistance, is also widely grown in the area.

The potato soils are loams. Of the cultivated land 60 percent is Caribou loam, which contains a high percentage of sand. Potatoes are also grown on Washburn loam, which is a heavier soil and less well drained.

Climatic data for Caribou in central Aroostook are shown in figure 61, which may be taken as representative of the whole area. Annual rainfall is between 30 to 35 inches. Summer temperatures are cool and rain is usually abundant and well distributed, making for ideal potato-growing conditions. Winter temperatures are well below freezing. The growing season is about 120 days. Planting takes place from mid-May to early June, and lifting from the second week in September to the second week of October. After the middle of September, killing frosts are likely to occur,

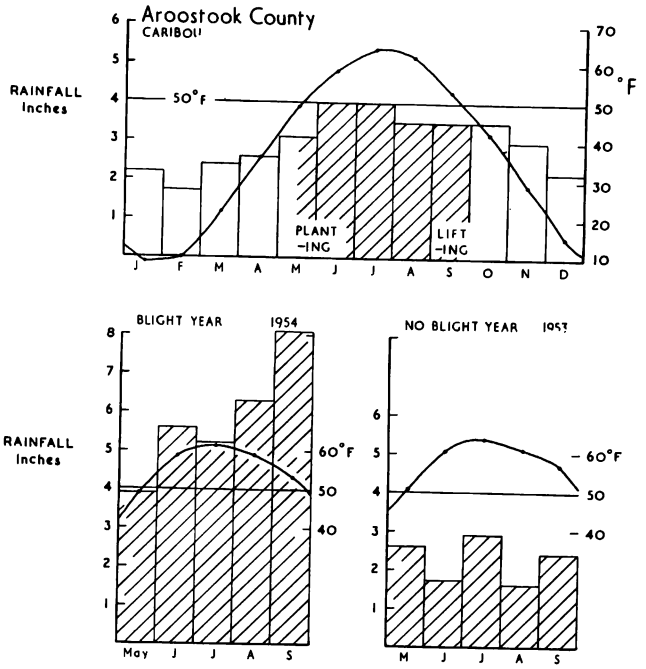


FIGURE 61.--Monthly rainfall and temperatures for Aroostook County Maine, U. S. A.: Above, long-term averages; below, "blight" and "no blight" years.

and from the second week of October, there is always the likelihood of severe damage from freezing to tubers left in the ground. Thus there is an annual race against time at harvest, and end-of-season growth of many crops has to be sacrificed to insure successful harvesting of the whole acreage.

Frequency of Blight Epidemics

Hyre and Bonde (1955) have described the severity of blight epidemics in Aroostook County over the period 1943-55. Their descriptions are set out in table 74, together with the average yields of potatoes in Maine from 1943 to 1953.

TABLE 74. --Severity of blight epidemics and average yields of potatoes in Aroostook County, Maine, 1943-55

Severe		Moderate		Slight	
Year	Yield	Year	Yield	Year	Yield
	Bu./acre		Bu./acre		Bu./acre
1943	355	1948	385	1944	268
1945	261	--	--	1946	358
1947	350	--	--	1949	465
1950	480	--	--	1952	360
1951	445	--	--	1953	370
1954	--	--	--	1955	--

These blight assessments have been based on the results of specific surveys plus general observation. They refer to the total effect of the disease in a particular season and not to defoliation alone.

During the period 1943-53, potato acreages have fallen, and there has been a general rise in yields due to improved cultural practices. The average yield over the years in this period, when blight has been described as "slight" has been 359 bushels per acre, and in the 5 years when the disease has been "severe," the average yield has been 361 bushels. Thus, for all practical purposes, the yield of potatoes has been the same in the two sets of years.

Blight on Haulm

Blight seldom occurs to any extent in Maine before the end of July. The months in which the first recorded field outbreaks have been made in Aroostook County from 1943-55 are shown in table 75. This has been compiled from material appearing in the Plant Disease Reporter and supplied to us by R. Bonde. The years in which the disease has been assessed as "severe" are indicated.

TABLE 75. --Time when blight was first recorded and years when severe, Aroostook County, Maine, 1943-55

July outbreaks		August outbreaks		September outbreaks		Blight generally absent
Year	Severe	Year	Severe	Year	Severe	
1944	--	1943	X	1947	X	1948
1945	X	1946	--	1949	--	1952
1954	X	1950	X	--	--	1953
--	--	1951	X	--	--	1955

In 7 years out of 13 the disease was either generally absent or its effect was slight. In 2 years (1943, 1947), when the disease was described as "severe," Cassell (1944a) and Bonde and Schultz (1949) have said that the main damage was caused by tuber infection.

In 4 years out of 13 (1945, 1950, 1951, 1954) there were fairly heavy losses due to premature defoliation. In the same years tuber blight infection was also heavy. The 2 years (1945, 1954) that damage to potato tops by blight was the worst were both years of July outbreaks. An early outbreak date, however, is not necessarily followed by severe defoliation losses, and this is shown in 1944. In that year, a field outbreak was recorded on July 8, but according to Cassell (1944b) it did not develop, owing to the onset of hot dry weather in early August.

Very full information on the amount of defoliation during the 1954 season is available from a survey carried out in late August and early September 1954 and reported by Bonde (1955b). Defoliation in this year was probably the heaviest of any year in the 1943-55 period. The results of the survey of the whole potato area are summarized in table 76.

Generally, the fungus appears relatively late in Aroostook, and rarely causes complete defoliation of potato plants on a large scale.

TABLE 76. --Amount of defoliation and percentage of total fields (2, 160) affected, Aroostook County, Maine 1954

Amount of defoliation (percent)	Percentage of total fields
	Percent
0	39.9
< 1-5	17.0
5-25	18.8
25-75	10.5
75-100	13.8

This is intimately bound up with the very intensive spray program against the disease, which is followed by practically all growers in the area.

Blight Losses Due to Premature Defoliation

The growing season is short (120 days), and the growth curve (fig. 62), adapted from Akeley, Stevenson, and Cunningham (1955), of potatoes in Aroostook County is correspondingly steeper than in areas where potatoes have longer to grow. These workers have

summarized the results of 3 years of vine-killing trials at Aroostook Farm, Presque Isle, held between 1950 and 1952, in which they have given details of potato yield increases during the later stages of growth. An extract from these results shows that in the 4 late varieties (Sebago, Katahdin, Kennebec, and Green Mountain), approximately 45 percent of the final yield was formed after mid-August, and approximately 15 percent after early September.

U.S.A.

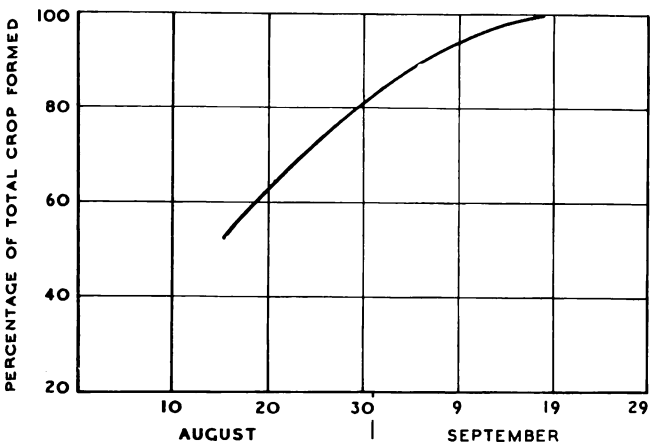


FIGURE 62.--Mean rate of bulking curve for late varieties at Aroostook Farm, Presque Isle, Maine, 1950-52.

Figures have been supplied by Dr. Bonde that give the dates at which the 75-90 percent blight defoliation stage was reached on the unsprayed potato plots at Aroostook Farm over the period 1950-55 (table 77).

When these figures are related to the growth curve of potatoes in the area, they indicate no yield losses due to premature defoliation on the sprayed plots. In 3 years out of 6 (1952, 1953, 1955), losses on the unsprayed plots due to premature defoliation will have been negligible. In 1950 and 1951, there will have been about a 15 percent yield loss, and in 1954, almost a 40 percent loss on the unsprayed plots. It may be concluded that premature defoliation caused by blight at Aroostook Farm, which may be taken as representative of the whole area, is not a serious problem on the sprayed crop, but blight will cause heavy losses in unsprayed crops very frequently.

In the area as a whole, the only data on which an approximate yield loss due to premature defoliation can be based are the survey figures for the bad blight year of 1954, already referred to in table 76. This survey took place over a period of 2 weeks, August 26 to September 10, and during this time the blight position in individual fields will have changed very radically. If it is assumed, however, that very much the same state of affairs would have been revealed if the whole survey had been carried out on one day, September 2, which is the mean of the two end-dates, the following loss from blight would occur:

Percentage of total number of crops	Defoliation of haulm by blight on Sept. 2 (percent)	Yield loss (percent)
9	90 - 100	30
9	50 - 90	15
25	5 - 50	10
57	0 - 5	0

TABLE 77. --Percentage defoliation due to blight on unsprayed and sprayed potato plots, Aroostook Farm, Maine, 1950-55

Year	Date of 75-90 percent defoliation on unsprayed plots	Defoliation on sprayed plots at lifting
		Percent
1950.....	Aug. 31-Sept. 2	([1])
1951.....	Sept. 3	1 1/2
1952.....	Sept. 8[2]	([1])
1953.....	Sept. 10[2]	([1])
1954.....	Aug. 20	5-10
1955.....	Sept. 14	([1])

[1] Trace.
[2] Only 20 percent defoliation at lifting.

Over the whole acreage, this works out as an average loss of yield, due to premature defoliation, of 6.5 percent. Since this is an approximation, it would be better to state it as a loss of 5 to 10 percent, with a reasonable certainty that average losses did not exceed 10 percent.

The effect of premature defoliation, in addition to lowering yield, is to reduce the percentage of salable tubers in the sample. This is particularly so, if defoliation occurs very early. Stevenson, Akeley, and Webb (1955) give figures for a trial with artificial inoculation held in 1954 at Aroostook Farm. An extract from their results is shown in table 78.

A crop, maturing normally, produces about 95 percent United States No. 1 tubers. In a highly competitive market, such as that in

TABLE 78. --Date when 90 to 95 percent defoliation from blight was reached in a potato trial and yield of U. S. No. 1 tubers, Aroostook Farm, Maine, 1954

Variety	Date when 90-95 percent defoliation reached	U.S. No. 1 grade tubers in sample
		Percent
Green Mountain	Aug. 13	35
	Aug. 20	69
Katahdin	Aug. 13	51
	Aug. 20	80

the United States, it is usually only the No. 1 tubers that the farmer is able to sell. Early defoliation also reduces the percentage of solids in the tubers. This, however, is not a simple cause-and-effect relationship, as the percentage of solids is also intimately bound up with seasonal weather effects.

Blight in Tubers

The largest losses in Aroostook County from blight appear to be the result of rot following tuber infection with the fungus. Cassel (1944a) estimated an overall loss of 10 percent of the 1943 crop in storage due to blight. Large losses from the same cause were observed in the 1944 crop by Cassel (1944c) and in the 1945 and 1947 crops by Bonde and Schultz (1949). Bonde and Robinson (1950) reported that considerable loss from blight tuber rot occurred in some fields in Aroostook in 1949.

Tuber infection may take place in the soil before lifting, and this occurs to a greater extent in the Washburn loam soils, which are usually less well drained than in the Caribou loam. Bonde (1955a) reported that blight infection in Washburn loam soils may be accentuated by primary infection of the tubers with powdery scab, Spongospora subterranea. According to Bonde, there is generally less than 1 percent tuber blight at lifting time in the unsprayed plots at Aroostook Farm, which is on Caribou loam. Cassel (1944c) attributed some of the loss in the 1944 crop to the heavy rain preceding and during a hurricane of September 14, which washed fungus spores into the soil and into contact with the tubers.

However, Bonde and Schultz believe that most of the rot found in Aroostook is from infection that occurs while the crop is being harvested. The combination of a short growing season and a generally late attack of blight makes the Aroostook farmer particularly vulnerable to this. The advent of haulm killers during recent years has not entirely removed the danger, as heavy rains over the short harvest period may wash off the materials and thus to some extent nullify their effect.

Blight and Weather Data

The mean air temperature and rainfall figures for Caribou in Central Aroostook, together with the approximate planting and lifting periods of potatoes in Aroostook County are shown in figure 61. The low winter temperatures insure that in most years "groundkeepers" are killed, and therefore cannot act as a possible source of blight inoculum. Occasionally, however, heavy falls of snow before severe weather conditions set in enable some "self-sets" or "groundkeepers" to survive. Summer temperatures are cool. Neither low nor high temperatures during the growing season are factors likely to hinder the development of blight. Hyre and Bonde (1955), in a survey of weather data for a series of nonblight and blight years over the period 1902-53, concluded that at no time did high temperatures limit the effect of blight. Seven-day mean temperatures were below 75 °F. throughout the years.

Although there is a broad correlation between rainfall and blight epidemics in the area (e.g., 1954, a wet year, was a bad blight year; and 1953, a dry year, was generally free from blight), many other factors, including source of inoculum, need to be considered. In 1956, rainfall in June, July, and early August was high, but blight appeared late in the area, and this was ascribed to lack of inoculum following a year (1955) largely free from blight. Hyre and Bonde in drawing a "critical rainfall line" took a cumulated rainfall of 11.25 inches over the period June 2 to September 15 as the base above which blight was likely to be severe. The rainfall and temperature figures for 1954 (a blight year) and for 1953 (a no-blight year) are compared in figure 61.

It is impossible to study true weather-blight relationships in this area, because, apart from unsprayed control plots at Aroostook Farm, all potatoes are sprayed. Only in years when rainfall is so heavy that growers cannot get through their crops with sprayers is a severe blight epidemic likely to develop. Such a state of affairs occurred to some extent in 1954, when there were 15 rainy days in June, 22 in July, and 19 in August.

Control Measures

It has been considered for some time that potato cull (or dump) piles are a very important source of primary blight infection in Aroostook County. Bonde and Schultz (1943), as the result of extensive work carried out between 1935 and 1942, concluded that "the cull pile is the chief source of ... infection." These cull piles occur beside potato storage houses and merchants' warehouses. Over the last 10 to 15 years an intensive program has been conducted to get farmers to clear them up, but a survey carried out by Webb and Bonde (1956) shows that this has not been entirely successful. One of the chief methods of dealing with the cull pile is to spray it with a haulm killer early in the growing season.

Some form of protective spraying against blight is followed by all growers in the area every year. The first sprays are put on in early- to mid-July (before the crops start to meet in the drill), and spraying is continued at weekly to fortnightly intervals, depending on weather, up to lifting time. On average, 6 to 7 protective sprays are put on, but under prolonged conditions of blight weather, up to 12 sprays are given.

The use of organic fungicides (nabam plus zinc sulfate, for instance) is universal. There are two main reasons for this: (1) They are cheaper than the copper spray materials, and as practically all growers do their own spraying, the cost of materials is one of the principal items in the total cost; and (2) there are no phytotoxic effects from the use of organic fungicides. The effect of copper in a "no blight" year can depress yield as a result of scorch injury. In a spraying trial reported by Stevenson, Akeley, and Webb (1955), carried out at Aroostook Farm in 1953, the yield of U.S. No. 1 tubers for 6 varieties was depressed an average of 8 percent by spraying with basic copper.

The main disadvantage of using organic fungicides lies in their poorer adherence to the potato foliage; as a consequence they need to be applied more frequently than the copper sprays.

In general, potato crops are sprayed from the top only; droplances are not used to any extent. Since 1950 the use of low-volume spraying has very much increased. Peikert and Bonde (1954) have reviewed trials with low-volume machines carried out during the seasons, 1950-53. The normal rate of application is about 40 U. S. gallons per acre. At the present time approximately 70 percent of the farmers in Aroostook County are using low-volume spraying. About half the antiblight sprays are combined with treatments, principally DDT, against pests. The effect of these antipest sprays is to prolong the growth of the potato tops.

A spray warning service for Aroostook County was started in 1931, and reviews of possible methods on which to base a forecasting service for potato blight in the area have been made by Hyre and Bonde (1955) and Hyre (1955). It is now proposed to introduce a forecasting service to growers based on moving graphs derived from rainfall and temperature data. A certain amount of circumspection has to be followed in issuing spray warnings and blight forecasts, as there is always the danger of frightening off the buyers of the seed crop, which forms a very important part of the total potato acreage.

It was at first thought that the growing of blight-resistant varieties would provide an answer to the problem of the disease in this area. The results of promising trials with the variety Kennebec in 1949 and 1950 have been published by Akeley, Lombard, and Stevenson (1952). It was soon found, however, that specialized races of the blight fungus were present and that these were capable of attacking Kennebec and other blight-resistant varieties. The presence of 11 races of blight in Aroostook County has recently been shown by Webb and Bonde (1956). Kennebec, which is widely grown now receives a series of protective sprays, similar to that given to other varieties.

Potato haulm killing, to protect the tubers at lifting, is now general. Farmers start killing the haulm, beginning with the seed crops, in the first week of September. Some growers still rely on frosts to kill the haulm, while others use roto-beaters. But the tops are chiefly killed chemically with sodium arsenite, and little trouble from vascular discoloration of the tubers follows the use of this material. Some crops are killed mechanically by roto-beating.

Summary: Aroostook County

Blight does not cause heavy yield losses due to premature defoliation of the potato plants, except occasionally, as in 1954. Even in 1954, little or no blight occurred in the majority of fields toward the end of the growing season; where large losses occurred, they fell on the individual grower rather than on the area as a whole. That this is the general state of affairs in severe blight years is illustrated by a comparison of average yields in severe blight years (361 bushels per acre) with yields in slight years (359 bushels). Tuber infection in the soil is not likely to be heavy, except on some of the poorly drained fields. Tuber infection at lifting time, however, has in the past been a serious problem, due to the short growing season and short harvest period. The use of vine killers should now greatly reduce this source of loss.

The universal spray program with organic fungicides has an undoubted effect in reducing

yield losses as a result of early defoliation. But the fact that severe blight years only occur once in 2 years and the results from the unsprayed plots at Aroostook Farm must lead one to question the need for such an intensive program. One of the aims behind spraying has been to keep the foliage as completely as possible free from blight, to prevent tuber infection at lifting. As a result, heavy tuber losses would not occur when potatoes were lifted. Protective spraying continues up to lifting, but the need for the last one or two sprays has now gone. At the present time, the spray program does not appear to have adjusted itself to the changed conditions brought about by the use of haulm-killing methods.

Hastings Section, Fla.

The Hastings section, situated in northeastern Florida, is the oldest and largest potato-growing area in the State. In 1952, potato plantings totaled about 16,000 acres. Yields vary considerably from year to year, but on average, are about 190 bushels (5 tons) per acre. "New crop" (or early) potatoes are produced, chiefly for sale outside Florida, from the end of March to early June. During this time, the crop has to meet competition from the stored potatoes of the Northeastern and Midwestern States and the early varieties coming from other Southern States. The bulk of the crop is planted with seed from the Northern and Eastern States. The variety Sebago accounts for 95 percent of the acreage. Details of potato growing in the area have been given by Brooke and Spurlock (1950) and Eddins, McCulbin, Ruprecht, and Stevenson (1950).

The soil is principally Bayboro-Bladen fine sand and fine sandy loam, and many of the fields are rather poorly drained, so that waterlogging of the soil is not uncommon. Drought conditions are also likely to occur during the growing season; most farms have artesian wells, which can be used for irrigation. The climate is subtropical, and potatoes are grown under short-day conditions. There are considerable differences in rainfall from year to year. Thus, in March 1945 the rainfall was 0.23 inches, and in March 1948, 9.47 inches; the April rainfall in 1942 was 0.28 inches, and in April 1947, 5.97 inches. Very heavy rainstorms may occur: In 1944, 3 inches of rain fell within 2 hours on April 3. The crop is also liable to frost damage, but very high temperatures do not usually occur, except occasionally at lifting time when there may be sunscald of the tubers. Average rainfall and temperature figures for the area are set out in figure 63. The growing season is 90 to 100 days, and crops are dug before they are mature. Planting takes place from December 20 to February 1, and lifting from April 1 to May 15.

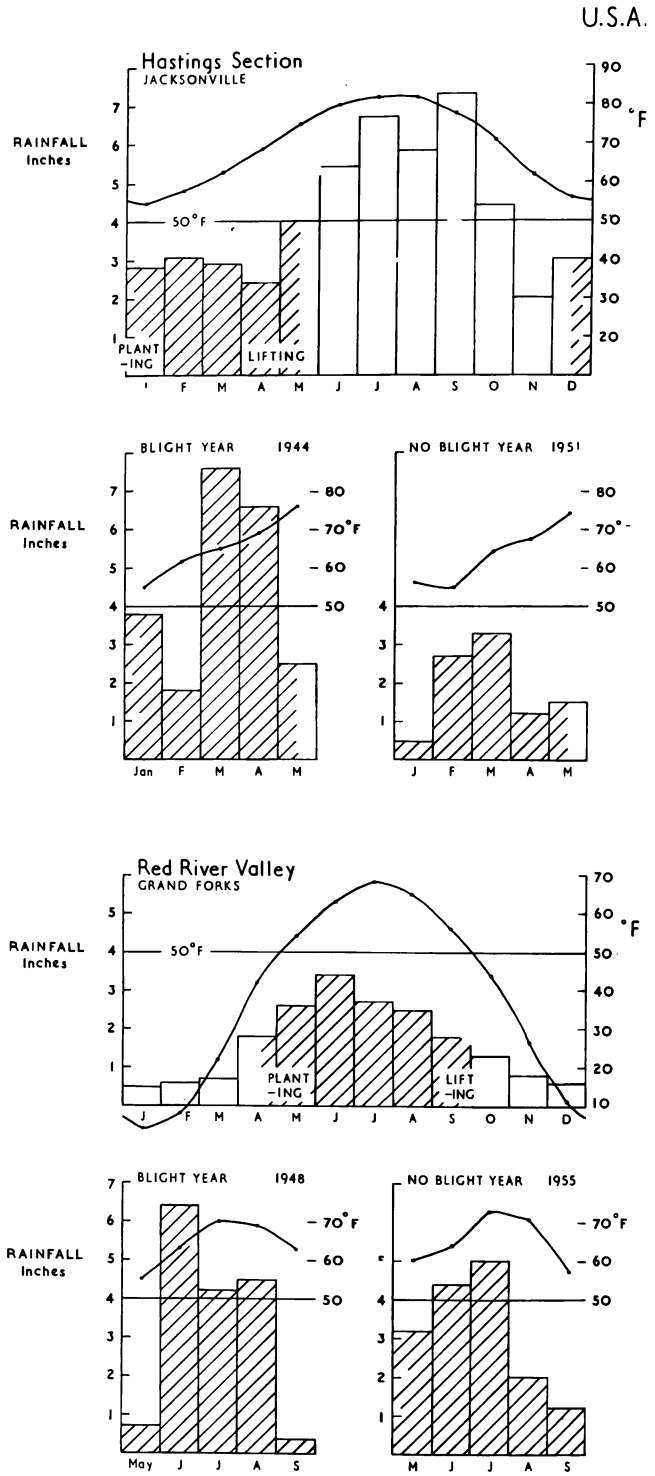


FIGURE 63.--Monthly rainfall and temperatures for Hastings section, Fla., and Red River Valley, Minn. and N. Dak.: Above, long-term averages; below, "blight" and "no blight" years.

Blight Epidemics: Frequency and Losses

A. H. Eddins has summarized the damage caused by blight, and the dates of the first

field outbreaks of the disease, over the period 1931-55. These data are set out in table 79.

"Damage" in this table refers to the estimated reduction in yield due to premature defoliation plus loss from tuber infection. The various categories of damage, together with their equivalent in percentage loss of crop and the number of years out of 25 (1931-55 period) that each has been recorded are as given in table 80.

TABLE 79. --First field outbreaks of blight and amount of damage to potatoes, Hastings section, Fla., 1931-55

Year	First field report	Damage	Year	First field report	Damage
1931	Apr.	Moderate.	1944	Mar. 1	Severe.
1932	Jan. 28	Do.	1945	None	None.
1933	Feb. 5	Severe.	1946	Mar. 13	Moderate.
1934		Do.	1947	Jan. 25	Do.
1935	Apr. 6	None.	1948	Feb. 25	Do.
1936	Mar. 15	Moderate.	1949	Feb. 15	Do.
1937	Jan. 2	Severe.	1950	Apr. 20	Little.
1938	Mar. 1	Moderate.	1951	None	None.
1939	Mar. 8	Do.	1952	Apr. 16	Moderate.
1940	Apr. 15	Little.	1953	Mar. 20	Do.
1941	Mar. 15	Moderate.	1954	Apr. 9	None.
1942	Apr. 1	Do.	1955	May 1	Do.
1943	May	Little.			

Estimated losses caused by blight are seen to be small. In summarizing losses in potato crops in Hastings from 1932 to 1943, Eddins (1943) estimated an average annual loss of 4.4 percent, and since that time losses have tended to decrease.

There is no point in comparing potato yields in this district for "blight" and "no blight" years. Large fluctuations in yield occur from year to year, due to drought, flooding, and frost damage. Economic considerations play a big part in deciding when potato crops are lifted in an early district, and the time of harvesting will in turn have a marked effect on yield.

Blight on Haulm

Blight may attack the crop throughout the growing period. A severe attack, which started soon after planting in 1937, has been described by Eddins and Clayton (1943). The attack was in part due to a high percentage of blighted tubers in the seed, which had come from the Eastern States.

TABLE 80. --Rating for "damage" as related to loss of crop and number of years each type of damage occurred, Hastings section, Fla., 1931-55

Damage	Loss of crop	Years
	Percent	Number
None		5
Little	1	3
Moderate	1-4	13
Severe	8-15	4

Very early field outbreaks are the exception, however, and the disease is usually first noted in March or April. This will be seen from the summary set out in table 81, where outbreak dates have been arranged, by month, for the period 1931-55.

TABLE 81. --Months in which outbreak occurred and frequency during the period 1931-55, Hastings section, Fla.

Outbreak occurring in--	Years outbreak reported
	Number
January	3
February	3
March	7
April	7
May	2
No blight	2
No data (1934)	1

There is no general association between the earliness of the first outbreak and the amount of damage done to the potato haulm. In 1947, for example, sharp frosts followed the initial outbreak on January 25; potato tops were killed, and the disease did not reappear until mid-March. The course of the attack in this year has been described by Eddins (1947).

Dr. Eddins has also supplied figures showing the amount of defoliation caused by blight in his spray plots at Hastings over the period 1949-54 (table 82).

TABLE 82.--Amount of blight on haulm at lifting time, Hastings section, Fla., 1949-54

Year	Blight on unsprayed plots at lifting	Blight on nabam sprayed plots at lifting
	Percent	Percent
1949	100	7.5
1950	13.8	0
1951	0	0
1952	15.0	([1])
1953	57.5	([1])
1954	([1])	0

[1] Trace.

In only 1 year (1949) out of the 6 did the sprayed plots show a significant increase in yield over the unsprayed, and serious defoliation is the exception. Sometimes, a prolonged period of rain after the disease has become established prevents farmers from taking protective action, and then widespread severe defoliation may occur. This happened in 1944.

Blight in Tubers

Overall losses from blight infection of tubers are not serious. According to Dr. Eddins, "Tuber infection during recent years has caused little loss, as the foliage has been kept almost free of late blight. If rains occur during epidemics, and the foliage is infected, a trace to 10 percent of the tubers may be infected." Only occasionally, as in 1944 when heavy rains exposed the tubers, does a serious amount of infection take place while the potatoes are still in the ground. Infection at lifting is not usually severe. If the potato tops are blighted at this time, the conditions of lifting play an important part. When the land and potato tops are wet, infection is likely to be heavy, but if the fields are dug under dry conditions little loss should occur from tuber blight.

The crop is washed and dried before shipment for sale. However, the effect of this on the development of tuber blight has not been determined. No figures have been published on the amount of infection developing during transit of potatotes from the Hastings section. That such development in transit can be a serious problem in early potatoes has been shown by Ramsey (1942), who found that consignments of Florida potatoes inspected on the Chicago market in January 1940 frequently showed 5 to 10 percent tuber blight.

Blight and Weather Data

Average temperature and rainfall figures for Jacksonville together with planting and lifting dates for potatoes, are set out in figure 63. An account of an unusual and very early attack by blight in 1937, given by Eddins and Clayton (1943), has already been mentioned. A week after planting, the disease was found in seed pieces, and a high proportion of these rotted in the ground. Many of the sprouts that were produced were killed by blight before or shortly after emerging. Stands were reduced 10 to 20 percent in most of the fields in the Hastings area, and in individual farms up to 90 percent of the plants were lost. The disease continued to attack the plants after emergence and became very destructive in some fields. Rainfall, although not particularly heavy in January 1937, was well spread out, and air temperatures were abnormally high (13° F. above average). In table 83 a comparison of the January figures for 1937 and the succeeding years up to 1945 brings out these points.

Rainfall and temperature data for 1944 (a blight year) and 1951 (a no-blight year) are compared in figure 63. The course taken by blight in 1944 has been described by Eddins (1944) and by Rhoads (1944). The season was favorable to growth until March 21, at which date a little blight was general through the

TABLE 83.--Number of rainy days, total rainfall, and mean temperatures in January at Jacksonville, Fla., 1937-45

Year	Rainy days	Total rainfall	Mean Temperature
	Number	Inches	°F.
1937	12	2.60	68.1
1938	9	1.17	56.5
1939	5	1.59	58.2
1940	7	1.61	47.4
1941	11	3.18	56.2
1942	6	1.30	55.1
1943	4	1.62	59.4
1944	7	3.16	56.7
1945	7	3.93	57.6

fields. During the last 10 days of March, 5.43 inches of rain fell, followed by 3.16 inches in a 2-hour period on April 3. Blight spread rapidly during this time, and by April 20 the plants in nearly all the potato fields had been killed by the disease and by water damage. During and after the rain, it was impossible to get into the crops to protect them against blight and the growing season in most fields was reduced by 2 to 3 weeks. In 1951, the no-blight year, rainfall was below average for each of the 5 months, January to May.

The weather conditions associated with severe blight losses appear to be a fairly prolonged period of heavy rains, but this happens only exceptionally. Eddins, Ruehle, and Townsend (1946) have stated that blight at Hastings "has caused maximum losses when the rainfall has ranged between 5.56 and 8.31 inches during the last 30 to 40 days of the growing period." Temperature conditions are generally favorable to blight development during the growing season, though frosts, which may occur as late as March, have been known to kill off the haulm and completely stop an epidemic (as in 1947). It is possible that the short-day conditions under which the crop is grown, leading to heavy dew formation, play a part in blight development in this area.

Control Measures

Protective measures are taken every year by the majority of growers. According to Brooke and Spurlock (1950), most growers in 1949 were not equipped to spray against blight, and were using dusts as a control. Since then, there has been an increase in spraying as opposed to dusting, and a change from copper dusts to organic fungicides. In 1956, the use of nabam sprays with zinc sulfate was general. The danger of copper dusts causing scorch injury to potato foliage in dry seasons with a consequent reduction in crop yields has been pointed out by Eddins and Clayton (1943). Spraying starts when the plants are 6 to 10 inches high, and 3 to 6 sprays are given during the growing season. This regular annual spray program is also a feature of the "new crop" potato growing areas in Florida and Alabama. According to Dykstra and Reid (1956), control measures are more haphazard in other Southern States.

Haulm killing before lifting is not carried out. It is difficult to see how this could become a regular practice in an early area, as the early grower cannot afford to wait the 2 weeks between top killing and lifting, which is necessary to prevent tuber infection. The market for his crop may quite easily disappear while he is waiting.

Summary: Hastings

Blight does not cause a heavy average loss. Even in the absence of control measures (as shown by spraying trials at Hastings), there was a serious loss of yield due to the disease in only 1 year in 6. It appears that farmers in the area consider the expense of a regular annual control program necessary to insure themselves against occasional serious loss. Even so, the control program broke down in 1944 under conditions of prolonged rain.

Red River Valley, Minn. and N. Dak.

The Red River, which is formed by the juncture of the De Sioux and the Otter Tail Rivers just North of Wahpeton, N. Dak., is the boundary between Minnesota and North Dakota. It flows north for 533 miles and eventually discharges into Lake Winnipeg in Manitoba, Canada. The width of the valley varies considerably along this length and in places it is 200 miles wide.

There were 78,000 acres of potatoes in Minnesota in 1953, and 94,000 acres in North Dakota (U.S.D.A., 1954). Separate acreage figures are not published for the Red River Valley, but in both States the valley is the most important potato area. Average potato yields are below 190 bushels (5 tons) per acre. About 40 percent of the potatotes are grown for seed. Red-skinned varieties are preferred, and the chief variety is Red Pontiac. The soil is a black, organic sandy loam; the better soils are on the land nearest the river. The whole area is very flat and drainage is a major problem, particularly as short, very heavy falls of rain may occur during the growing season. The mean annual temperature and rainfall figures for Grand Forks, N. Dak., in the center of the valley, are shown in figure 63. Planting takes place from the end of April to the end of May, and lifting is in September and early October. The full growing season is about 120 days.

Frequency of Blight Epidemics; Extent of Losses

Over the 10-year period 1946-55, blight was serious in only 1 year. This was in 1948, but even then, damage due to the disease was confined to the northern part of the valley and did not occur to any extent south of Grand Forks. In a series of fungicide trials carried out during the 6-year period, 1945-50, at 3 centers in the North Dakota half of the valley, blight was present only in 1948, and then in no more than trace amounts. The results of these trials have been summarized by Wallin and Hoyman (1954). In the Minnesota side of the valley, Buchholtz (1948 and 1949) has given reports of spraying trials on Bliss Triumph in 1947 and 1948. In neither year

was there any significant increase in yield as a result of spraying.

A feature of the disease in this area is its usually late first appearance. Wallin and Hoyman (1954) have given outbreak data for the North Dakota part of the valley. The earliest occurrence on record was in the latter part of July in 1952. In 1944 and 1948, blight was reported on August 3 and 2, respectively. During the period 1949-53, the disease was first observed in the last 2 weeks of August or the first week in September. First outbreaks usually occur some little time earlier in the Minnesota part of the valley than in the North Dakota part.

Loss of yield through premature defoliation is not a serious problem in the Red River Valley. There is, however, a danger that severe infection of the tops in individual fields may occur under certain weather conditions. The generally high day and the low night temperatures during the latter part of the growing season lead to heavy dew formation, and if blight inoculum is present in a field it will usually be able to survive. Hoyman and Wallin (1957) have been working with blight isolates from this area, which have been able to survive in leaves at considerably higher temperatures (over 100° F.) than those at one time considered possible. In a field where blight "smolders" along in this way, 3 or 4 days of cool, cloudy weather will give the disease the opportunity to develop rapidly.

Blight in Tubers

Tuber infection is the main problem in the Red River Valley. Infection in the soil is not usually important, though individual growers may have heavy losses. Heavy losses are associated with the generally poor drainage conditions in the valley. Reporting the result of a survey carried out at harvesttime in 1948 (the bad blight year), Cook and Lutz (1950) recorded that "tuber rot was worse in the low wet areas than in the higher better drained parts of the fields. In the low areas up to 100 percent of the tubers were affected with blight, and had rotted. Only 1 percent or less of the potatoes were affected in the better drained areas." These low areas, however, form only a small proportion of the total acreage planted to potatoes.

Infection of tubers from blighted tops at lifting is the main source of loss. Even this is not very important, owing to the general absence, or negligible amount, of blight at harvest and the generally dry conditions at lifting.

Blight and Weather Data

Temperature and rainfall figures for the growing season in a blight year (1948) and a no-blight year (1955) at Grand Forks, N. Dak., are shown in figure 63. The progress of the disease in 1948 has been described by Eide and Brentzel, quoted by Miller and O'Brien (1948). Eide (Minnesota) stated that "during July 30-August 3 blight was found scattered in an area about 75 miles long and 25 or less wide, extending from a short distance south of East Grand Forks to north of Kennedy. By August 11-17, it was present practically over the entire area. By September 1, it had killed the vines in many fields, being especially severe around East Grand Forks." Brentzel (N. Dak.) noted that the weather was favorable for the spread of blight during the end of July and early part of August, but after that it was unfavorable for the spread of the disease. In 1955, blight caused little or no damage. The main difference between the 2 years was the considerably higher rainfall in August 1948. The somewhat higher temperatures in 1955 may have retarded the development of the disease in this year.

The factors operating against blight in this area are the high temperatures, low rainfall, low humidities, and rather short growing season. These factors also operate against large potato yields.

Control Measures

Dusting rather than spraying is carried out in the Red River Valley, owing to a general shortage of water. In the Minnesota part of the valley, dusting appears to be more common than in North Dakota, where at the present time little is done. There was a marked reduction in the quantities of fungicides used in the area following the withdrawal of price supports for potatoes by the Federal Government after 1950.

Dusting with DDT and Toxaphene is a routine measure against insect pests, particularly leaf hopper, in the valley. Early blight (*Alternaria solani*), although present in most years, is not considered a serious problem. Organic dusts are most commonly used against late blight and a high proportion of the application is done by airplane.

Wallin and Hoyman (1954) consider that a lengthy control program against blight is unwarranted in the North Dakota part of the valley, and the results of spraying trials both in North Dakota and Minnesota confirm this. The same writers, and also Wallin, Eide, and Thurston (1955), have discussed the value of a blight warning service and a method of basing this on an analysis of temperature and humidity data. An effective warning service for blight would be of great value in an area like this, where the disease occurs only occasionally. However, there are a number of factors operating against a service: (1) The large size of the valley and fairly considerable variations in weather conditions within the valley; (2) the difficulty in obtaining weather

data; (3) the difficulty of getting the forecasts out quickly enough to the individual growers. At the present time the forecasting service obtains its weather data from instruments operated by interested individuals (plant pathologists, growers, etc.) and not from the main Weather Bureau stations. These stations do not give sufficiently good coverage of the area and many do not supply humidity figures. The problem of notifying growers is one of a small trained personnel that has to deal with a potato crop thinly scattered over a wide area.

One factor that operates in favor of spraying according to a warning service as opposed to routine spraying is that growers are already carrying out an annual control program against insect pests. Thus, the equipment is available to control blight in the odd year that conditions make it necessary. Hoyman (1947) has discussed the value of different haulm killing methods under Red River Valley conditions. Most haulm destruction is now carried out by roto-beating, and it has been found that this does not cause vascular discoloration of the potato tubers, unless there have been drought conditions preceding killing.

Summary: Red River Valley

Blight is not a serious problem. A routine control program against blight does not appear justified in the area, and many growers take no action against the disease. A blight warning service would be of great value in the Red River Valley, but there are many difficulties in the way of this. In its absence, it might pay growers to put on 2 to 3 applications of organic fungicides in August as an insurance against the odd blight year. Applications in July appear unnecessary, in view of the generally late appearance of blight, and September applications would almost certainly be too late to have any beneficial effect on yield.

South Fork, Long Island, N. Y.

In 1953, 55,000 acres of potatoes were grown on Long Island, a slightly higher acreage than that grown in up-State New York. The average yield was 320 bushels (8-1/2 tons) per acre. Potato growing on Long Island can be divided roughly into 3 areas: (1) The western area, which is rapidly being built up and has never been a bad area for blight; (2) the North Fork where almost all the potatoes are grown under irrigation; and (3) the South Fork, where the greater part of the acreage is grown without irrigation. Most of the work on blight under Long Island conditions has been carried out in the South Fork area, which has, therefore, been selected for more intensive study.

In the South Fork, potatoes are produced principally for table stock purposes. The chief varieties grown are Katahdin and Green Mountain, with some Irish Cobbler along the coast. Seed comes from Maine and Prince Edward Island. Soil type is a sandy loam, which tends to be low in organic matter. Figure 64 sets out the mean annual temperature and rainfall figures for the area. Planting extends from the end of March up to mid-April, and lifting, which starts in the middle of August, goes on through September into October.

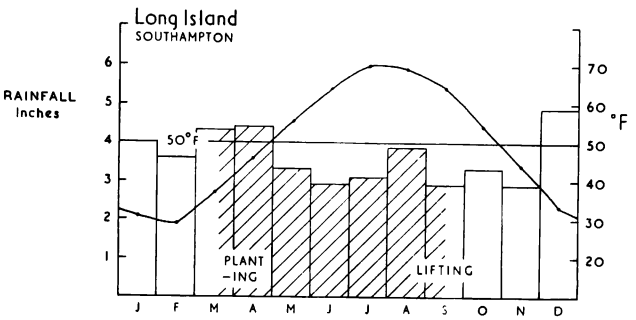


FIGURE 64.--Long-term average monthly rainfall and mean temperature in relation to the potato growing season for South Fork, Long Island, N. Y.

Frequency of Blight Epidemics

The severity of blight attacks over the 10-year period 1946-55 in the South Fork area of Long Island has been summarized in table 84.

The first field outbreaks of blight are not usually recorded before mid-July. Table 84 shows that there was severe blight damage in 1 year out of 10, and that in the remaining 9 years the disease was either absent or caused very little damage.

Overwintering of the fungus in this area has been investigated by Peterson (1947). He concluded that infected seed pieces and cull piles were the chief sources of inoculum in the spring. Although diseased groundkeepers were readily found in grainfields that had produced a potato crop the year before, none of them appeared to have been produced from diseased tubers. It was thus not possible to incriminate groundkeepers as inoculum sources.

Blight in Tubers; Blight Losses

The amount of infection with blight taking place while the tubers are still in the ground is usually from none to a trace. Skaptason, Peterson, and Blodgett (1940) stated that the high copper content of the soils in the district was probably a factor in inhibiting the germination of the blight sporangia. The copper has accumulated under conditions of continuous spraying with bordeaux mixture over a period of years, as potatoes were very often grown on the same fields year after year. Tuber infection at lifting is not a serious problem, owing to the longer growing season here than in many other parts of the U.S.A. The potato

TABLE 84.--Blight incidence and source of data for South Fork, Long Island, N. Y., 1946-55

Year	Blight incidence	Source of data
1946.....	Blight present but little or no damage.	United States Plant Disease Survey (1946).
1947.....	Probably worst year for blight ever recorded in the State.	Miller and Wood (1947).
1948.....	Blight present but loss practically negligible.	Miller and O'Brien (1948).
1949-55.....	Blight damage slight or nil.	Information supplied by L. C. Peterson and confirmed for 1951-54 by Hyre (1955).

haulm has usually been dead a week or more, before lifting.

The only recently published estimate of losses was given for the bad blight year of 1947. In this year Miller and Wood (1947) quote an estimate that there was an overall loss in New York State of 20 percent of the potato crop. Fifteen percent of the loss was attributed to reduced yield as a result of premature defoliation, and 5 percent to tuber infection.

Results have been given by Buchholtz (1948, 1949) of spraying trials against blight, carried out at Sagaponack, South Fork, Long Island, in 1947 and 1948. These have been set out graphically for 1947 in figure 65. This figure incorporates some additional material supplied by L. C. Peterson, showing the progress of the blight on the tops of the treated and the control plots. The yield of the unsprayed plots in this year was 27 percent below that of the plots sprayed with bordeaux, and this figure represents approximately the loss that blight caused in the trial. There was no significant increase in yield from spraying in 1948.

Blight and Weather Data

Long-term average temperature and rainfall data for Southampton, situated in the South Fork of Long Island, are shown in figure 64. Despite the high summer rainfall, blight is severe only occasionally, and one of the main reasons for this appears to be the high summer temperatures. Mean monthly temperatures at Southampton in July and August are 70° and 69° F., respectively. However, this is not the complete story; in 1947, the only bad blight year during the 10-year period 1946-55, mean

U.S.A.

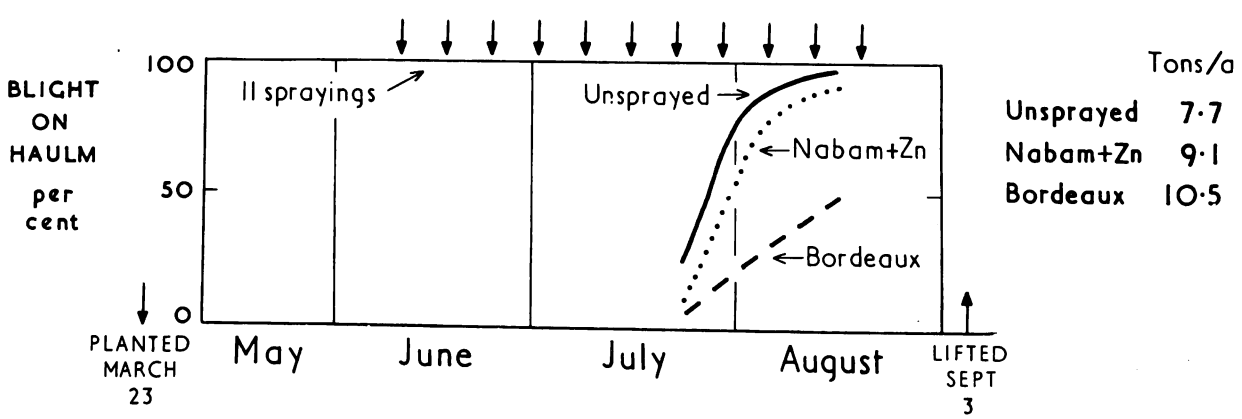


FIGURE 65.--Progress of blight on haulm and corresponding yields of sprayed and unsprayed Green Mountain variety, at Sagaponack, Long Island, N. Y., 1947.

temperatures in both July and August were 2° to 3° above normal. The attack in 1947 seems to have been associated with very high humidity conditions.

Control Measures

All commercial growers follow an intensive spray program at South Fork. First applications are put on when the potato plants are 4 to 6 inches high. The initial sprays are combined with an antipest treatment, usually DDT. The most important insect pests are the Colorado beetle, flea beetle, and potato aphid.

Most of the spraying is now done with organic fungicides. The organic fungicides are not so efficient as copper when applied at the same intervals, but there has been no serious blight year since 1947. There may be danger of overcompacting the sandy soil in this area by the large number of spray treatments that are commonly given. Some growers follow a split spraying schedule, starting off with an organic fungicide and finishing with copper over the latter part of the season, when the danger of blight is greater. Practically all the spraying is at high-volume rates, and the fungicides are applied from the top. If it is necessary to kill the haulm before lifting, the most popular method is with mechanical beaters. Sodium arsenite and the di-nitro compounds are used for chemical destruction. An account of control methods against blight has been given in a publication of the New York State College of Agriculture (1955).

A blight warning service is operated in the State by R. S. Dickey, Plant Pathologist of the New York State College of Agriculture at Cornell University, Ithaca. This service works on the basis of first and later confirmed reports of the disease, which are then sent to county agents, who in turn inform the growers. Approximately 95 percent of the potato growers are informed of the presence and progress of blight in this way.

Summary: South Fork, Long Island

Only in 1 year out of 10 (1946-55), has blight caused serious damage in the area. It is unlikely that this has been mainly due to the spraying program followed, as experience in this and other parts of the United States indicate that a spray program may breakdown under severe blight conditions, particularly when organic fungicides are the chief materials used. In this area, it appears that the amount of protective spraying could be reduced.

BLIGHT EPIDEMICS IN THE U.S.A.: GENERAL

The preceding sections have shown that there are considerable variations in the importance of late blight in the different potato-growing areas of the United States. The most favorable areas for the development of the disease are also those which provide the best conditions for potato growing, namely a relatively cool summer with abundant rainfall. These areas are the New England States, western New York State, and Pennsylvania--in short, the northeastern region.

In the remaining Eastern States, as far south as North Carolina, potato blight is not so important. However, a distinction should be drawn here between the relatively low-lying land stretching in from the coast and the mountainous areas of some of these States. In the mountainous regions of North Carolina and West Virginia, for example, blight occurs to some extent every year. The Southern States, which concentrate on the production of a spring and early summer crop of potatoes are only occasionally affected to a serious extent. The two States from which the largest losses have been reported are Florida and Alabama. The importance of blight also falls off in a westward direction across the country. The disease can be severe in parts of some of the North Central States; e.g., Wisconsin and Minnesota, but high summer temperatures and relatively low rainfall limit its development. In the arid and semiarid conditions of the Western States, where potatoes are grown under irrigation, blight is not a serious problem, although it is sometimes reported.

The first report of Phytophthora infestans in the United States dates back to 1843, when Stevens (1933) states that it was found near Philadelphia, but it is of comparatively recent occurrence in some States. Walker (1950) writes that it was reported on potato for the first time in Florida in 1903; in California in 1904; in Texas in 1931; in Kansas in 1936; and in Colorado in 1941. The first year that blight developed so extensively as to become an economic problem in the North Dakota part of the Red River Valley was 1942, according to Brentzel (1943).

SEVERITY OF BLIGHT EPIDEMICS

In a country so vast as the United States, with potatoes being grown under all kinds of varying climatic conditions, generalized statements about the severity of blight on a year-by-year basis mean very little. Within most States, too, conditions differ widely, and this has a marked effect on the development of blight. In Minnesota, for example, which is roughly the same size as Great Britain, blight was severe in the Red River Valley in 1948, but was hardly found anywhere else. In 1952 in the same State, there was widespread infection with blight in south Minnesota, but only traces of the disease could be found in the Red River Valley.

Short accounts of blight epidemics from the different States were included with data on other

plant diseases over the period 1917-39 in Supplements to the [U.S.] Plant Disease Reporter (Plant Disease Bulletin until 1923). Supplements giving accounts of the severity of blight on potatoes and tomatoes, again on a State-by-State basis, were published for each of the years from 1946 to 1952. These reports show the differing importance of blight for particular areas, which can be expressed as a frequency of severe blight years. Thus the frequency of severe blight years in Aroostook County, Maine, is about 1 in 2. Cook (1949) has summarized data for a number of States. He gives the frequency of years in which the disease has been important as 7 out of 20 in Vermont; 13 out of 34 in New Jersey; 5 out of 20 in South Carolina; and 2 out of 31 in eastern Virginia.

SOURCES OF BLIGHT INOCULUM

It is generally agreed that the most important sources of blight inoculum are infected seed pieces and cull piles. In the Southern States, practically all the potato acreage is planted with northern-grown seed, and the degree to which this is infected with blight will play an important part in the development of epidemics in the South. Peterson (1947) has investigated the possibility of a number of weed and cultivated solanaceous plants acting as inoculum sources of the fungus under Long Island conditions. He concluded that "none of the perennial members of the Solanaceae found growing wild on Long Island function as overwintering suscepts for P. infestans." There is no evidence that solanaceous weeds are important in other parts of the United States. Similarly groundkeepers have not been incriminated as inoculum sources even where they occur, although over large parts of the United States the severe winters make the survival of groundkeepers exceptional.

Outdoor tomatoes may serve as a source of infection to potato crops; but, in general, the transference is the other way round. About 50 percent of the tomato transplants in the United States are grown near Tifton in southern Georgia and from here they are shipped to all parts of the north. In 1946, these plants were infected with blight and proved a potent source of disease inoculum to tomato and potato crops, in what turned out to be a disastrous blight year. Tomatoes may serve as an oversummering host for the disease in the Southern States. In wet summers, a number of outdoor tomato fields are abandoned by the growers and blight surviving on these can be carried over on to the winter potato crop. An account of the importance of tomato blight in the United States is included in a report on the world distribution and present status of the disease compiled by Miller and O'Brien (1955).

METHODS OF BLIGHT ASSESSMENT

In assessing the percentage of defoliation caused by blight in fungicide trials, most U. S. workers now use the method described by Horsfall and Barratt (1945) and Horsfall (1945), which is based on a probit scale. In field survey work, however, many plant pathologists still prefer to describe the degree of blight infection in words, i.e., as "trace," "slight," "moderate," or "severe." In the summer of 1956, an opportunity was taken of comparing this latter method of assessment with the British method, using the B.M.S. scale. This comparison was made on numerous blighted crops in eastern and central United States. Table 85 shows the approximate equivalents.

TABLE 85. --Descriptive designation of blight attacks compared to B. M. S. scale for blight

Designation of blight attack	Equivalent percentage defoliation
Trace.....	Up to 0.1
Slight.....	0.1 - 1.0
Moderate.....	1 - 50
Severe.....	Over 50

LOSSES FROM BLIGHT

Over the period 1917-39, estimated losses to the potato crop caused by blight for each State were published in Supplements to the [U.S.] Plant Disease Bulletin and the [U.S.] Plant Disease Reporter. These losses were expressed as the percentage of total crop lost per State, which was converted into a loss of so many thousands of bushels. No attempt was made to differentiate between the losses due to premature defoliation and the losses caused by tuber infection. Chester (1950), writing about these loss estimates, which were also given for numerous other plant diseases, states that "the annual disease loss reports were based on estimates of loss in the various States made by the principal Survey Collaborators, usually with the assistance of other State specialists. These loss estimates were sometimes little better than guesses . . . Yet they represented the only available comprehensive body of data on losses from plant diseases in the United States, and they are undoubtedly more reliable than some other published disease loss estimates." The map (fig. 66) shows the sort of use made of these estimates.

Since 1939, no systematic countrywide attempt has been made to estimate losses due to blight. The survey carried out by Bonde (1955b) on the amount of defoliation caused by

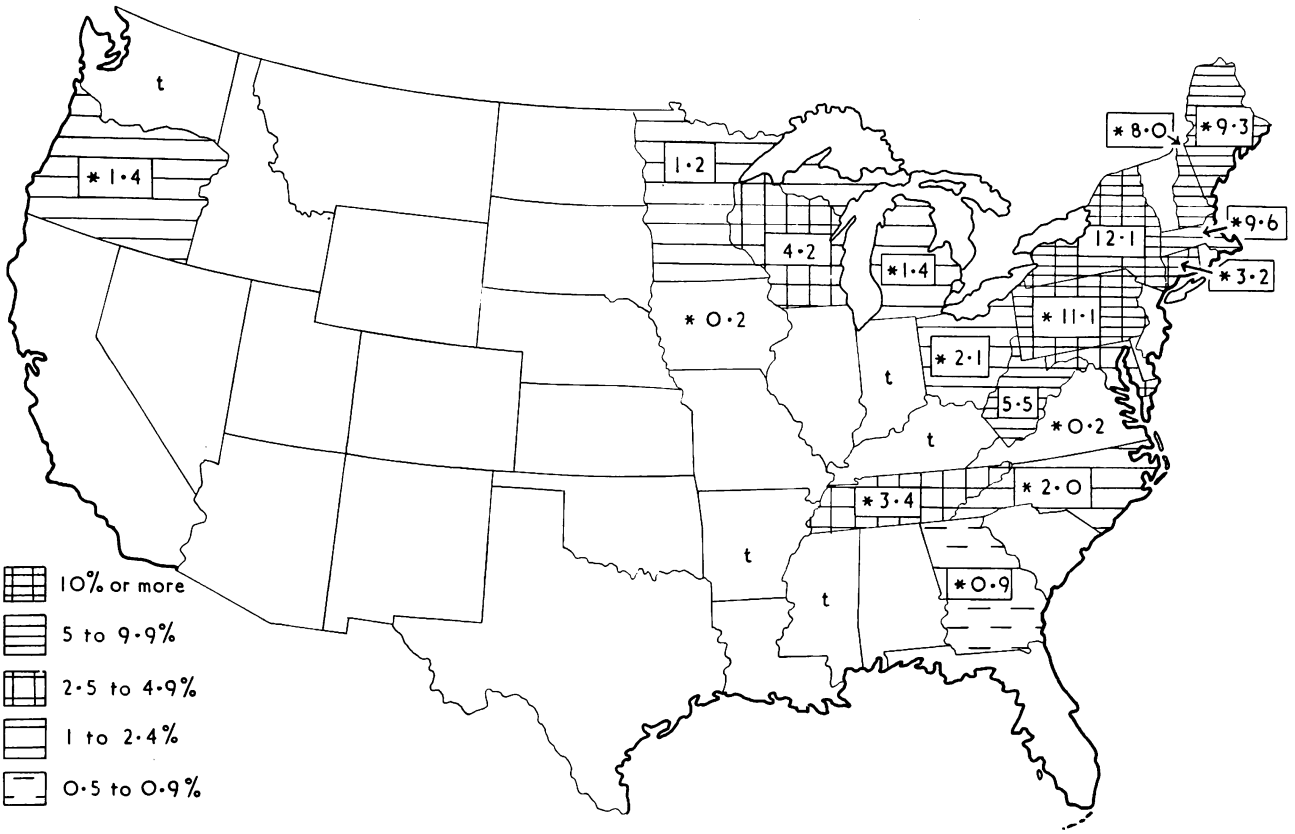


FIGURE 66.--Percentage losses from potato blight for the period, 1920-29, U. S. A. (After Barrus, Boyd, and Wood, 1931.)

blight in Aroostook potato crops reported above provides the type of information on which yield loss estimates can be based. The Aroostook potato-growing area is relatively compact, however, and it would be very much more difficult to carry out a survey of this nature in the Red River Valley.

The intensive study made of four potato-growing areas in the United States leads to the conclusion that heavy losses due to premature defoliation by blight are the exception. Even when losses occur, the overall picture may be a bigger potato crop in the "blight" than in the "no-blight" years. This fact, however, will be of little consolation to the individual grower who does suffer a heavy loss in the bad blight year. The short growing season in many of the potato areas means that a loss of a few weeks growth has a big effect on total yield, and also, most important in a country where the supply of potatoes almost always exceeds demand, that it causes a fall-off in the percentage of salable-sized tubers.

Tuber infection in the soil does not appear to be a serious cause of loss, except under badly drained soil conditions. Infection at lifting time has been responsible for heavy losses in the past, and this has been largely a consequence of a short growing and lifting season, coupled with wet lifting conditions. It has, for example, been an important problem in Aroostook County (growing season 120 days), but much less important on Long Island (growing season 150 days). The use of insecticides, principally DDT, tends to intensify this problem, as potato tops remain green longer where these are used. Efficient haulm killing methods should largely prevent this type of blight loss.

BLIGHT AND WEATHER DATA

Among the most important factors that influence the development of epidemics in particular districts are the weather conditions in the 2 months preceding the month of lifting the crop. Thus, in Aroostook County, where the main harvest month is September, the weather in July and August largely decides the severity of the blight attack. Table 86 sets out the average temperature and rainfall figures for the 2 months before the lifting month as against the frequency of severe blight years in 5 potato-growing areas in the United States. These are the 4 areas that have already been considered in detail, together with the North Platte Valley in Nebraska, an irrigated district in one of the Western States in which severe blight epidemics do not occur.

TABLE 86. --Average monthly temperatures and rainfall before lifting and frequency of blight years in 5 U.S. areas

Area	Average monthly temperature--		Average monthly rainfall--		Frequency of severe blight years
	2 months before lifting	1 month before lifting	2 months before lifting	1 month before lifting	
	°F.	°F.	Inches	Inches	Percent
Aroostook County, Maine.....	64	62	4.0	3.3	50
Hastings, Fla.	63	69	2.9	2.4	16
South Fork, Long Island, N. Y.	70	69	3.0	3.8	10
Red River Valley, Minn. and N. Dak..	68	66	3.4	2.9	10
North Platte Valley, Nebr.	71	62	2.4	1.3	--

The frequency of severe blight years has been expressed as a percentage. Thus, a percentage of 50 means that 1 year out of 2 is a severe blight year. A "severe blight year" is defined as a year in which there is a loss of more than 10 percent in yield on unsprayed potato crops as a result of premature defoliation.

AROOSTOOK COUNTY: The temperature and rainfall conditions are very favorable to blight. The diurnal range of temperature during the potato-growing season is about 20° F. Very hot days are uncommon. Rainfall is well distributed and relative humidities are average.

HASTINGS: Temperatures are higher than in Aroostook, but are not so high as to limit seriously the development of blight. However, it should be noted that temperatures are continuing to rise here at the end of the growing season, whereas in Aroostook they are falling. Diurnal range of temperature is approximately 20° F. Rainfall is low and badly distributed, and this together with the fact that it is an early crop being grown in the area are probably the chief factors limiting blight losses.

SOUTH FORK, LONG ISLAND: High temperatures limit blight development. Rainfall is higher than in Aroostook, and relative humidities are also high. Conditions here are similar to those in the potato-growing region of eastern Virginia, where Cook (1949) has reported that only 2 years out of 31 were severe blight years. Average total rainfall for the 2 months before lifting at Norfolk, in eastern Virginia, is 8.0 inches, but average monthly temperatures at 66° and 74° F. limit the the development of the disease.

RED RIVER VALLEY: The average temperature and rainfall figures suggest a greater frequency of blight years than, in fact, occurs. The average temperature figures are obscuring a much greater diurnal range of temperature than in Aroostook County. In the Red River Valley, the diurnal range is from 25° to 30° F., and very hot days are quite frequent, with the temperature rising above 100° on occasional days. Rainfall is well distributed, but relative humidities are low. The area is also subjected to strong drying winds during the potato-growing season.

NORTH PLATTE: Temperature conditions are similar to those in the Red River Valley. This and the low rainfall account for the absence of blight.

The general picture for the U.S.A. is that high temperatures are one of the chief factors limiting blight development. In the Western States, high temperatures are normally combined with low rainfall to make conditions even more unfavorable to the fungus. The coolest growing areas, which are also wet ones., are in the New England States, and these are also the areas in which potato blight is most severe.

CONTROL MEASURES

The two most marked features of the control of potato blight in the United States are (1) the intensive control program followed by almost all growers in those areas where blight occurs to any extent, and (2) the preponderant use of organic fungicides (Cox, 1957).

The justification for an intensive control program must be considered on economic grounds, but there are a number of basic reasons why the United States growers are spray conscious. Many of them, particularly in the important potato areas, such as Aroostook County, are potato specialists. They keep no livestock, and the other crops they grow are there primarily to give the land a rest from potatoes or to build up soil fertility. Another type of specialist is the man who produces two crops a year. He grows a summer crop of potatoes in the north and then moves south with his equipment to grow a winter crop. The result of this specialization

is that most growers have their own spraying equipment and, concentrating most of their efforts on one crop, wish to make the best possible job of it. In addition, there is the need to deal with a wide range of insect pests, so that in the potato-growing areas of the United States, spraying would go on even in the absence of blight. It thus becomes very difficult to decide what is the true cost to the grower of spraying against blight, since he will be using the same equipment as he uses against insect pests, and in some treatments antipest and antiblight sprays will be combined. In addition, if he is a specialist with specialized equipment and stops spraying against blight, about the only thing he saves is the cost of the fungicide, as the productive alternatives for his men and equipment are probably nil.

Whether a routine program for blight control is needed in any particular area in the United States can best be decided by considering the effect of the disease on unsprayed crops. No large-scale surveys of the amount of defoliation caused by blight on unsprayed crops have been carried out. Indeed, in areas like Aroostook County, where all the growers spray, they cannot be carried out. In the absence of survey material, the results of spraying trials must be used, but it is pertinent to ask how true a picture of the uncontrolled disease the unsprayed plots in these trials give, surrounded as they are by sprayed potatoes.

With these points in mind, the yield losses caused by blight on the unsprayed plots at Aroostook Farm, Maine, over the period 1950-55 (table 77) can be considered in relation to the cost of a routine control program. Table 87 sets out these losses, which have been estimated from the 75 percent blight defoliation dates in relation to the potato growth curve (fig. 62). No account has been taken of tuber blight losses, which in any case were very small.

TABLE 87. --Percentage loss of yield due to blight on unsprayed potatoes Aroostook Farm, Maine, 1950-55

Year	Loss
	Percent
1950	15
1951	15
1952	--
1953	--
1954	40
1955	--
Average	12

The average yield of potatoes in Maine is approximately 360 bushels per acre, so that an annual average loss of 12 percent represents a loss of 43 bushels per acre. In monetary terms, putting the value of 1 bushel of potatoes at $1 (a low figure), this equals an annual loss of $43 per acre. This loss has been prevented by spraying. Assuming an annual average application of 6 sprays at $5 per spray ($2 for materials), the annual cost of spraying amounts to $30 per acre. This cost is seen to be well-justified, particularly as one benefit not taken into account in these calculations is that there is a higher proportion of Grade 1 tubers from the sprayed potato crop in blight years.

At the other extreme, the value of a routine control program in the South Fork of Long Island or the Red River Valley in Minnesota and North Dakota appears very questionable when viewed against the fact that the frequency of recent blight years has only been 1 year in 10. The application of 4 antiblight treatments at $5 each for a period of 10 years costs $200 per acre, which exceeds the average value of an acre of Minnesota potatoes. Wallin and Hoyman (1945) have stated that a lengthy control program is not warranted in the North Dakota part of the Red River Valley.

Cook (1949) wrote that "the routine application of fungicides that is so often recommended is economically sound only for those areas where disease losses occur with sufficient regularity so that the benefits over a period of years will profitably counterbalance the cost of spraying or dusting every year." He stressed the need for an effective blight warning service that would tell the growers the years in which spraying is unnecessary, and thus save them considerable sums of money. By advising potato and tomato growers in eastern Virginia not to spray during 1947, Cook considered that he saved them up to $2,000,000.

One criticism of the U. S. control program that has been developed in Aroostook County (see p. 126) is that spraying goes on too long in an endeavor to keep the haulm completely free from blight up to lifting. With the present use of haulm killers, the last 1 or 2 sprays should be unnecessary.

The advantages or disadvantages of using organic fungicides have been discussed under Aroostook County. One of the most important advantages of these materials is that in hot dry summers when blight is absent, they do not have a phytotoxic effect with a consequent lowering of the yield of the sprayed crops. Stevenson, Akeley, and Webb (1955) and Eddins and Clayton (1943), among others, have referred to this phytotoxic effect where copper materials are used. However, copper is still generally recognized as being a more effective control of blight in bad blight years, and when these years occur there is a marked tendency for growers to switch back to copper sprays during the bad season.

METHODS OF SPRAYING

The U. S. grower appears to have very effectively cut down the losses normally associated with spraying. In addition to relying chiefly upon organic fungicides, he grows his potatoes in wide rows (36 inches) and fits wheel guards to his tractor and sprayer wheels. If there is a tendency for yield per acre to fall to some extent as a result of these wide rows, it should be remembered that with its vast land resources, output per man and not output per acre is the primary consideration in North America. Another factor minimizing wheel damage losses is the growing of upstanding potato varieties, like Katahdin and Red Pontiac, which have replaced some of the older more sprawling varieties, such as Green Mountain. Against this, however, it should be remembered that the very large number of spray treatments so often given will have a tendency to overcompact the soil between the potato drills with a consequent adverse effect on the growth of the crop.

In general, high-volume spraying (100 to125 U.S. gallons per acre) is used, although in Aroostook County low-volume spraying has gained very rapidly in popularity during the last few years, and now 70 percent of the growers are spraying at low volume. Dusting is carried out in a few areas where water is in short supply, but spraying is generally recognized as being the more efficient technique.

Top spraying without the use of drop lances is universal. The grower aims to protect the lower foliage by starting his spray program early and keeping pace with the growth of the crop. But in view of the known poor adherence of the organic fungicides, his outlook on this point appears sanguine. There seems to be a tendency for the growers to make rather a fetish of spraying, without considering too closely the efficiency of the job they are making.

HAULM, OR VINE, KILLING

The interest in "vine" killing is of comparatively recent origin and most of the work on the subject has been reported since 1945. Apart from preventing blight infection of the tubers at lifting time, the practice has a number of other advantages, including (1) the control of tuber size in seed crops; (2) prevention of late-season spread of virus diseases in seed crops; and (3) easier harvest by destroying top growth and weeds.

Haulm killing is now widely practiced throughout the potato-growing regions of the United States. In an area like Aroostook County, where it has obvious advantages on a number of counts, it is more or less universally carried out every year. Various methods are used; of these, spraying with sodium arsenite or with the dinitro compounds, in particular DNBP, is the most common. Rose and Cook (1949) have reviewed these and other methods used in the United States. Tops are also killed with chemical dusts (calcium cyanamide), by rotobeaters and flame burners.

A number of writers have reported a browning of the stem end of tubers in crops treated in this way, and also a vascular discoloration of the tubers. Peterson and Gwinn (1952) have summarized the literature on this subject, which contains a large amount of conflicting evidence. In general, however, workers agree that one of the principal factors involved in the use of chemical sprays is the speed with which the haulm is killed; and the faster the rate of killing, the more likely is vascular discoloration to occur. The fact that this trouble has been widely reported in North America and not from the British Isles would indicate that it is associated with the relative immaturity of the American crops at killing. At the present time (1957), vascular discoloration brought about by vine killing appears to be of little importance in the United States. This may be associated with a greater use of sodium arsenite, which kills the tops slowly.

POTATO BLIGHT FORECASTINGS

The first attempts in the U.S.A. to forecast blight outbreaks by an analysis of weather data were made by Moore (1937) for the Charleston area of South Carolina, and Melhus (1945), who has reported on a blight forecasting service that issued warnings during 1943 and 1944 to potato growers in the Upper Mississippi Valley States.

Cook (1949) developed a blight forecasting method for eastern Virginia based on weekly mean temperatures and cumulative rainfall. The critical temperature above which blight would not be important was considered to be 75° F. Cumulative rainfall data from past blight and nonblight years was used to fix a "critical rainfall line," which by definition was "a straight median line ... constructed between the lines for rainfall for the blight and nonblight years."

Blight forecasts were based on a 2-week period during which the mean weekly temperatures remained below 75° F., and the actual cumulative rainfall line remained above the "critical rainfall line." Growers were told not to spray when weekly mean temperatures were above 75° F. and/or the actual cumulative rainfall line fell below the "critical rainfall line" for a period of 2 weeks. The method was said to be 84 percent accurate for eastern Virginia.

Cook (1947) considered that "the purpose of the forecasts is to eliminate needless spraying or dusting in years when blight is not important and to insure prompt and adequate protective measures in years when it threatens to cause serious damage." The emphasis here, on

preventing needless spraying is interesting, but is readily explained by the fact that only 2 out of 31 years in eastern Virginia had been bad blight years. Cook used his method successfully in 1947, when he issued four warnings to potato and tomato growers not to spray. His forecasting charts for 1946 (a "blight" year), and 1947 (a "nonblight" year), are reproduced as figure 67.

More recently, studies have been made in the North Central States by Wallin and Waggoner (1949); Wallin and Samson (1953); and Wallin, Wade, and Darling (1953); and in the Northeastern States by Hyre and Horsfall (1951); Hyre and Bonde (1955); and Hyre (1954 and 1955), to test the efficiency of Cook's method under differing climatic conditions. Wallin found that in Iowa, Indiana, and Wisconsin, cumulative rainfall and temperature data alone did not give a sufficiently reliable basis on which to issue blight forecasts, and this he attributed to the lack of correlation between periods of high humidity favorable to the fungus and the amount of rainfall. In further studies in North Dakota and Minnesota, Wallin and Hoyman (1954) and Wallin, Eide, and Thurston (1955) have used the frequency of 10-hour periods during which the temperature does not exceed 75° F. and the relative humidity does not fall below 90 percent with subsequent daily temperature maxima remaining below 95° to predict the development of blight. Hyre (1955) has reported that a modification of Cook's method has been tested out successfully in a number of the Northeastern States. The chief difference between this and Cook's original method is the replacement of a fixed "critical rainfall line" by moving graphs based on the total precipitation over a 10-day period.

The fact that cumulative rainfall forms a reasonable basis for making forecasts in eastern United States, whereas it is unreliable in the North Central States, may be associated with the greater frequency and larger amounts of rain that occur in the east. There is one great advantage in the use of simple rainfall and temperature data for making forecasts in that this information is readily available through the United States Weather Bureau, while humidity data is not generally available.

At the present time (1957), potato blight forecasting in the United States is still in a very experimental stage. Some of the difficulties with which it has to contend have already been discussed in the section on the Red River Valley. The collection and the dissemination of information on blight occurrence, spread, and severity are accomplished through the U.S.D.A. Plant Disease Survey, of which Paul R. Miller is the head. This is centered at Beltsville, Md. Cooperating State pathologists provide the information on which the blight situation for the country as a whole is built up, and they receive the full picture back from Beltsville in the form of twice-weekly newsletters.

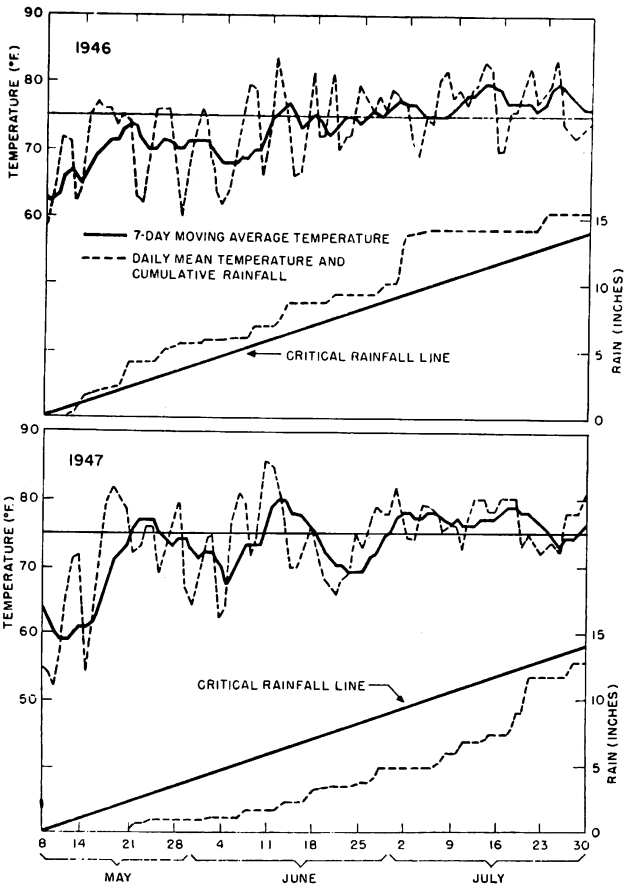


FIGURE 67.--Forecasting charts for a blight year (1946) and a nonblight year (1947), at Norfolk, Va. (From Cook, 1949.)

BREEDING FOR BLIGHT RESISTANCE

The United States Department of Agriculture and the State experiment stations cooperating in the National Potato Breeding Program are now responsible for the very large majority of new varieties released to the farming community. The aim is not to produce a number of varieties that can be grown throughout the country but to breed varieties suited to the particular needs of the various States, which differ widely. However, the cooperative nature of this work makes it possible to find varieties that have a wide adaptability, e.g., Kennebec. Stevenson (1956), who was in charge of this work until recently, has described the progress made in producing potato varieties resistant to various diseases, including late blight, and resistance to insect pests.

The story of the search for American blight-resistant potato varieties has been given in detail by Peterson and Mills (1953). Pioneer work in the use of Solanum demissum as a source of blight resistance was carried out by Reddick at Cornell University; and Reddick and Peterson (1945) have described the characteristics of Empire, the first "blight resistant" variety to be introduced in the U.S.A. Empire was first grown in 1940 at the Cornell University Agricultural Experiment Station, Ithaca, N. Y., and placed in the hands of commercial seed-potato growers in 1945. At the time of its introduction, Reddick and Peterson wrote of its blight resistant qualities, ". . . it must be assumed for the present that Empire ultimately may break down." This, in fact, proved to be the case; and this breakdown has been repeated with more recent introductions, where resistance has been based on major genes, owing to specialization of the blight fungus. The most successful of the "blight-resistant" varieties to come onto the market has been Kennebec, which contains the R_1 gene for blight resistance. This variety has been described in detail by Akeley, Stevenson, and Schultz (1948). Although Kennebec was quickly attacked by blight, both the haulm and the tubers, the variety possessed other desirable commercial properties, and it is now widely grown, particularly in Maine. The position is, however, that where Kennebec is grown, it now almost always receives a full antiblight spray schedule.

Breeding for field or partial resistance to blight is now considered to be the most hopeful approach to the problem. Some of the newer American potato varieties, in particular, Sebago, show a higher degree of field resistance than the old varieties like Green Mountain, which they are replacing. Up to the present, this trend cannot be said to have had any effect on the intensity of the farmers' blight-spraying programs.

Much research into the genetics of blight resistance and the various physiologic races of Phytophthora infestans, including the "plasticity" of the fungus, has been carried out in recent years. The principal workers in the United States now dealing with these aspects of the disease are W. R. Mills of the Pennsylvania State College, L. C. Peterson of Cornell University, and M. E. Gallegly of the University of West Virginia. Mills and Peterson have cooperated with Black of Scotland and Mastenbroek of Holland to produce a universally accepted, international nomenclature for blight races (Black, Mastenbroek, Mills, and Peterson, 1953).

SUMMARY: UNITED STATES OF AMERICA

Potatoes are grown under a great range of conditions, and the incidence of blight varies considerably between different regions. An intensive study has been made of blight epidemics in four widely separated areas and this has illustrated the variation in blight problems throughout the country. The disease is most serious in northeastern United States, where summers are cool with abundant rainfall, i.e., the best conditions for maximum potato crops. The overall yield losses associated with severe blight years, however, may not be great, as has been shown by a comparison of yields in a number of recent slight and severe blight years in Aroostook County. Average yields for the two sets of years were very similar.

Possible loss of crop yield through premature defoliation does not appear to have played such an important part in shaping the farmer's control program against blight as the fear of tuber blight infection. Until recently, heavy tuber losses were common, and these followed the lifting of crops while some green, blighted haulm remained alive. That the haulm was still green reflects the short growing and harvest periods for the crop throughout large parts of the United States. Thus, the farmers' intensive antiblight schedule aimed and still aims at keeping the potato tops free from blight to prevent infection at harvest. The present use of haulm killers should enable farmers to cut down on the number and frequency of their blight-preventive spray treatments.

CANADA

The area planted with potatoes in Canada is approximately 300,000 acres per annum. In 1940, just over half a million acres were grown, but plantings have fallen steadily since then. On the other hand, production methods have shown a consistent improvement, so that total production of potatoes, which is normally between 60 to 70 million bushels per annum (1 bushel weighs approximately 60 lb.), has remained at about the same level over recent years (Parks, 1955a). Approximately 85 percent of the acreage planted produces table stock (ware) potatoes, and the remaining 15 percent is devoted to seed-potato production. There is an important market for Canadian seed potatoes, principally in the United States, Argentina, Uruguay, and Cuba.

The average annual consumption of potatoes is somewhat higher in Canada than in the United States. It is now about 150 lb. per head per year, but there is a marked downward trend in the face of competition from other vegetables. The annual yield is just under 6 tons per acre.

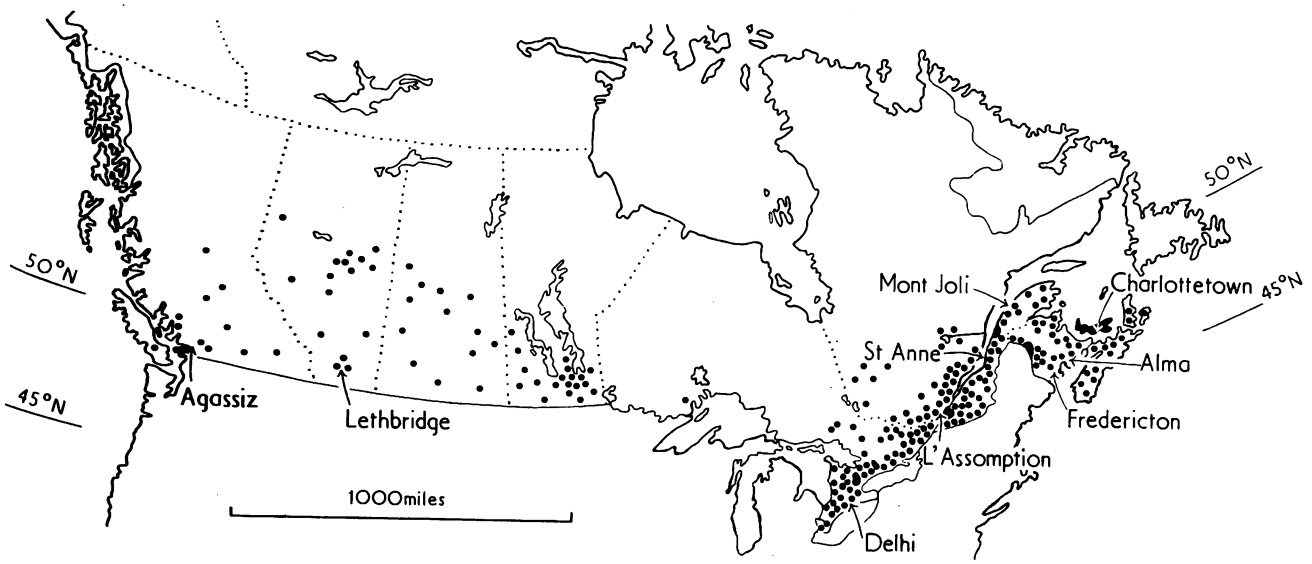


FIGURE 68.--Distribution of potato growing in Canada, 1953. Each dot equals 1,000 acres.

POTATO DISTRIBUTION AND VARIETIES

Potatoes are grown to some extent in all the Canadian provinces, but conditions are not very favorable to the crop in central Canada, and the largest concentrations are in the east (see fig. 68, after Hudson, Stutt, Van Vleit, and Forsyth, 1949). Important growing areas are the Maritime Provinces, notably Prince Edward Island and the St. John Valley in New Brunswick; the Gaspé Peninsula and an area round Montreal in Quebec Province; and the counties north and west of Toronto in Ontario. About 85 percent of the total Canadian certified seed crop is grown in Prince Edward Island and New Brunswick; each province grows about 25,000 acres of seed potatoes per annum. In western Canada there is an important potato district in the Lower Fraser Valley of British Columbia. Table 88, taken from figures published by the Dominion Bureau of Statistics, shows the breakup of the Canadian potato acreage by province in 1953, which was a year of generally high yields. These illustrate the better growing conditions for potatoes that are found in the areas nearest the oceans.

Potato statistics are not published for Newfoundland. Wart disease (Synchytrium endobioticum) exists there and potatoes cannot be exported from Newfoundland to any other of the Canadian provinces.

The varieties grown in Canada are almost all the same as those in the U.S.A., the most important being Katahdin, Sebago, Irish Cobbler (early), and Green Mountain. The only varieties of importance that do not appear in the United States list are Canso and Keswick, which were bred specifically for blight resistance and have been derived from initial crosses using Solanum demissum as one of the parents.

SOIL, CLIMATE, AND CULTIVATION

Potatoes are grown over a wide range of soil types from the red sandy loams on Prince

TABLE 88. --Acreage and yield of potatoes in Canada, 1953

Province	Acreage	Yield
	1,000 acres	Bu./acre
Prince Edward Island	39	273
Nova Scotia.....	12	231
New Brunswick.....	49	289
Quebec.....	100	166
Ontario.....	63	189
Manitoba.....	19	170
Saskatchewan.....	13	131
Alberta.....	15	179
British Columbia....	11	300
Total or average..	321	209

Edward Island to the dark organic soils of the Red River Valley in Manitoba. The length of the growing season is almost everywhere short (not more than 120 days). This is mainly due to a late spring, and it affects not only central Canada, but also the Maritime Provinces, which are subjected to the cold Labrador current of the North Atlantic and the cold winds that sweep down from the interior of northern Quebec. The longest and most equable growing season occurs in the limited area of the Lower Fraser Valley and on Vancouver Island in British Columbia, and this is reflected in the high yields of potatoes grown there.

The same degree of specialization does not exist among potato growers in Canada as in the U.S.A. Nonetheless, even on so-called mixed farms where potatoes are grown, the range of crops is probably smaller than on European farms producing potatoes. Growers are usually well equipped mechanically, and nearly all of them have their own spraying machines. Potato cultivations are very similar to those carried out in the U.S.A., and have been described in detail by Parks (1955b).

POTATO BLIGHT INVESTIGATIONS

Research on the disease in Canada has tended to concentrate on two main problems. First, the chemical control of blight: This includes the testing of different fungicides and haulm (vine) killers. Most of this work is now done at the Science Service Laboratory, Charlottetown, P.E.I. Second, the identification of blight races and the breeding of blight-resistant varieties: This work has been carried out at the Science Service Laboratories at Fredericton, New Brunswick, and Ottawa.

The Dominion Laboratory at Charlottetown is famous as a center of research into potato diseases. It was founded in 1915, and the first Plant Pathologist-in-Charge was Paul A. Murphy, who, both on Prince Edward Island, and later in Eire, did much fundamental work on the biology and control of Phytophthora infestans. A case study treatment of Prince Edward Island is now given, followed by a generalized account of blight, covering the whole country.

Prince Edward Island

Prince Edward Island has a total area of about 1,000,000 acres. Between 35,000 and 40,000 acres of potatoes are grown annually, producing an average yield of approximately $6\frac{1}{2}$ tons per acre. About 70 percent of the total potato acreage is used for the production of certified seed.

The most important variety grown is Sebago, most of which is exported as seed. Other varieties grown are Green Mountain (principally for home consumption), Irish Cobbler, Katahdin, and the blight-resistant varieties Kennebec, Keswick, and Canso. There is a very characteristic red sandstone soil on the Island. The most intensive farming is carried on in Prince County in the northwest and most of the potato crops are grown there.

The potato-growing season extends from the end of May to the end of September (about 110 to 120 days). The Island is subjected to cold air currents from the north until late into the year, which accounts for the late planting time. Average temperature and rainfall data for Charlottetown are set out in figure 69. Summer temperatures are not high, and it is unusual for the thermometer to go above 85° F. Annual rainfall is about 42 inches with a slight peak in the autumn and winter. In general, apart from the shortness of the season, growing conditions are very favorable for potatoes.

Frequency of Blight Epidemics

Descriptions of blight epidemics on Prince Edward Island are included in the Annual Reports of the Canadian Plant Disease Survey. In a number of years estimates of yield losses caused by premature defoliation due to blight and estimates of tuber blight losses have been made. These, together with the field outbreak dates and an appraisal of the severity of the disease supplied by L. C. Callbeck of the Science Service Laboratory, Charlottetown, are set out in table 89 for the period 1945-54. (In those years where no estimates have been given, yield losses were described as low.)

A clear picture of epidemics on Prince Edward Island is shown up by this table. In 4 years out of 10 (the "severe" years), blight occurred early, continued to spread, and caused heavy overall losses through premature defoliation of the potatoes; in 1 of these 4 years, tuber blight losses were also heavy. In 4 years out of 10 (the "severe (late)" years), the disease was widespread at the end of the season and caused little loss through defoliation, but in the 2 out of the 4 years it brought about large tuber blight losses. In 2 years out of 10, the disease was present in only trace amounts and losses were negligible. There is no doubt that blight is a most serious

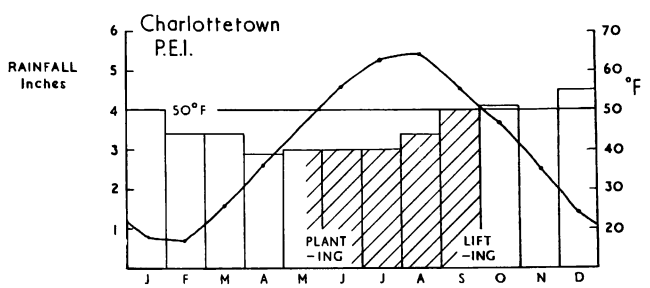


FIGURE 69.--Long-term average monthly rainfall and mean temperature for Charlottetown, Prince Edward Island, Canada. (For climagrams for Fredericton, Lethbridge, and Agassiz, see fig. 71.)

TABLE 89. --Outbreaks and losses from blight on Prince Edward Island, Canada, 1945-54

Year	Outbreak date	Severity	Defoliation losses	Tuber blight
			Percent	Percent
1945	July 14	Severe (late)	0	2-5
1946	End Aug.	Trace (late)	--	--
1947	July 22	..do	--	([1])
1948	July 26	Severe	5-10	8
1949	End Aug.	Severe (late)	--	10-12
1950	Mid-Aug.	..do	--	10
1951	July 20	Severe	20	--
1952	July 21	Severe (late)	--	--
1953	July 10	Severe	20	--
1954	July 19	..do	15	--

[1] Trace.

problem on the Island, particularly when it is remembered that the losses described above occurred despite an intensive control program.

Blight Losses Due to Premature Defoliation

Estimates have been quoted above of yield losses from premature defoliation. These estimates referred to the Island as a whole, and losses on unsprayed crops would have been considerably more serious. This can be seen from figure 70, which shows the progress of blight on potato haulm, and the yield of sprayed and unsprayed potatoes (over the period 1948-55) from trials held at Charlottetown. The results of these trials have been published in the Annual Reports on Potato Fungicides by L. C. Callbeck for 1949-55, and for 1948 by Callbeck (1949a). If the difference in yield between the sprayed and unsprayed plots is taken as being approximately equal to the yield loss due to blight (a fair assumption in these trials), then the average loss from blight over the 8-year period (1948-55) at this center equaled 26 percent of the potential crop, and in no year did it fall below a 10-percent loss of crop.

The variety each year for these trials was the susceptible Green Mountain, whereas the variety most commonly grown on the Island is Sebago, which shows a high degree of field resistance to blight. The results on the sprayed plots shown in figure 70 refer to the plots sprayed with bordeaux mixture. In 3 out of the 8 years (1948, 1953, and 1955), the sprayed plots were artificially inoculated with Phytophthora infestans, but these 3 years were all years of severe blight epidemics on Prince Edward Island, and the inoculation is unlikely to have had much effect in increasing blight losses. The yield loss in 1952 seems very high in relation to the progress of blight on the haulm of the unsprayed plots, even though planting was very late that year. The results in 1952 must therefore be considered anomalous. Nevertheless, it will be seen that blight losses are very heavy, and heavy nearly every year.

Blight in Tubers

The amount of tuber blight in the sprayed (bordeaux) and unsprayed potato plots at Charlottetown are set out in table 90.

TABLE 90 --Tuber blight in sprayed and unsprayed plots, Charlottetown, Prince Edward Island, 1948-55

Year and average	Amount of tuber blight in--	
	Sprayed plots	Unsprayed plots
	Percent	Percent
1948	0.4	6.6
1949	.3	20.4
1950	1.3	18.1
1951	1.1	9.3
1952	.3	8.8
1953	.6	4.1
1954	.9	1.6
1955	1.0	7.2
Average	.7	9.5

Here again, the variety in the trials was Green Mountain, which is highly susceptible in the tubers; Sebago is resistant in the tubers. Thus, the high degree of infection while the potatoes were still in the ground can to a large extent be explained by the susceptibility of the variety under test. Even so, it is remarkable that tuber rot losses in the unsprayed plots should be so high almost every year, and this would appear to be connected with the generally high moisture content of the Island soils.

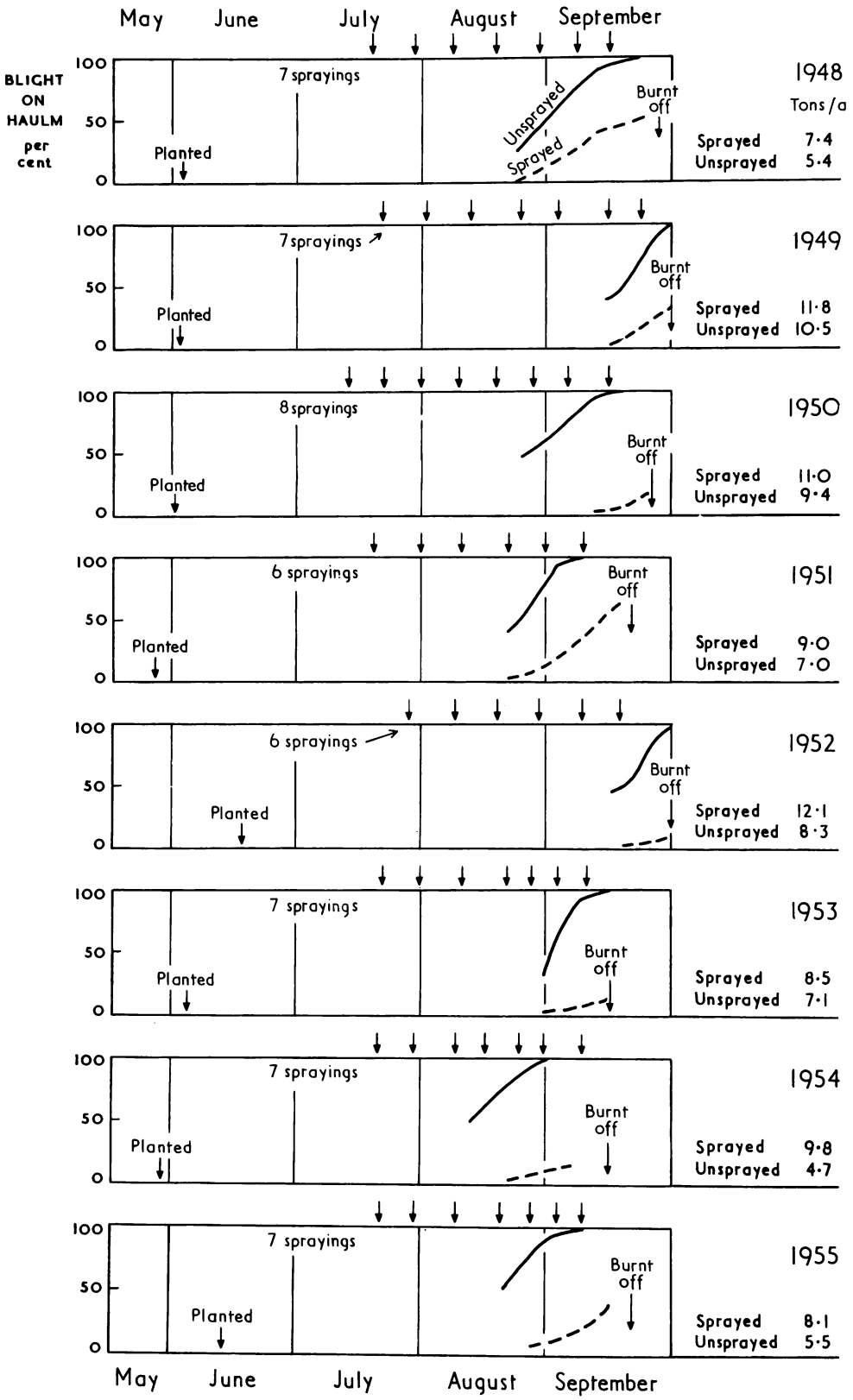


FIGURE 70.--Progress of blight on haulm of sprayed and unsprayed Green Mountain potatoes, with corresponding total yields in tons per acre, Charlottetown, Prince Edward Island, 1948-55.

The estimates of tuber blight losses in the commercial crop quoted in table 89 show that in some years (as in 1948, 1949, 1950) losses are very heavy. In the past, a high proportion of this loss will have followed the infection of the tubers by blighted haulm at lifting time, and this is understandable in an area with a short growing season like Prince Edward Island. Haulm killing has now greatly reduced tuber blight losses in the commercial crop, but heavy tuber infection via the soil can still occur on the Island, if the combination of an unsprayed crop and a blight-susceptible potato variety exists.

Blight and Weather Data

Mean air temperature and rainfall figures for the experimental station at Charlottetown are shown in figure 69, together with the planting and lifting times of potatoes. Temperatures are usually favorable to the development of blight throughout the growing season.

The average total rainfall for the July-to-September period at Charlottetown is 10.53 inches. L. C. Callbeck has set out the July-to-September rainfall against the severity of blight for each year over the 34 years, 1922-55. The results are shown in table 91.

The precipitation for the period ranged from 6.38 inches in 1945, when blight was severe at the end of the season, to 20.1 inches in 1942, a year of an early and severe attack. In 1935 there was no blight with 15.7 inches of rain, but it was severe in 1951 when the precipitation was almost identical, 15.6 inches. Both 1954 and 1955 were very bad blight years, although rain was below normal. In 1954 there were 8.85 inches during July to September, and in 1955, 8.78 inches.

Although there is a broad correlation between the amount of rain and the severity of blight, the number of years that are exceptions to a general rule indicate that total rainfall figures alone are insufficient to divide the "nonblight" from the "blight" years. Callbeck has given the main reasons for this: "A total July to September precipitation of above average might be made up largely of infrequent heavy rains, each of which was quickly followed by conditions favoring rapid drying, and thus making it impossible for the fungus to become established. On the other hand, the summer might be characterized by numerous light rains and drizzles whose total fall would be considerably below average, but which coupled with dews and periods of high relative humidity, would keep the foliage damp for many hours at a time."

TABLE 91. --Severity of blight in relation to rainfall, Charlottetown, Prince Edward Island, 1922-55

Total rainfall, July to September (inches)	Years with--		
	No blight	Trace of blight	Severe blight
	Number	Number	Number
Below 9.5.....	2	6	5
9.5-11.5.....	1	2	7
Over 11.5.....	1	1	9

Since 1951, in an attempt to find a closer relationship between weather conditions and the severity of blight epidemics, studies of weekly weather records, including humidity data, have been made in relation to the occurrence of the disease. Table 92 shows the weather summary for 1954.

The first field outbreak of blight in 1954 occurred on July 19, and in unsprayed fields potato tops were dead by early August. Those farmers who sprayed got through this period, and conditions became less favorable to blight after the middle of August.

From the records kept since 1951, it seems that blight makes its appearance about a fortnight after the first week following July 1 in which the average relative humidity remains at 80 percent or above. A week at this humidity level once blight has started increases the disease. This fits in well with what happened in 1954. Weekly humidity figures are now being used on Prince Edward Island as one of the main criteria on which potato blight forecasts are based.

Control Measures

The importance of cull piles as a source of blight inoculum has been recognized for a number of years, and a successful campaign has been waged against them. In the summer of 1956, so far as was known, there was only one potato cull pile in existence on the Island. During recent years, Green Mountain has become considerably less important on Prince Edward Island, and Sebago increasingly important so that it now dominates all other varieties. The use of Sebago may be looked upon as a partial control measure against blight, as this variety exhibits a high degree of field resistance to the disease. However, the differing susceptibility of Green Mountain and Sebago must not be looked upon as the main reason for the substitution of the one variety by the other. Green Mountain fell into disrepute with table stock growers, owing to net necrosis, which develops in the tubers following primary leaf roll infection. The chief advantages from the point of view of blight control in growing Sebago are that the progress of the disease can be kept in check on this variety with fewer spray applications than are required on Green Mountain, and that tuber blight infection is considerably less.

TABLE 92. --Weather summary at Charlottetown, Prince Edward Island, 1954

Week	Mean temperature	Average humidity	Rain	Days with rain
	°F.	Percent	Inches	Number
July 1-7	64.9	80.0	0.35	3
July 8-14	66.6	70.6	.17	2
July 15-21	65.8	86.0	2.25	5
July 22-28	66.3	88.4	1.21	3
July 29-Aug. 4	66.7	84.1	1.18	3
Aug. 5-11	62.6	88.6	.93	5
Aug. 12-18	62.6	80.1	.47	3
Aug. 19-25	63.0	78.2	.04	2
Aug. 26-Sept. 1	62.1	71.2	.58	3
Sept. 2-8	62.4	75.3	.44	1
Sept. 9-15	55.4	76.5	.60	2
Sept. 16-22	56.8	81.8	.18	1
Sept. 23-29	54.2	82.9	.45	4
Total	--	--	8.85	[1] 37

[1] In addition, there were 11 days over the period on which rain fell, though the amount was too small to be recorded.

The majority of potato growers on the Island follow an annual protective spray program against blight. Most of this spraying is carried out by the farmer, and there is very little contract (custom) spraying. Where dusts are used, however, they are usually applied by contractors. Practically all spraying is carried out at high volume (80 to 125 gal. per acre), and sprays are applied from above the crop only. The chief materials used are the carbamates (dithiocarbamates), but a fair proportion of the growers are still using bordeaux mixture, owing to its better adherence to the potato plants. The phytotoxic effect that occurs with the use of bordeaux in hot dry summers in other areas in North America has not been noted on Prince Edward Island. This, together with the fact that bordeaux is still being used extensively, despite the obvious disadvantages in preparing the material, emphasizes the usually wet and humid conditions under which potatoes are grown.

About half the antiblight sprays are combined with treatment against insect pests. These are the Colorado beetle, potato flea bettle, and aphids. Early blight (Alternaria solani) is not a problem. Haulm killing is now a common practice, and the principal chemical used is sodium arsenite. A few growers use calcium cyanamide in dust form.

A survey of the blight control practices of Prince Edward Island potato seed growers was carried out in 1953 (a severe blight year). Questionnaires were sent out by post to 300 farmers and 107 replied, which represents 2.4 percent of all seed growers on the Island. The results of this survey were presented in the 1953 Report on Potato Fungicides. A brief summary of the findings follows.

1. 77 percent of growers used a wet spray; 8 percent used a dust; 15 percent applied no fungicide.
2. Of those growers who used a spray, 48 percent used carbamates; 31 percent used bordeaux; 9 percent used fixed copper; 12 percent used a split schedule (carbamates followed by copper).
3. From 1 to 9 spray treatments were given; average 3.4 treatments. From 1 to 4 dust treatments were given, average, 2.8 treatments.
4. The average number of treatments given according to the type of material used were: Carbamates, 3.9; bordeaux, 3.2; split schedule, 3.0; fixed copper 2.1.
5. The number of sprays applied varied with potato variety: Average figures for Green Mountain were 4.8; for Canso, 4.3; for Katahdin, 3.5; for Sebago, 3.4; and on Irish Cobbler, 3.2.
6. 24 percent of the growers used a haulm killer.

L. C. Callbeck, commenting on this survey, stated that the average number of spray treatments given (3.4) was about half the optimum required to control blight in this year.

A considerable amount of experimental work with potato fungicides and on haulm killing methods has been carried out for some years now at the Science Service Laboratory at Charlottetown. This includes annual screening tests of new materals. Callbeck (1950a) has reported on investigations into the copper/lime ratios in bordeaux mixture, and the same

worker (Callbeck, 1954) has given details of the effect of incorporating zinc salts in potato fungicides. Haulm killing trials have been described by Callbeck (1949b). It has been found that less tuber blight has occurred in plots sprayed with bordeaux mixture than in those sprayed with organic fungicides in each year since 1945, when the organics were first tested at Charlottetown. Mean tuber blight percentages for the period 1945-51, were bordeaux, 0.7; nabam, 5.1; zineb, 6.9; unsprayed, 13.1 A possible explanation is the lethal effect on blight spores of copper residues accumulated in the surface soil, whereas dithiocarbamate residues remain toxic for a much shorter time.

A blight warning service for growers was started in 1947. Weekly press and radio reports based on field observations of the disease and current weather conditions are issued. Average weekly relative humidities exceeding 80 percent are considered to favor the onset or increase of blight. The Island is well placed to receive up-to-date reports on the progress of blight, since 70 percent of the potato crop is for seed, and 30 seed inspectors are out in the field during the summer months. A good deal of circumspection has to be exercised in the issue of blight warnings for the very reason that seed production is so important, and it is essential not to frighten away the buyer of the seed crop.

Summary: Prince Edward Island

Potato blight is a most serious disease on the Island. Average annual yield losses due to premature defoliation following blight attack on unsprayed plots at Charlottetown over the period 1948-55 equaled 26 percent of the possible crop. Premature defoliation also causes heavy losses in the commercial crop despite the control program. Tuber blight is a serious problem, particularly where a blight susceptible variety like Green Mountain is grown. However, now that haulm killers are available there should be good control of infection at lifting. This used to be a trouble due to the short growing season for potatoes. It is surprising that a survey carried out in 1953 revealed that 15 percent of the seed growers had no control program for blight.

BLIGHT EPIDEMICS: FREQUENCY AND LOSSES

The first records of potato blight in Canada go back to the early 1840's, when the disease was found in the Maritime Provinces. Since 1920, annual accounts of the severity of the disease in the different Canadian Provinces have been published in the Reports of the Canadian Plant Disease Survey.

Blight is most serious in the Maritime Provinces (Prince Edward Island, New Brunswick, Nova Scotia) and Newfoundland; in western Quebec and eastern Ontario; and in the Lower Fraser Valley of British Columbia. These are also the principal potato-growing areas in the Dominion and the areas where potato-growing conditions are most favorable. There is an obvious link between the blight areas in eastern Canada, and those in the Northeastern States of the U.S.A.

Blight has not been recorded to any extent north of latitude 52°, but only a few potatoes are grown in the north of the country, owing to the shortness of the growing season. H. N. Racicot has estimated that 30 to 40 percent of the losses due to blight in Canada are caused by premature defoliation of the potatoes, and 60 to 70 percent of the loss is due to tuber blight infection. Most of the tuber blight is caused by contamination with infected haulm at lifting time, and is therefore largely preventable. Blight infection in the soil is not, generally speaking, an important problem, and this is possibly linked with the fact that most potatoes are grown on light soils.

The Annual Reports on blight have been examined in detail for the 10-year period 1946-55, and much of the data for individual areas given below, including quotations on the course of the disease in blight years has been obtained from this source.

MARITIME PROVINCES. Prince Edward Island is the worst area for blight in Canada, and L. C. Callbeck has described the frequency of severe blight years there as 3 years out of 4. The disease is not quite so serious in Nova Scotia and New Brunswick, and the frequency in those provinces is about 1 year out of 2.

The principal potato-growing area in New Brunswick lies in a narrow strip of about 60 miles in the St. John River Valley, along the western boundary of the province. This area is opposite the potato-growing district in Aroostook County, Maine, which has been considered in detail in the section of this study covering the U.S.A. The chief difference between the two areas is the greater acreage and concentration of potatoes on the U.S.A. side of the border, but the importance of blight and the problems that the disease presents are very much the same. In New Brunswick 1954 was a bad blight year. The following extract shows how serious the disease was. "Late blight was first reported in N.B. on 16 July . . . The disease developed rapidly and by mid-August practically every field in the potato growing areas showed some infection. Some fields, particularly Irish Cobbler were already completely killed . . ." On a number of occasions, including 1956, the initial blight outbreaks in New Brunswick took the form of an attack concentrated in stem lesions and lesions on the growing points of the potato plants. No satisfactory explanation has been put forward to account for this type of attack, and it does not seem to be correlated with potato variety. However, once stem lesions have been

established within a crop and the weather becomes favorable for blight development, the potato field is then destroyed very rapidly.

The principal losses in New Brunswick result from yield reduction caused by premature defoliation. Haulm killing has cut out a large part of the tuber infection that used to occur. Infection in the soil is not usually a serious problem due to the large "hills" and light soils in which the potatoes are grown. J. L. Howatt has drawn a distinction between those years in New Brunswick when the disease has been severe and those years when it has caused severe losses. The disease is said to be severe in 1 year out of 2, but in many of these severe years, farmers who follow a regular control program are able to keep the disease under control, and overall potato yields for the province may even be enhanced by the wetter growing conditions. Occasionally, the wet weather may be so continuous that the spraying program breaks down because the farmer cannot get his machine through the crop. This happened in 1954, with the result that most crops were prematurely defoliated and there were heavy yield losses. Years like this occur about 1 year in 8. They are reflected in high potato prices during the autumn and early winter. In fact, Howatt has gone so far as to define a bad blight year in New Brunswick as a year in which the price of table stock potatoes exceeds $3 per bushel shortly after harvest!

QUEBEC. In this province, blight was severe in 5 out of the 10 years from 1946 to 1955. The importance of the disease varies with district, and it is worst in the area around Montreal, where the frequency of severe blight years is about 1 year in 2. Along the south bank of the St. Lawrence from St. Anne-de-la-Pocatière to Mont Joli, the frequency is about 1 year in 3. The chief climatic differences between the Montreal and this area are the cooler growing conditions along the St. Lawrence and the tendency for dew formation to be less there than in western Quebec, owing to the more northerly latitudes with shorter nights.

Although the first field outbreaks of blight in the province may occasionally be reported in early- to mid-July (as in 1954), the disease in general appears later in Quebec than in the Maritimes; tuber blight losses rather than yield reduction following premature defoliation constitute the main problem. The course of events described for 1952 seems to be typical of a severe blight year in Quebec Province: "Late blight was first reported in fields about August 6 . . ., and by August 18 it was known in many districts. Late blight was slow in developing, but warm weather accompanied by heavy dews and rain favored its development in September. Many growers dug their potatoes while the tops were still green or partly destroyed by late blight and stored the tubers in warm storage spaces. Losses at digging time were as high as 10-80 percent of the crop . . . It is conservatively estimated that 10 percent, or 1 1/2 million bushels of the crop, was lost. Fields dug after the tops were killed with a herbicide showed little tuber rot."

ONTARIO. The disease is most important in eastern Ontario, but even there the frequency of severe blight years is only about 1 year in 4 or 5. During 1946-55, the worst outbreak of blight in eastern Ontario appears to have taken place in 1951, when it was described as follows: ". . . late blight became epidemic by mid-August. It was estimated that about 10 percent of the acreage was slightly affected, 25 percent moderately affected, and 65 percent severely affected. The reduction in yield, from the premature death of the vines, varied from 0 to 25 percent, and averaged 5 percent. An additional 5 percent was lost from decay of the tubers."

MANITOBA, SASKATCHEWAN, ALBERTA. Blight is not important in these provinces. The first record of blight in Saskatchewan was made in 1946, and in southern Alberta in 1952. The main potato-growing area in Manitoba lies in the Red River Valley, which has been described in the U.S.A. section of this study.

BRITISH COLUMBIA. The most important potato-growing area is the Lower Fraser Valley, where the frequency of severe blight years is about 1 year in 3. Over the period 1946-55, serious losses in the potato crop have occurred in 1948, 1953, and 1954. The greatest source of loss is due to blight infection of the tubers, and much of this is caused by contamination with infected haulm at lifting.

BLIGHT AND WEATHER DATA

Figure 71 shows the long-term average air temperature and rainfall conditions for three centers across Canada. These are Fredericton, New Brunswick; Lethbridge in southern Alberta; and Agassiz at the eastern end of the Lower Fraser Valley in British Columbia. The average temperature and rainfall at Charlottetown, Prince Edward Island, has already been shown in figure 69. These climagrams illustrate the very different conditions under which potatoes are grown in Canada.

MARITIMES, QUEBEC, AND EAST ONTARIO are very similar as to temperature and rainfall regime in the potato-growing areas. Winters are severe, so that the survival of potato groundkeepers is unusual. During the summer months, rainfall is well distributed, and very high temperatures are unusual. The diurnal range of temperature is approximately 20° F. Summer temperatures are higher in western Quebec and eastern Ontario than in the Maritimes, but very high temperatures are exceptional. The mean air temperatures for July,

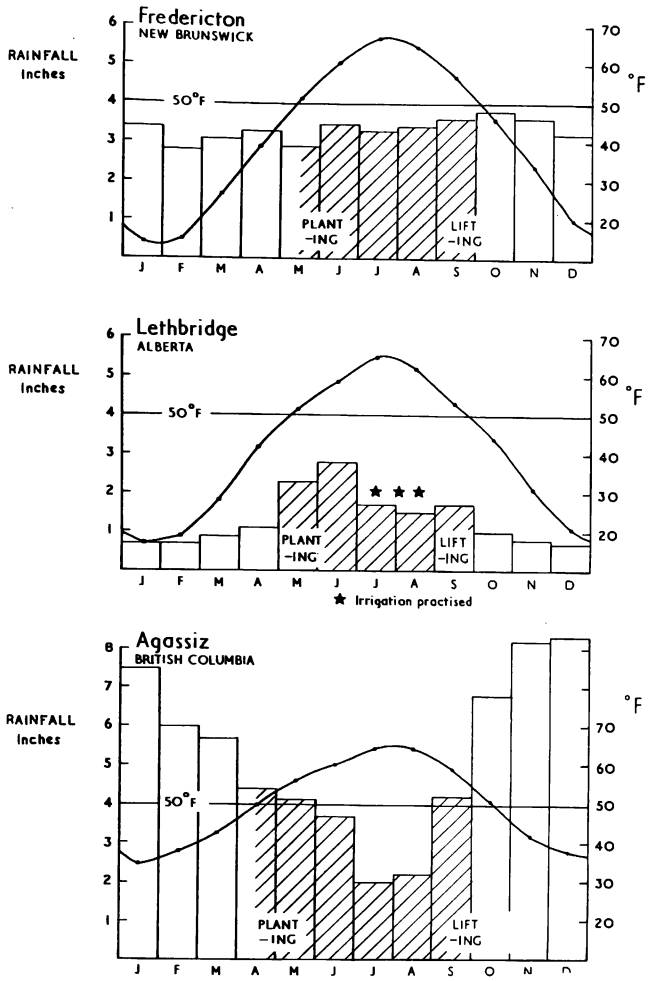


FIGURE 71.--Long-term average monthly rainfall and mean temperatures in relation to growing periods for three centers in Canada.

August, and September, together with the average total rainfall for the July-September period are compared in table 93 for five centers in the region. The frequency of severe blight years at each center is also given.

The greater severity of blight on Prince Edward Island is most probably explained by the higher humidity conditions on the Island. This is not shown up by the table. Humidity data for Prince Edward Island has been discussed on page 145 but, in general, information on humidity is scanty or lacking for the region. However, the folly of dogmatizing about humidity and blight are illustrated by an interesting observation made in New Brunswick on the interrelationship of temperature and humidity with blight attacks. The Science Service Laboratory at Fredericton maintains a potato substation at Alma, on the coast about 60 miles west of St. John. Although humidity conditions at Alma are high, due to frequent coastal fogs, blight is almost always worse some distance inland where humidity is lower. This is explained by the higher inland temperatures; the lower temperatures on the coast slow up the progress of the disease.

The lower rainfall in eastern Ontario partly explains the lesser importance of blight there as compared to the other centers (table 93). The lower summer temperatures at St. Anne, compared to those at L'Assomption, play a part in the less serious nature of blight at St. Anne. Particularly important in Quebec are the September temperatures, as the blight attacks tend to be late in the province and the main source of loss arises from tuber blight infection. The higher September temperatures in western Quebec, combined with greater dew formation, would seem to be an important factor in making blight losses greater than in eastern Quebec.

MANITOBA, SASKATCHEWAN, ALBERTA. Weather conditions in central and western Canada, apart from the coastal areas, are unfavorable to blight. Generally speaking, precipitation during the growing season is low and evaporation high. Daily temperature maxima are high and the diurnal range of temperature is around 25° to 30° F., as compared to nearer 20° in eastern Canada. Relative humidities are low during the summer, and this is partly the outcome of the dry warming winds that blow across the region and the abundant sunshine.

TABLE 93. --Temperature and rainfall during growing season and frequency of blight years, 5 locations, Canada

Centers	Mean temperature			Total rainfall, July-Sept.	Frequency of severe blight years
	July	Aug.	Sept.		
	°F.	°F.	°F.	Inches	Percent
Charlottetown, Prince Edward Island.....	66	66	58	10.5	75
Fredericton, New Brunswick.....	67	65	57	10.3	50
L'Assomption, W. Quebec.....	69	67	58	10.5	50
St. Anne-de-la Pocatière, W. Quebec.....	65	63	55	10.7	33
Delhi, E. Ontario.....	70	69	61	8.5	20

The climagram for Lethbridge in figure 71 illustrates the type of rainfall regime typical of the prairie provinces, i.e., a marked summer rainfall peak. Even so, rainfall is deficient and potatoes are grown under irrigation in the area. Summer temperatures are lower at Lethbridge than in the potato-growing areas of Manitoba and Saskatchewan. However, blight is not a problem.

LOWER FRASER VALLEY, BRITISH COLUMBIA. The climagram for Agassiz shows the longer growing season in this area than in the rest of Canada. The mild winters allow potato groundkeepers to overwinter and these may serve as a source of blight inoculum. Blight is checked by the drier conditions of July and August, but high rainfall around lifting time has made tuber blight infection a serious problem.

CONTROL MEASURES

The blight control program in Canada follows very much the same pattern as that in the U.S.A. Recent accounts of methods have been given by Callbeck (1950b and 1953). As in the U.S.A., the spray program has to deal, in addition, with a number of insect pests.

The main differences between the two countries appear to be that (1) the control program is generally less intensive in Canada (in comparing similar areas in the two countries, such as Aroostook Co. with the Maritime provinces, a greater number of sprays are applied in Aroostook than in the Canadian region); (2) there is a relatively greater use of copper fungicides in Canada than the U.S.A. (although organic fungicides are mainly used in Canada, principally due to their lower cost and the ease with which they can be applied, copper materials, in particular bordeaux (10:5:100), are still used by a large number of growers); and (3) there is a greater relative use of dusts in Canada. Again, comparing the Maritimes with Aroostook, dusting is carried out on a greater scale in the Maritimes. According to Howatt, up to 20 percent of the growers use dusts in some years in New Brunswick, but in bad blight years, many of those who normally dust, change over to spraying.

In general, blight control is good in the Maritime Provinces and the coastal areas of British Columbia. In New Brunswick there is a tendency to change over to low-volume spraying, though this does not seem to be happening much elsewhere in Canada. The blight control program is inadequate in many parts of Quebec Province; while in central Canada few measures are taken to control blight, as the disease is not usually a serious problem. One feature that emerges is that not enough growers are using haulm-killing methods.

BLIGHT-RESISTANT POTATO VARIETIES AND BLIGHT RACES

Two varieties, Keswick and Canso, containing the R_1 gene for blight resistance and derived from Solanum demissum hybrids, have been grown fairly extensively in Canada. Shortly after they had been introduced into commercial practice they were found attacked by specialized races of the blight fungus and they are now sprayed against blight in the same way as other varieties. A comparison of the foliage and tuber resistance to blight of 64 varieties, including some British ones, was made under severe blight conditions in 1954 at St. Anne-de-la Pocatière by Campagna (1955).

Much work on the identification of blight races from the different Canadian Provinces has been carried out at Fredericton by Howatt and his colleagues. The results of surveys carried out by them, showing the distribution of blight races throughout Canada, have been published in the 1954 and 1955 Reports of the Canadian Plant Disease Survey. The 1955 results are shown in table 94.

The amount of material sent in by the different provinces varied considerably, and the survey does not pretend to be a complete one. Both surveys in 1954 and 1955 showed race 4 to be predominant in Canada. Race 0, originally considered to be the common race, cannot be determined with accuracy in the presence of other races, so that it is difficult to show its importance. From the result of surveys carried out in 1952 and 1953 at Ottawa, Graham (1955) concluded that in Canada, ". . . the so-called common race of P. infestans is actually composed of Races 0 and 4."

Recent work at Fredericton by Howatt and Hodgson (1954) and Howatt and Grainger (1955) has questioned the adequacy of the newly proposed international nomenclature for blight races (fig. 16) on the grounds of the erratic behavior of certain blight isolates on the differential hosts.

SUMMARY: CANADA

The Maritime Provinces are the worst area for blight in the Dominion. A close analysis of epidemics on Prince Edward Island has been possible. In other parts of Canada a frequency of "blight" years has been established from the accounts given in the Reports of the Canadian Plant Disease Survey. The major source of loss from blight has been tuber infection, particularly infection at harvest-time. This is closely linked with the short growing and lifting periods for potatoes. The control program is very similar to that in the U.S.A.

TABLE 94. --Distribution of blight races in Canada, 1955

Race of *Phytophthora infestans*	Prince Edward Island	New Brunswick	Nova Scotia	Quebec	Manitoba	Saskatchewan	British Columbia	Total
0	--	--	2	--	--	--	--	2
1	1	1	--	--	--	--	--	2
2	--	--	2	--	--	--	--	2
3	19	13	6	4	--	--	8	50
4	59	50	12	14	3	1	8	147
1,2	--	2	--	--	--	--	--	2
1,3	--	7	1	2	--	--	--	10
1,4	--	21	5	1	--	--	1	28
2,4	2	1	--	--	--	--	--	3
3,4	13	22	3	3	--	--	--	41
1,3,4	--	--	12	5	--	--	--	17
Total	94	117	43	29	3	1	17	304

MEXICO

Potatoes are not an important crop in Mexico. With a population of nearly 30,000,000, the total annual production of potatoes is only about 150,000 tons (F.A.O., 1955). At the most, this allows an average annual consumption of 5 lb. potatoes per head per annum, but this figure takes no account of the portion of the total production which is used for seed. The main reason for the low production of potatoes--about 80,000 acres are grown annually--is the low yield per acre. In 1954, this was 1.8 tons per acre. The result is that potatoes are very expensive and are considered a luxury crop.

In Mexico (fig. 72), potato production can be divided into two main types: (1) The cultivation of indigenous varieties at high elevations in the Sierra; and (2) the cultivation of imported varieties at lower altitudes, usually under irrigation.

The Sierra is the principal area of production. Two of the most important native varieties grown in this region are Leona and Amarilla de Pueblo. Imported potato varieties come largely from Denmark and Holland and include Alpha, Furore, Gineke, Prummel, Bintje, and Up-to-Date. The imported varieties differ from the indigenous potatoes in that they have a shorter period of vegetative growth and are potentially higher yielders.

Potato blight is the chief factor limiting potato production in Mexico. Potatoes are grown chiefly where and when blight is not likely to be a problem, i. e., at high elevations in the Sierra and under irrigation during the dry season, which occurs in the winter months (fig. 73). Although these conditions are inimical to blight, they are also very unfavorable to good potato yields and are the main factors responsible for the present low yields that are obtained. Growers found it impossible to produce potatoes at lower elevations in the wet season, owing to the earliness and rapidity with which they were destroyed by blight.

A program was established in Mexico in 1951 by the Rockefeller Foundation, with the object of improving potato cultivation methods and exploiting new areas of production. Among the areas that show possibilities of becoming important centers of potato production are those known as the "high valleys" of the Mesa Central (Central Plateau)--principally the valleys of Mexico and Toluca. It has been demonstrated during the last few years that potatoes can be grown with much better results in these areas if use is made of the rains. To do this it is necessary to grow potato varieties showing some resistance to blight and to protect them with an intensive spray schedule.

BLIGHT EPIDEMICS

The greater part of the area in which potatoes are grown in the Sierra is situated above 3,000 meters, i.e., about 10,000 ft. Potato blight is not a serious problem at these altitudes. The story is very different in the high valleys. At Toluca, where systematic blight observations began in 1951, the disease has been devastatingly severe each year since then, according to information from Dr. Niederhauser. Its effect at this center can be illustrated by what happened to an unsprayed crop of Alpha in 1956. The crop was planted on May 15, and blight was first noted on the foliage on June 20. The tops were completely dead by July 25, and only a few marble-sized tubers were produced.

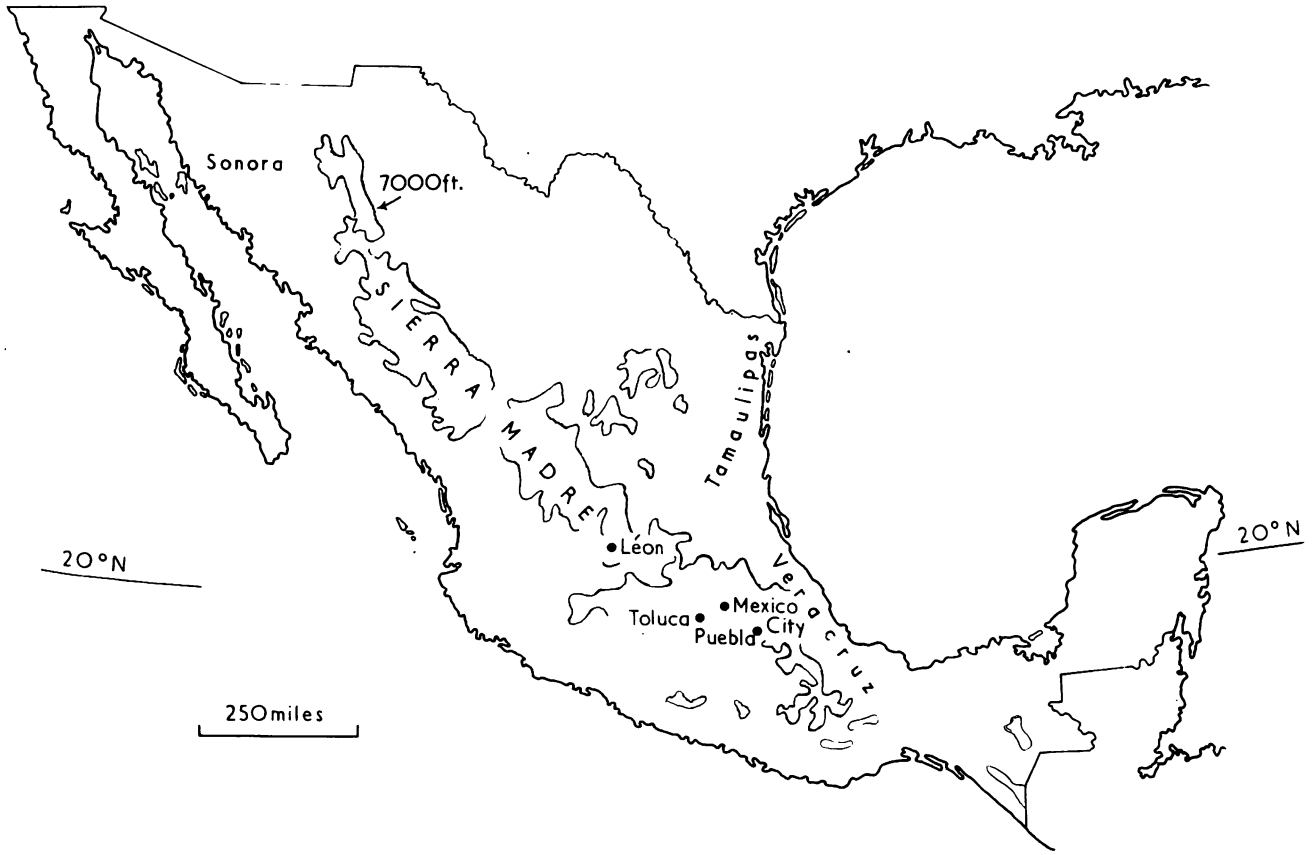


FIGURE 72.--Mexico, showing potato growing areas referred to in text.

BLIGHT LOSSES

It can be seen that the effect of blight in the high valleys is to cause complete loss of the unprotected potato crop. In the past, owing to the low level of technical development in cultural methods, this has meant the virtual elimination of potato growing from these valleys during the summer months. Thus, the cultivation has had to be in areas where, owing to unfavorable climatic conditions, both potential and actual potato yields are very low. How serious this is can be seen from some figures quoted by Niederhauser and Cervantes (1956) in which they compare the national average yield of potatoes in Mexico with yields of crops protected against blight and grown at two centers in the high valleys. The original figures were given in terms of tons per hectare, but have been converted in table 95 into tons per acre.

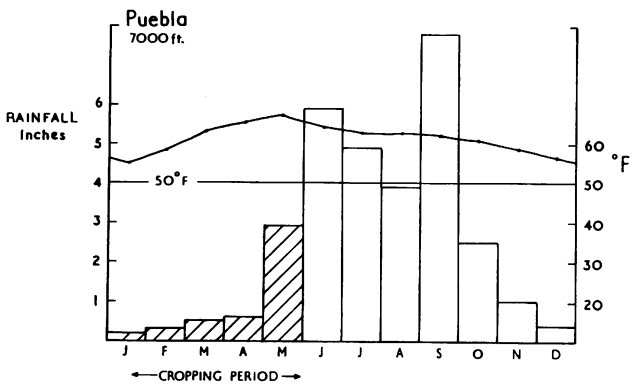


FIGURE 73.--Long-term average monthly rainfall and mean temperatures for Puebla, Mexico: The rainfall regime is typical for the potato growing areas in Mexico, but temperatures vary greatly, according to altitude.

The figures in table 95 relating to Chapingo and Toluca are for small acreages of potatoes only. Even so, the differences between potato yields there and the national average yields are most striking.

According to Dr. Niederhauser blight infection of the tubers is very slight (usually hard to find) in the Sierra, and it is only a little more prevalent in the high valleys. There appears to be no good explanation for this.

TABLE 95. --Comparison of national average yields of potatoes with those at 2 centers where potatoes were protected from blight, Mexico, 1952-55

Year	Average yields of potatoes		
	Mexico (national average)	Chapingo	Toluca
	Tons/acre	Tons/acre	Tons/acre
1952	1.8	9	17
1953	1.9	7	13
1954	1.8	11	15
1955	--	10	14

Thus, the main losses caused by blight in Mexico result from the premature defoliation of the potato plants by the disease.

BLIGHT AND WEATHER DATA

Figure 73 shows the average temperature and rainfall conditions for Puebla, a potato-growing district lying to the southeast of Mexico City. The rainfall regime is typical of that in the potato-producing areas of Mexico, i.e., a dry season during the winter months (November to April) and a wet season in the summer (May to October). Rainfall in the summer is often very heavy and continuous. Mills and Niederhauser (1953) state that at Toluca, in 1952, rainfall was over 20 inches in both July and August. Temperature conditions in the potato districts vary, mainly with differences in altitude.

At Puebla (7,000 ft.) growers plant their potatoes in late January, during the dry season, hoping for just enough rain to grow a crop but not enough to favor blight development. At León (6,000 ft.) the farmer grows his crop in the dry season under irrigation. Work being carried on at Toluca (8,000 ft.) is designed to show how potatoes can be grown during the wet season (May to September or October), but this can only be done if a rigorous blight control program is followed.

In the Sierra (above 10,000 ft.), potatoes are grown in the summer months. Niederhauser attributes the lack of blight under these conditions to low temperatures. Unfortunately weather records are not available, but this state of affairs accords well with observations made in parts of the Sierra of Peru, as reported by Bazán de Segura. She tells us that blight has never been reported from the important potato-growing areas of the Province of Puno, where temperatures average about 50° F. during the growing season.

In Mexico, potatoes have also been grown at sea level as a speculative crop in the states of Veracruz and Tamaulipas, near the Gulf of Mexico, and in the state of Sonora, near the Gulf of California. Blight has not been observed on these plantings, which are grown under irrigation during the dry season. Mean temperatures during the summer (which exceed 80° F.) are too high for potato growing.

CONTROL MEASURES

It is apparent that the main way of controlling blight in Mexico up to the present time has been to escape the disease. The most successful of these escape methods has been to grow the potatoes in the dry season, under irrigation, chiefly at heights above 5,000 ft. where growing conditions are cool. But irrigation is expensive and not generally available.

The most hopeful means of obtaining economic yields of potatoes appears to be to make use of the summer rains, and at the same time to employ modern methods of blight control. The workers of the Rockefeller Foundation at Toluca and elsewhere have shown that this can be done. Niederhauser and Mills (1953) have discussed the growing of potato varieties showing a degree of "field" or "partial" resistance to blight (notably Alpha and Voran). It has been shown that these varieties can be satisfactorily protected by ordinary spray schedules, when more susceptible varieties cannot be produced commercially even with regular and thorough spraying.

Recommendations for the spraying program have been made by Niederhauser and Cervantes (1956). Generally speaking, the first spraying should be at about the time the first rains are expected. If the plants emerge from the ground some time before the rainy season, it should be given while the plants are still small (4 to 5 inches high). Usually the spraying should be repeated at intervals of 10 to 15 days. At Toluca, 6 applications are normally required over the growing season, and sometimes 10 are needed. Both bordeaux mixture and the organic fungicides have given satisfactory blight control in the high valleys.

POTATO BREEDING PROGRAM

Mexico is the site of a most important potato breeding program, sponsored by the

Rockefeller Research Foundation. This program aims at the production of new varieties showing complete, or almost complete blight resistance. A number of factors make the high valleys near Mexico City an excellent area for the direct field selection of blight-resistant breeding material. Most, if not all, of the wild species of Solanum that are highly resistant to blight are found in central Mexico. These species have been in close association with Phytophthora infestans over a long period of time. Mills and Niederhauser (1953) first demonstrated that this association has given rise to a number of naturally occurring biotypes of the fungus in the field. Since then, Niederhauser, Cervantes, and Servin (1954a and 1954b) have reported the natural occurrence of 14 of the 16 races of blight named in the international nomenclature (fig. 16). In addition, they have found an additional race, provisionally termed "1,2,3,4,5," capable of attacking a clone of S. demissum which apparently possesses a fifth gene for resistance to blight. Thus, in central Mexico, the highly specialized races of the blight fungus are among the prevalent field races, and it is under these conditions that the search for blight-resistant potatoes is being made.

Field experience in Mexico has shown repeatedly that resistance to blight based only on major genes, either singly or in combination, which have been derived from S. demissum or other wild Solanum species, is of little or no value. While this type of resistance confers immunity to specific races of the blight fungus, other races are either already present or quickly arise to attack the plants. Niederhauser says, "We have not yet found a tuber-bearing Solanum species that is immune to P. infestans at Toluca." Field or partial resistance shows much greater promise. Niederhauser, Cervantes, and Servin (1954a) have described the interaction between host and fungus, where "partial resistance" is exhibited: "Several species, including some clones of S. demissum, show a high resistance to P. infestans even though foliage lesions are produced on them. These resistant-type lesions are slow spreading, often turn necrotic, and sporulation is sparse. Petiole and stem lesions tend to be superficial and do not kill the distal portions of the affected leaf or stem. Relatively few lesions develop on a plant, and these are more often on the lower older leaves." The genetical basis of "field resistance" has not yet been fully explored; major genes may or may not be involved. The importance of field resistance lies in the apparent ability of this resistance of a variety to remain constant despite specialization in the blight fungus. The potato-breeding program in Mexico is now working to incorporate a high degree of such resistance in commercially acceptable potato varieties.

A recent event in Mexico, of fundamental and historic interest, has been the discovery of circumstances in which Phytophthora infestans has an active sexual phase (Niederhauser, 1956; Gallegly and Galindo, 1957. Not only have oospores been obtained readily in culture, but at Toluca they have been found on potato foliage in the field. Oospores are formed abundantly by the pairing of two compatibility groups of the fungus. In the initial experiments, these compatibility groups were represented by sets of isolates from Mexico, which were paired with isolates from the United States and Canada. Both compatibility groups are present in the field in Mexico.

Dr. Niederhauser writes: "Having found oospores in leaf lesions in the field, we believe that the oospores probably do function in the field, and enable the fungus to survive in the field through the dry season." He continues: "The finding of oospores. . . suggests that any partial resistance we find may be effective against any race [of blight], since the pathogen is happily breeding as the season progresses and sooner or later should come up with a race that would take over. Furthermore, the partial resistance that we have observed in S. demissum and other species has apparently been stable for many hundreds of years and has enabled these species to survive."

High hopes, therefore, exist for the production in Mexico of commercial potato varieties showing a high degree of resistance to blight. To what extent such varieties would be adaptable to the main potato-growing regions of the world, situated in more northerly latitudes, remains to be seen.

SUMMARY: MEXICO

Mexico is an example of a country where blight has largely been escaped. But the effect of this escape on potato yields has been little short of disastrous. The use of modern protective methods against the disease has been demonstrated at Toluca and elsewhere to be a more effective method of overcoming blight. The imaginative action of the Rockefeller Foundation, in establishing a potato-breeding program in this country under conditions of maximum severity of blight, is paying handsome dividends.

SOUTH AMERICA

PERU

Peru is of particular interest in any study connected with potatoes. Lake Titicaca, which is partly in Peru and partly in Bolivia, is regarded as the World center of origin of the potato plant (fig. 74). In addition, potatoes play a larger part in the diet of the population of Peru than in any other country of South America. The combined weights of potatoes and other starchy roots consumed per head in 1952 was 169 kg. (372 lb.), most of this being in the form of potatoes. This is a rate of human consumption comparable to that in some of the large European potato-producing countries, such as Germany and France. The population of Peru is about 9 million persons, and to produce enough potatoes for them requires a large acreage of the crop, as the average yield per acre is very low. Over the period 1948-52, 543,000 acres of potatoes were grown annually, and these produced an average yield of 2.3 tons per acre (F.A.O., 1956).

Low yield per acre is in part a reflection of inferior cultural methods, but a more important factor is the unfavorable climate in which the greater part of the potato crop is grown. Production is carried out in different areas throughout the length of the country, but all of these fall into one of two distinct zones. These are the "Costa," or Pacific Coast zone, where potatoes are grown in the river valleys at heights up to 9,000 ft.; and the "Sierra," or mountain zone, where they are grown from 9,000 to 13,500 ft. According to figures given by Hawkes (1941), 30 percent of the total production comes from the Costa and 70 percent from the Sierra. There is no reason to believe that these proportions have changed appreciably in recent years. The chief characteristics of the two zones are as follows:

COSTA: The haciendas (plantations) are owned by Creoles or Europeans, and worked on modern lines. Many of the fields are large, and cultivations, including spraying, are mechanized. In general, potato growing is possible all the year round, owing to the absence of frosts; but, depending on altitude, the main growing season is either in the winter or summer. At Lima (520 ft.) the growing season is in the winter (May to November); summer temperatures are too high for successful potato production. At Arequipa (7,600 ft.) the main growing season is in the summer (January to June). Annual rainfall is very low throughout the Costa; at Lima, average annual rainfall is 1.8 inches, and at Arequipa, 4.2 inches, but sea fogs give rise to high humidity conditions. It is necessary to grow all potatoes with channel irrigation. The majority of the crops are planted with indigenous varieties, but some North American varieties are also grown.

SIERRA: Most of the country's potato production is in these regions. Yields are lower than in the Costa. Cultivation is chiefly carried out by Indians, and methods are primitive. Part of the crop is still preserved as the traditional "papa seca" or chuño. Most crops are grown during the summer, without irrigation. Rainfall is generally adequate, but temperatures are low (mean monthly temperatures seldom exceed 55° F. during the growing season), and this is one of the main reasons for the low potato yields. Slow-maturing indigenous potato varieties are grown.

FIGURE 74.--Key map of Peru.

Much of the information on potato blight in Peru has been provided by Consuelo Bazán de Segura, of the Central Experiment Station of La Molina, at Lima.

BLIGHT EPIDEMICS: GENERAL

Potato blight was considered of little or no economic importance in the Costa until 1947, when it caused heavy losses. No satisfactory reason for the first appearance of the disease in epidemic proportions at this time has so far been put forward. Since 1947, there have been a number of other years when severe attacks of blight have developed, but the incidence of the disease has shown a considerable variation from year to year.

Bazán de Segura (1952a) states that potato blight has been troublesome in the Sierra since 1949. There are variations in the importance of the disease between the different regions in the Sierra, and up to the end of 1956 there had been no reports of blight occurring in the important potato-growing areas in the Department of Puno.

Under the Costa conditions, where sea mists favor the disease, blight remains localized in the aerial parts of the potato plants and no case has been observed of tuber infection. This is due to the small amount of rain during the growing season. On the other hand, in the Sierra, tuber infection is a most important problem. Many of the Indian growers in the Sierra think that the leaf and tuber attacks are caused by two completely independent and different diseases. Reasoning in this way they see nothing to be gained from saving the plants by spraying or dusting if the tubers are to be attacked by the "other" disease. Little protective action against blight is taken in the Sierra, but since 1947, a high proportion of the growers in the Costa have been spraying.

BLIGHT ON THE HAULM

COSTA: Details have been supplied by Bazán de Segura of blight incidence during the period 1951-56 in the Carabayllo Valley, a potato-growing district, 16 kilometers to the north of Lima. These data are shown in table 96.

TABLE 96. --Blight incidence in the Carabayllo Valley, Peru, 1951-56

Year	First appearance of blight	75 to 90 percent blight stage on unsprayed potatoes by--
1951	July 15	--
1952	July 20	Sept. 8
1953	May 17	--
1954	([1])	--
1955	([1])	--
1956	June 15	Sept. 2

[1] Blight of little importance.

The disease was described as severe in 1952 and 1956. No record of the 75 to 90 percent blight stage was made in 1951 and 1953, and in the other 2 years, 1954 and 1955, blight was of little importance.

The observations given in table 96 show that even with this very limited number of records there was considerable variation in the time of the first appearance of blight--between May 17 to July 20. The disease may attack the potato plants from shortly after emergence onward. Bazán de Segura (1950) states that during a number of bad blight years in the Lima area, it was very common to find blight attacking very small plants (5 cm. high).

The time at which the 75 percent blight stage occurs in relation to the stage of growth of the potato plants decides the scale of the loss that blight produces through premature defoliation. Bazán de Segura and Lamas Carrera (1953) have described the results of a spraying trial carried out in the Carabayllo Valley in 1952 (a severe blight year), when the amount of defoliation caused by blight was measured at intervals, and the produce of the sprayed and the unsprayed plots was weighed. Blight assessments were made by Horsfall and Barratt's method. The effect of the disease on the control plots of the two potato varieties in the trial is shown in table 97.

TABLE 97. --Blight record on untreated plots at Carabayllo Valley, Peru, 1952

Variety	Time of planting	Date when tops reached 75 percent blight stage	Yield
			Tons/acre
Papa Blanca	June 18-July 2	Sept. 4	1.3
Papa Amarilla	June 18-July 2	Sept. 6	.3

From planting until 75 percent of the tops had been destroyed by blight was just over 2 months, and this accounts for the very low potato yields. Blight attacks of this kind, which occurred in the Carabayllo Valley in both 1952 and 1956, obviously have a completely devastating effect on some unprotected potato crops. But the position is complicated by the wide range of time over which crops are planted in the area. This stretches from May to July. Without detailed survey information on this and other points, it becomes impossible to assess with any accuracy the extent of blight losses in the Valley.

There are wide variations in the incidence of blight among different growing areas in the Costa within a particular year. This is so, even where the areas are in close proximity. For example, 1956 was a severe blight year in the Carabayllo Valley, but the disease was only present in trace amounts in the outskirts of Lima.

SIERRA: Blight attacks are not so severe on the potato tops in the Sierra as in the Costa. The disease does not usually appear until 3 or 4 months after planting. There are still large areas from which it has not been reported.

The course of a typical blight attack at the Maco hacienda has been described by Llaveria, Revilla, and Sanchez (1955). Experimental work is carried out at this hacienda in conjunction with the Station of La Molina, and these workers give the results of a fungicide trial against blight carried out during the 1953-54 growing season (table 98). Blight on haulm was measured by a simple scale numbering from 0 to 4. The potato variety grown was Maco.

Since the fungicide was applied by hand, and the applications were repeated at frequent intervals, it can be fairly assumed that the yield of the treated plots (11.5 tons per acre) shown in table 98 represents approximately the full potential yield of the potato crop. There was, therefore, a 36 percent loss in yield on the control plots due to premature defoliation by blight. This seems rather a high figure, in view of the relatively long time (130-135 days) between the time of planting the controls and the time the 75 to 90 percent blight stage was reached on them. However, it would appear that the normal potato growing season in the Sierra is a long one (around 170 days), and this is due to the cool conditions and the slow-maturing indigenous potato varieties that are grown.

Bazán de Segura has told us that in a blight year in the Sierra, the disease appears sometime in January and the 75 to 90 percent blight stage occurs sometime in February. This is the most precise information that is available.

A marked characteristic of blight in the Sierra is the way that the foliage attack is localized almost entirely at the base of the leaf petioles and on the main stems of the plants. The leaf petioles become brittle and are easily broken by the wind. The name "Palo Negro" ("The Black Stick") given to the disease by the growers has arisen from this form of attack.

BLIGHT IN TUBERS

Tuber infection before lifting the crop does not occur in the Costa. But according to Llaveria, Revilla, and Sanchez (1955), there have been many cases in the Sierra where tuber blight, in conjunction with secondary rots, has caused up to 30 percent loss of crop. It is not stated whether losses on this scale occurred before or after lifting, but infection at lifting is a major problem. However, infection in the soil also takes place; in the trial at Maco carried out in 1953-54, the control plots showed 5 percent infection with blight at harvest.

Lack of knowledge about the disease is the main reason for losses occurring after harvest in the Sierra. Very often the farmer's reaction to the appearance of blight on the potato tops has been to lift the crop, and this has resulted in severe tuber infection.

BLIGHT AND WEATHER DATA

COSTA: Long-term average temperature and rainfall figures for Lima are shown in figure 75, together with the main growing season for potatoes in the area. The crop is grown under irrigation during the winter months. Total annual rainfall is extremely low (average 1.8 inches), and the small amount of rain that does fall comes during the potato-growing season. At this time, however, Humboldt current effects give rise to more or less

TABLE 98.--Blight record of Maco potatoes in plots at Maco hacienda, Peru, 1953-54

Plots	Time of planting	Blight outbreak	Date when tops reached 75 to 90 percent blight stage	Yield
				Tons/acre
Treated[1]	Oct. 10	1st week of January	After March 1	11.5
Control	Oct. 10	1st week of January	3d week of February	7.4

[1] The figures refer to the treatment which gave the best results; in this case, a copper dust.

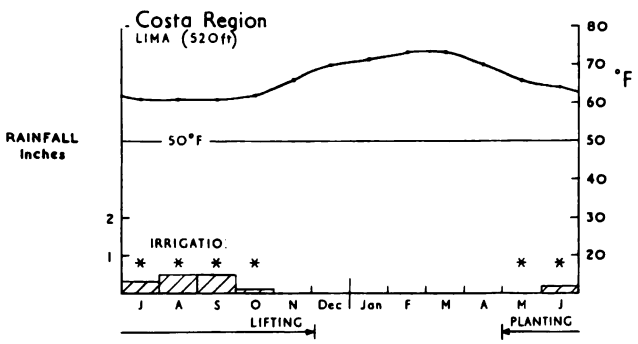


FIGURE 75.--Long-term average monthly rainfall and mean temperatures in relation to potato cropping at Lima, in the Costa region of Peru.

permanent sea fogs, and days with even a few hours of sunshine are rare.

Bazán de Segura (1950) has studied blight incidence in the vicinity of Lima in relation to weather conditions during the period 1945-50. The main object of this work was to formulate weather rules on which to base a blight forecasting service for the area. Relative humidity and temperature data were recorded at the Central Experiment Station of La Molina. The study included a detailed comparison of weather conditions in 1945 (a no-blight year) and 1949 (a blight year).

In both 1945 and 1949 average relative humidity figures remained above 75 percent practically every day (24 hours) during the growing season. The chief difference between the two seasons was the higher relative humidities at night in 1949. In 1945, there were very few occasions when a relative humidity of 96 percent or over was reached during the night hours; whereas in 1949, relative humidity was 100 percent for many hours on most nights. From these observations, it was considered that a tentative rule based on nocturnal humidities could be put forward. This was as follows:

> A nocturnal humidity of less than 95 percent should not endanger the crop; but night humidities greater than 95 percent will indicate the possibility of a severe blight outbreak.

This rule is stated in very general terms, and in particular, it lacks precision as to the number of nights of high humidity that are likely to give rise to severe blight conditions. No mention is made in it of temperature conditions, and these are compared for 1945 and 1949 in table 99.

Bazán de Segura considered that the large diurnal range of temperature in May and June 1945 probably had an inhibiting effect on the blight fungus, which in part was responsible for 1945 being a no-blight year, but her general conclusion from the study of weather data in these and other seasons was that relative humidity and not temperature is the principal factor in blight outbreaks. Temperature conditions, particularly during the main part of the growing season, are generally favorable to blight. Table 99 illustrates the fact that the diurnal temperature range is greatest at the beginning and end of the growing period.

The nocturnal humidity rule given above was used with success to issue spray warnings against blight to farmers near Lima in the winter of 1950. Unfortunately, however, the personnel has not been available to continue with this work since that year.

SIERRA: Precise weather data are not generally available for these regions. The winter (May to September) is a dry, cold season. Potatoes are grown in the wet season, during the summer months, from October to April, but there are considerable variations in the amount of rainfall at this time in different parts of the Sierra, and temperatures also vary, mainly with altitude.

Temperature and rainfall have been recorded at the Maco hacienda since 1953, and some of this information has been supplied by Bazán de Segura. In figure 76 rainfall and temperature data for Maco are shown in a "no-blight" season (1955-56) and a "blight" season (1953-54). In 1953-54, blight first appeared at the beginning of January and reached the 75 to 90 percent stage in the third week of February on unsprayed potatoes. It seems likely that the low temperatures in 1955-56 played an important part in checking blight in this season, as the monthly mean figures were below 50° F. throughout the season.

TABLE 99. --Average monthly temperatures at Lima, Peru, in 1945 (no-blight year) and in 1949 (blight year)

Year and month	Mean minimum	Mean maximum	Diurnal range	Mean
1945:				
	°F.	°F.	°F.	°F.
April	55	89	34	72
May	45	84	39	65
June	46	80	34	63
July	50	74	24	62
August	52	74	22	63
September	53	80	27	67
October	47	83	36	65
1949:				
April	55	87	32	71
May	53	82	29	68
June	51	77	26	64
July	48	74	26	61
August	51	75	26	63
September	48	77	29	63
October	50	77	27	64

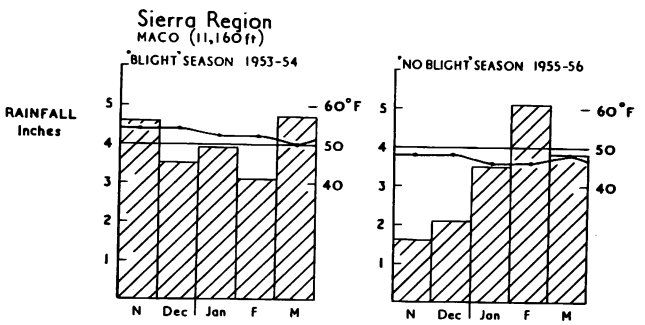


FIGURE 76.--Temperature and rainfall conditions in a "blight" and a "no-blight" year at Maco, in the Sierra region of Peru. The potato growing season is from October to April.

Blight has not been recorded from the potato-growing areas in the Department of Puno, which is one of the colder regions of Peru, with an annual mean temperature of 42° F. According to Bazán de Segura, it seems reasonable to suppose that the disease does not occur there, because of the low temperatures.

CONTROL MEASURES

In the Costa, many of the growers use fungicides (copper and dithiocarbamates) against blight. Most of these fungicides are applied as sprays with mechanical equipment. Some growers start spraying when the potato plants are only 2 to 4 inches high, and continue at 4- to 5-day intervals, even in the absence of the disease.

It might be possible to prevent the carryover of the blight fungus from year to year under Costa conditions, in view of the fact that tuber infection in the soil does not occur. But it is not clear to what extent the disease is perpetuated by the succession of potato crops that are grown throughout the year in parts of the Costa. Also it is not known how important a part infected seed potatoes brought in from outside play in the development of epidemics.

Control measures are not nearly so common in the Sierra, where it has been estimated that not more than 5 percent of the growers take action against blight. Llaveria, Revilla, and Sanchez (1955) have mentioned some of the factors unfavorable to blight control in these regions. They say that the small peasant farmers are in the main against spending money to combat blight, as they are not yet convinced that it is necessary. The topography is also unfavorable for control measures. The application of sprays is very often impossible, owing to lack of water. The cultivated land is situated on the slopes of the hills a considerable distance from the streams, which flow through the bottom of the valleys. The water has to be carried in drums or cylinders, either by mule or on trucks, and this is not always possible, owing to the poor condition of the hill roads.

In these circumstances, the use of dusts applied by hand machines has been advocated, and successful control of blight with such materials has been demonstrated in the trials at Maco in 1953-54. The prevention of tuber infection at lifting is one of the most urgent control measures required in the Sierra at the present time. Recommendations to cut and remove infected haulm 10 to 15 days before lifting have been made, but it is doubtful if this advice is very often followed.

A suggestion for limiting blight losses in the Sierra by "disease escape" has been made by Bazán de Segura (1952a). She has proposed that where it is possible to grow the potatoes under irrigation, planting should be advanced from the normal time (September-October) to July-August. On the assumption that blight will continue to appear at about the same time (January), the effect on yield through premature defoliation may be much reduced. This method, however, would appear to have only a very limited application, owing to the lack of irrigation facilities in the Sierra, and the early-planted crops may suffer from frost damage. Another approach to the problem on similar lines might be the growing of quicker maturing potato varieties to replace the present indigenous sorts.

Work on the identification of a number of different blight races in Peru and the testing of potato varieties for resistance to blight has been reported by Bazán de Segura (1952b).

SUMMARY: PERU

Severe losses from potato blight in Peru were not reported before 1947. Precise data on the incidence of the disease from year to year and between the different parts of the country are lacking; but available information shows that heavy yield losses through premature defoliation occur at times both in the Costa and in the Sierra. The main potato-growing districts are in the Sierra, where it would appear that low temperatures result in a generally slow progress of blight on the haulm. These low temperatures are also unfavorable to high potato yields. A major problem in the Sierra is the danger of tuber infection at lifting time. This arises principally from the general ignorance of blight shown by the Indian growers.

CHILE

Potato blight was not found in Chile until 1950, but in 1951 the Chilean crops suffered a first and devastating epidemic, comparable in some respects to that in Ireland in 1846. The story of this latter-day catastrophe has been told by Müller (1952) who went out to Chile as an F.A.O. expert in 1951 to review the situation in the light of his European experience and to assist the Chilean Government in the inauguration of control measures. The progress of the disease in relation to weather conditions, from the first outbreaks until 1956, has been the subject of a special and very detailed study by P. M. Austin Bourke, who, also under the United Nations Technical Assistance Program, but as a representative of the World Meteorological Organization, went out from Ireland in 1955 to assist and advise on meteorological aspects of the problem. Before Mr. Bourke left on his mission the authors discussed with him the particular data desired for Chile in the present study of blight epidemics. The information he has generously provided, in correspondence, and in his U.N. (W.M.O.) report (Bourke, 1956), has enabled us to compile a rather full section for Chile, tracing the course of establishment of the disease in a country where it was until recently unknown, and exemplifying the use of blight progress curves with the "Irish Rules" for the definition of blight weather, in world blight exploration.

POTATO DISTRIBUTION AND CULTIVATION

In Chile, which has a population of about 6 million and a total land area of some 286,000 square miles, potato growing is almost entirely confined to a region extending from about La Serena in the province of Coquimbo in the north, to the islands of Chiloe in the south (see maps, fig. 77). This region, which extends over a thousand miles, may be divided into three zones. In the northern dry zone, including the provinces of Coquimbo and Aconcagua, there is scarcely any rain in the summer months, but there is potato cropping all the year round with the help of surface irrigation. In the southern zone, comprising the provinces of Valdivia, Osorno, Llanquihue, and Chiloe,

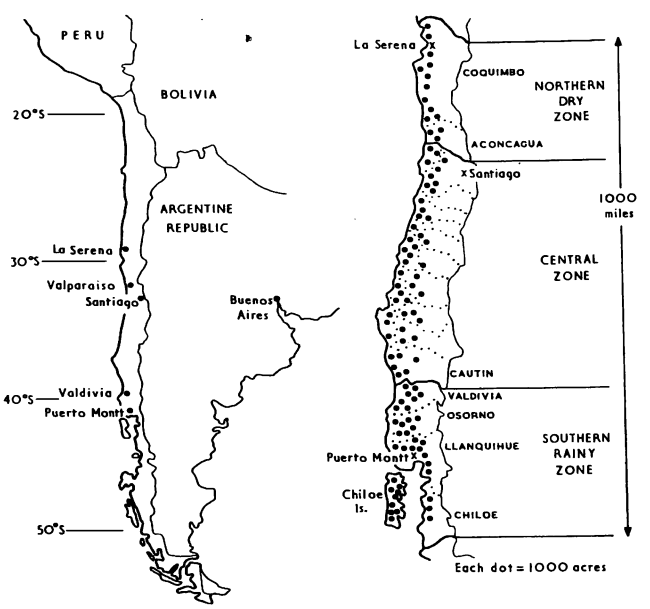


FIGURE 77.--Sketch maps of Chile, showing localities referred to in text and approximate distribution of potato growing.

abundant summer rainfall occurs, and with much lower temperatures in the winter, the principal cropping is in the summer, with early varieties in the late winter and spring, much as in southern Ireland. In the central zone, including all the provinces from Santiago to Cautin, conditions are intermediate between the two extremes.

Of the total of 57,724 hectares (145,000 acres) of potatoes grown in Chile in 1954-55, as shown by the official statistics, 18,665 hectares were in the southern zone. This zone, in which the greatest losses from blight have occurred, is of special importance, not only because of the high degree of local dependence upon the potato for staple food supply, but because, up to the present, it is the only Chilean seed-growing area (Montaldo, 1950). The acreage in the northern zone is relatively small, only 5,600 hectares. The annual production of potatoes for Chile as a whole, in recent years, has been about 6 million quintals (59,000 tons), with a mean yield of about 4.3 tons per acre. The mean annual consumption of potatoes per head is about 175 lb., but in the south, where the potato is the most important food crop, the consumption is about 400 lb.

Before the appearance of blight in Chile most of the potatoes grown were of the "Corahila" type--a varied mixture of indigenous varieties with red skin and firm yellow flesh, all very susceptible to blight and rather slow in bulking. Some European varieties, such as President and Industrie, were grown before 1951, and since that time there has been an extensive substitution of Ackersegen and Voran for the Corahila. Most of the potato plots or fields in Chile are small, and manual cultivation is the rule. Planting distances are variable, but generally they are about 30 inches between the rows and 15 inches between sets. Earthing up is not widely practiced.

The climagrams in figure 78 show the long-term monthly average rainfall and mean temperatures in relation to the cropping periods for La Serena in the north and Puerto Montt in the south.

THE BEGINNING OF BLIGHT IN CHILE

The first confirmed record of potato blight in Chile was on October 17, 1950, when the fungus was identified in the laboratories of the Ministry of Agriculture on the foliage from a crop growing in Mallarauco, a sheltered valley southwest of Santiago. In December of that year it was also found on tomato plants in the same district. It was then soon discovered that the disease was present to a greater or less extent throughout all the potato-growing areas. Evidence later collected by Müller (1952) showed that this blight or "tizón" had already been causing damage in some of the smaller islands of Chiloé in 1949. It does not appear to have been present in 1937, for a careful search was made for it in Chiloé in that year by both Chilean and American plant pathologists in connection with a seed-potato certification scheme, and no trace of it was then found. Bourke narrows down the date of introduction to some time between 1937 and 1948, and considers that it probably came from the Argentine; not, as has been suggested, by way of migrant labor returning to Chiloé from the Argentine but by way of ships' stores. The most severe blight epidemic on record in the Argentine occurred about Buenos Aires in 1940-41, and it may have been that diseased tubers were first brought to Chiloé at that time by ships plying between Buenos Aires and Chile round the southern tip of the continent (see map, fig. 77). Whatever the route of introduction, the presence of the disease in parts of Chiloé by early 1949 has been fairly well established.

From study of the available weather records Bourke found that conditions were almost certainly unfavorable for the development of the disease from then until early in February 1950, after which the symptoms were probably masked by the dying down of the winter crop. But conditions at that time, with many humid periods and much heavy rain, were ideal for tuber infection both in the ground and at lifting. Oehrens (1953), in his unpublished thesis, "Tizón de la Papa," recorded that many serious cases of rotting of tubers in storage occurred in the southern provinces during the autumn months (March to May) in 1950. Thus the disease, first recognized in October 1950, was distributed throughout the country in the seed potatoes from the 1949-50 crop in the south. It happened that the weather conditions were exceptionally favorable for blight in the following season, and it was then that the first devastating epidemics occurred. The old story of alarm, scientific inquiry, and suffering of a peasant population was enacted in miniature, but it was enacted again.

The parallel between the first epidemics in Chile in the years 1950 and 1951, and those in Ireland in 1845 and 1846, is quite instructive. In the first of the Irish Famine years the attack was also late--not until September in general; only a part (estimated at about a quarter) of the crop was lost, but the seed was universally infected. It also happened then that weather conditions in the following year were exceptionally favorable for blight, and so came the really devastating and tragic epidemic, with the tops killed, not in September but early in August, when the tubers were still very small. It takes at least two blight years to build up a first epidemic, and in this sense, blight years are most serious when they come in pairs.

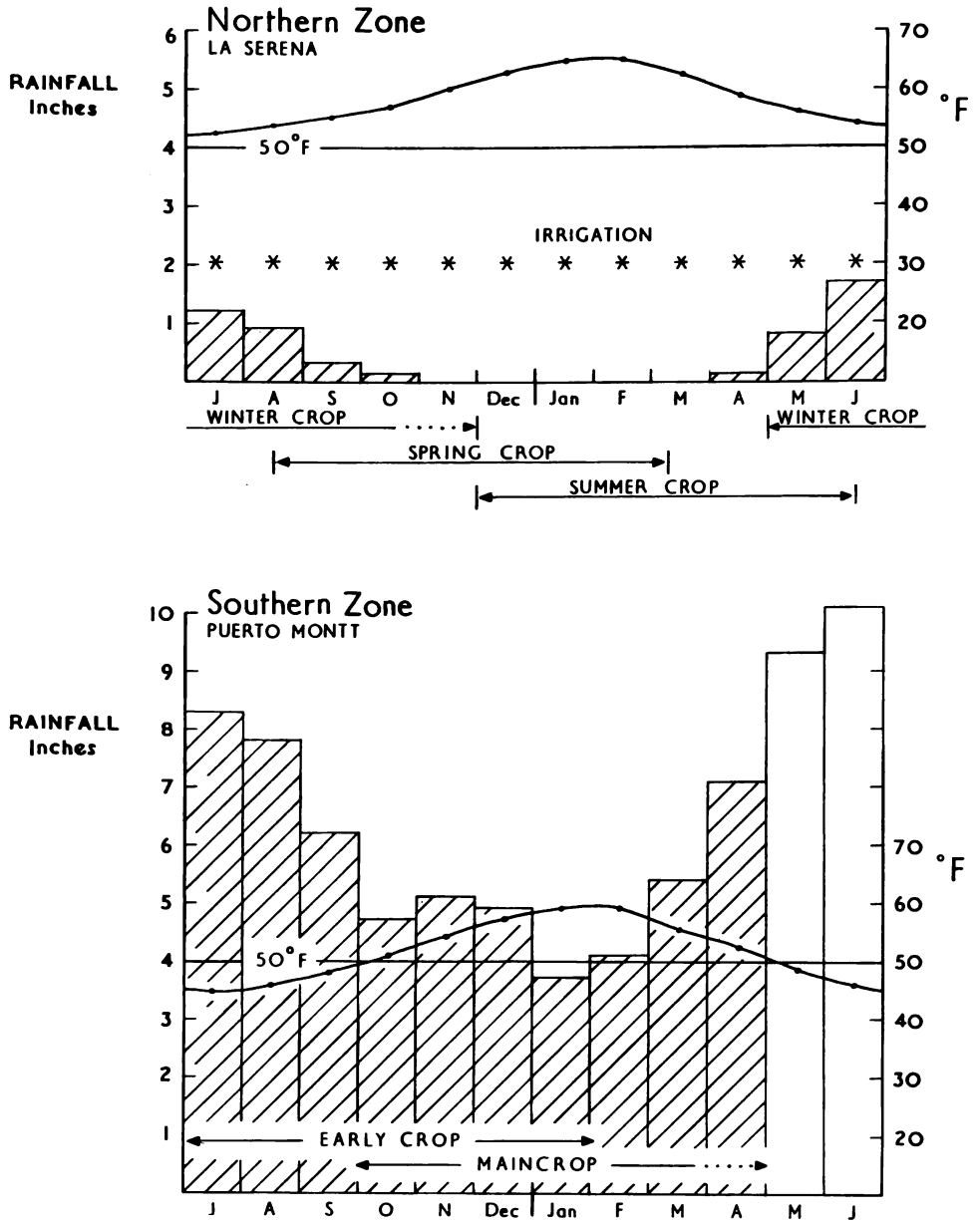


FIGURE 78.--Long-term average monthly rainfall and mean temperatures in relation to cropping in the northern and southern potato growing zones of Chile.

COURSE OF THE EPIDEMICS IN THE SOUTHERN ZONE

It is in the southern rainy zone of Chile that blight is of the greatest consequence. Bourke (1956) has collected and sifted all the available information on the incidence of blight in this region for each year since 1949, and he has presented this in the form of estimated blight progress curves. From these the probable mean starting and 75 percent dates are taken and lined up in table 100, as against the mean temperature and rainfall figures for December, January, and February in each of the years. There is perhaps a month's range each way in planting and lifting dates, but typically the maincrops are planted about the end of October, are aboveground by the end of November, beginning to form tubers in December, producing most of their crop in January and February, and dying down with little growth left in March. Thus the months of December, January, and February in the southern zone of Chile correspond approximately with the months of June, July, and August in the south of the British Isles. (See tables 3 and 29 for England and for Ireland.)

The mean temperatures over the growing period in this part of Chile are very similar to those in southern Ireland, and the rainfall figures, though perhaps varying more from year to year, are also very similar.

TABLE 100.--Rainfall, mean temperatures, and deviations from mean temperatures in relation to blight at Puerto Montt, Chile, 1949-56

Year	Rainfall			Deviation from mean temperature			Blight in southern zone	
	Dec.	Jan.	Feb.	Dec.	Jan.	Feb.	Started about--	75 percent date about--
	In.	In.	In.	°F.	°F.	°F.		
Average[1]	4.4	3.5	4.1	57	59	59	--	--
1949-50	3.7	9.5	5.6	+1	+2	+3	Feb. 4	Mar. 31
1950-51	4.6	7.0	2.0	0	-1	-2	Dec. 8	Jan. 31
1951-52	3.7	1.1	1.7	+3	+2	+2	Nov. 25	Feb. 28
1952-53	.9	6.0	3.9	+3	+1	+3	Dec. 23	Mar. 26
1953-54	4.6	2.7	2.3	+3	0	+1	Dec. 27	Mar. 31
1954-55	7.4	5.4	5.1	+2	+3	+2	Dec. 3	Mar. 10
1955-56	8.1	6.1	2.6	+1	-3	+1	Jan. 3	Mar. 31

[1] Long-term average temperatures are for 1911-40; rainfall averages are for 1911-48.

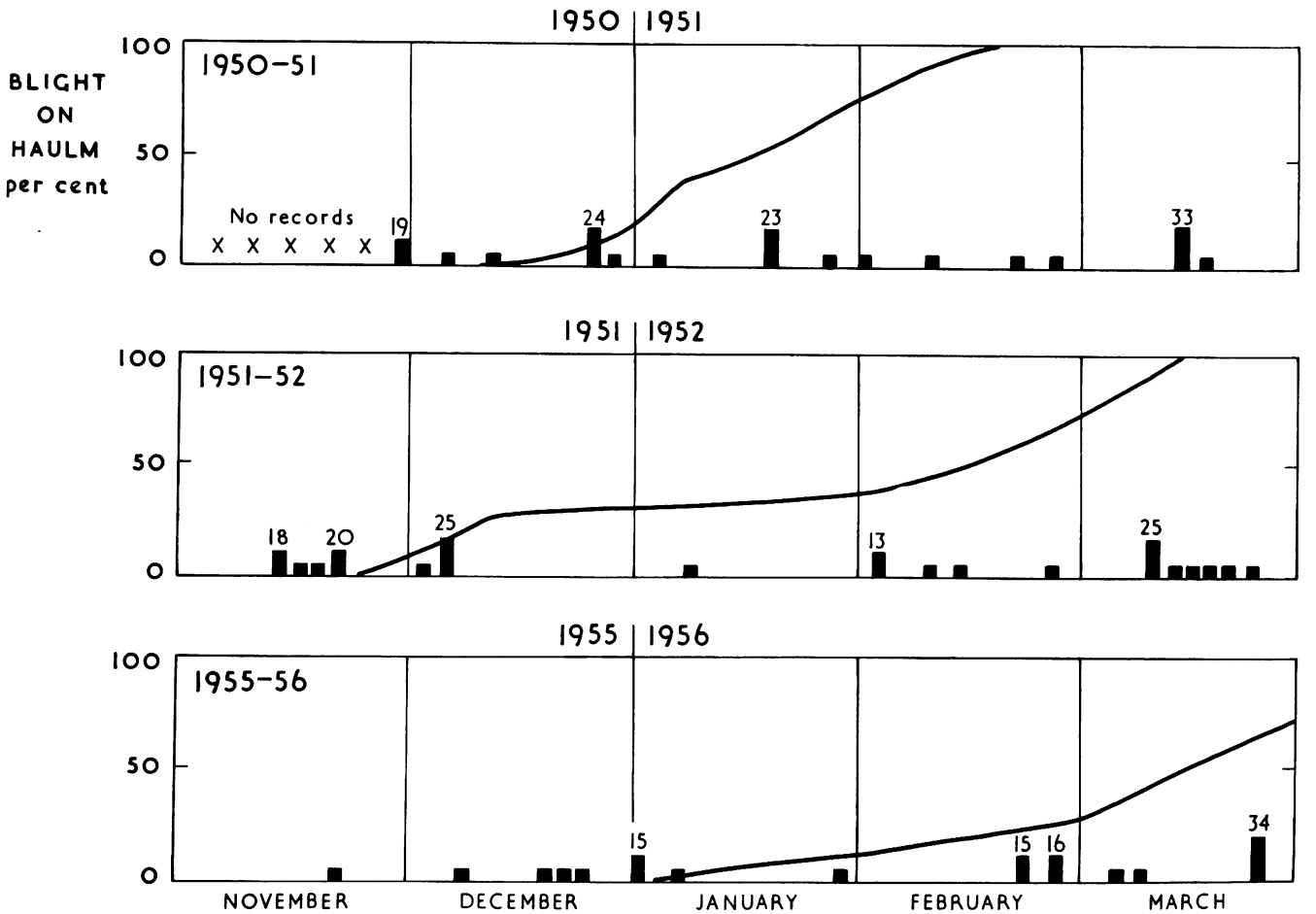


FIGURE 79.--Approximate progress of blight attacks in relation to blight weather spells for unsprayed maincrop potatoes in the southern zone of Chile. The effective duration in hours of the longer spells is given; the shorter spells ranged from 1 to 10 hours. (Data from Bourke, 1957.)

In each year since 1950 blight attacks in the southern zone of Chile have started at sometime between the end of November and the end of December. In 1950-51 the disease made rapid progress, and by causing 75 percent destruction of the haulm by the end of January, it gave rise to a loss of about half the crop. In all the subsequent years the progress of the disease has been retarded after the outbreak, so that it has not reached the 75 percent stage until sometime in March, thereby causing little or no defoliation loss, but considerable infection in the tubers.

To some extent the courses of the epidemics in the 6 years were consonant with the simple mean temperature and rainfall figures. In the one severe blight year, 1950-51, the mean temperatures were below average. In four of the subsequent years the monthly mean temperatures were 2° to 3° F. above average, and many of the rainfall figures were low. In 1955-56, however, when the least severe epidemic occurred, the January mean temperature was well above average, and the rainfall in December and January was high. Thus, although in southern Chile as in the British Isles, high rainfall and mean monthly temperatures only slightly below average tend to favor the development of blight and temperatures 2° to 3° F. above average with lower rainfall tend to hold it in check, rainfall and temperature figures alone are inadequate indicators of the occurrence of blight weather.

By study of the available humidity records for southern Chile and the application of his "Irish Rules" (see section on Republic of Ireland), Bourke was able to obtain a fair indication of the "blight weather spells" that probably occurred in each of the 6 years. In figure 79 these spells are here charted in relation to the estimated progress curves for blight in the years 1950-51, 1951-52, 1955-56. Bourke stresses the importance of the "effective duration" of the blight weather spells; the longer spells are therefore distinguished by taller blocks in the diagrams, and their effective durations in hours are also given in figures. Beaumont periods occurred in correspondence with most of these longer spells, but were rarely associated with the shorter spells of 1 to 10 hours.

Figure 79 shows clearly that in 1950-51 the rapid progress of the disease was related to the numerous spells of blight weather, some of long duration, which occurred at short intervals throughout December, January, and February. In 1951-52, with several spells of long duration in November and the beginning of December, the attack began earlier than in 1950. At first its progress was rapid, but thereafter, until the beginning of February, there was only one short spell and the progress of the disease on the maincrops was arrested. In 1956, with only short spells in December despite the high rainfall, the attack did not start until the beginning of January. It was stimulated by a long spell at that time, but thereafter there was only one short spell until the end of February, and the attack did not become serious until the haulm was dying down in March.

In the southern potato-growing zone of Chile severe blight weather conditions such as those accompanying the epidemic of 1950-51 have not recurred in the subsequent 5 seasons, and from a general analysis of past weather records Bourke estimates that such exceptionally severe epidemics are unlikely to occur in this region more often than 1 year in 8 or 10. "Blight years," in which the attack is more moderate and much of the loss is by tuber infection, will occur more often, but there is as yet insufficient data to establish their frequency. Although the mean temperature and rainfall figures during the growing period in southern Chile are very similar to those in southern Ireland, and the mean diurnal range of temperature is also much the same (about 15° F.), blight weather evidently occurs less frequently than in Ireland, and the general incidence of blight over the years has so far been much lower. Bourke attributes this to the lesser frequency in this part of Chile of young atmospheric wave depressions with wide warm sectors such as are responsible for the longer and more important periods of blight weather in Ireland.

EPIDEMICS IN THE NORTHERN ZONE

The extreme north of Chile is one of the driest regions in the world; and the desert conditions do not change until about latitude 27° S., where the mean annual rainfall is about half an inch. From there southward, the rainfall progressively increases to about 5 inches at La Serena (30° S.), 10 inches at Valparaiso (33° S.), and 100 inches at Valdivia (40° S). The coastal potato cultivations in the northern potato zone about La Serena are dependent upon irrigation, but even so, potato growing would not be possible over much of the year but for the influence of the cold Humboldt current, which strikes the Chilean coast at about latitude 40° S., and sends a branch northward up to the coast of Peru. This ocean current cools the air above it, giving rise to much sea fog and cloud and keeping the temperatures low and remarkably constant. Thus, although it is at about the same latitude as Brisbane (30° S.), La Serena has a mean temperature of about 52° F. in midwinter, rising only to 65° F. in midsummer.

A mean temperature of 65° F., though rather high, is by no means high enough to inhibit blight. Even so, the climagram for La Serena (fig. 78), with its striking dearth of rainfall, would not suggest much likelihood of blight attacks. The low temperatures for the latitude and the proximity to the sea should give rise to suspicion, but the diagram provides no direct

indication of the dense and wetting morning fogs (camanchacas) which are common along the coast and sometimes persist for much of the day.

In 1950 blight appeared in the winter crop about La Serena--the disease having been brought in with seed from the south--and although the attack on the winter crop was not then serious as the winter was cold, the infection appears to have spread over, with favorable weather in October and November 1950, onto crops of the spring and summer plantings. According to Müller the attack reached epidemic proportions from January 1951 onward, diminishing in November 1951. The winter of 1951 was mild and the winter crop in that year (sown about May) suffered severely. Montaldo (1953), cited by Bourke, reported that a crop of the imported variety Sebago, near La Serena during this winter season, was a complete failure because the newly emerged plants were heavily infected from neighboring crops of the Corahila potatoes. Weather conditions were favorable for the infection of spring-planted crops in November and December 1951, but the disease disappeared around La Serena by January 1952. In subsequent years the disease has recurred to some extent in the winter and spring crops, but the attacks have been less and less severe and the summer crops have been virtually free except in 1955, when Bourke found blight present on April 14, at the 10 percent stage by the B.M.S. key, on almost every crop he inspected in the La Serena region. This was associated with quite abnormal rainfall in March.

No survey records or even the most tentative of progress curves are available for the northern zone, but it would appear that over the summer months, with fairly high temperatures and virtually no rain, there is little blight, despite the sea fogs and despite the surface irrigation (which Bourke considers to have no effect on the incidence of the disease). In the La Serena district, however, blight weather can occur in the winter months with mean temperatures about 55° F., and extremely little rain. Whether they occur or not depends upon Humboldt current effects and not upon the movements of atmospheric depressions, for this part of Chile is beyond the northern limit of their track.

CONTROL MEASURES

Immediately following the first epidemic in 1950-51, varieties having some marked field resistance to blight, notably Ackersegen and Voran, were brought in from Europe to replace the very susceptible Corahila mixture of varieties. At first these "white" potatoes were not popular, but the prejudice appears to have died down, and Bourke reports that the more resistant varieties have now replaced the Corahila to the extent of 60 percent or more in the areas most subject to blight. Breeding work on other varieties is in progress.

Some protective spraying with bordeaux mixture and other copper fungicides is done in the La Serena and central areas, but the majority of the growers in the south, particularly in Chiloé, where the yields are small, are not convinced that it is an economic control measure. Müller (1952) advocated all the usual cultural methods of control now practiced in Europe after a century's experience of the disease, notably earthing up of the drills to protect the tubers from infection, precautions at lifting, and measures to minimize the inclusion of blighted tubers in seed stocks. He also advocated the avoidance of winter cropping in the south, to break the continuity of infection, and recommended the establishment of a "tizón look-out service." Bourke has carried this latter suggestion much further and shown how a forecasting service can be operated. He has also advocated quantitative blight survey work, on the lines of that carried out in England and Wales in recent years, to establish the true significance of the disease in the various regions and to guide control policy.

SUMMARY: CHILE

Potato blight was unknown in Chile until the late 1940's, when it was introduced probably by infected ware tubers in ships' stores from the Argentine. Outbreaks were identified in many parts of the potato-growing regions late in 1950, and in 1951 there was a devastating epidemic that caused great distress and privation, particularly in the Chiloé region, where the climatic conditions are rather similar to those of southern Ireland. Fortunately, and perhaps owing to less frequent persistence of moist warm air masses over the area, severe epidemic conditions have not recurred since 1951, although the disease has been present every year and has caused some infection of tubers. Other severe epidemics are to be expected in the future, but there is a hope that their impact may be lessened by the introduction that has taken place of more resistant varieties than the native Corahila. Severe epidemics can occur in northern coastal areas, despite very low rainfall, owing to the prevalence of fogs.

UNION OF SOUTH AFRICA

In the Union of South Africa, with a total population in 1954 of 13-1/2 million, there is a considerable production of potatoes. The F.A.O. (1956) figures for 1948-52 show some 140,000 acres each year, with a production of about 230,000 tons, indicating a mean yield of under 2 tons per acre. The Transvaal Highveld to the east of Johannesburg is by far the most important center of production (see map, fig. 80). In this area, in which there are some 40,000 acres, the average yield is about 4 tons (60 bags) per acre. There are lesser concentrations of production at similar altitudes (5,000 to 6,000 ft.) to the east of the Orange Free State, in Natal, and also on the lowland along the extreme southern seaboard from Cape Town to Port Elizabeth. The Union is of particular interest in a world study of potato blight, (1) owing to the striking contrast between the climatic conditions at an altitude of 5,600 feet in the Transvaal and those in the coastal areas of the south, and (2) because in the Transvaal the presence or absence of primary infection appears to play a greater part in determining the occurrence of blight epidemics than is the case under European conditions. There is little in the literature concerning the incidence of blight in the Union, and for information the authors are indebted to J. E. van der Plank, who has carried out inquiries into recent epidemics, in part for the special purposes of this study.

CLIMATIC AND CULTURAL CONDITIONS

Figure 81 shows the long-term average temperatures and rainfall for Bethal, well representative of the potato-growing areas in the Transvaal Highveld; and also for George and Cape Town in the south. The climagrams suggest that in the Transvaal, with abundant summer and low winter rainfall and the mean temperature line above 50° F. from August to May, there will be potato cropping only over this period; whereas at George in the south there will be cropping all the year round, and around Cape Town winter cropping will be the rule--the low rainfall and high temperatures in the summer months being unfavorable for the crop.

These indications are borne out in practice, although at Bethal, with an upland continental climate the diurnal range of temperature (from 54° to 80° F. in December and January) is greater than in the maritime regions. Fine warm days follow sharp cold nights, and the potato-growing period is limited by the occurrence of frosts. The average date for the last severe frost is September 20 to 30, and for the first severe frost of the succeeding winter about April 20 to 30, so that the growing period during which the plants may be above-ground is from the end of September to mid-April. Planting may be done in September, but the first heavy rains are generally needed to moisten the ground, and planting is not generally completed before mid-October. With nearly optimum temperatures and plenty of sunshine a 120-day growing period is adequate, and the first crops will normally ripen in January. When the crops are nearly mature they are earthed up well and normally kept in the ground until they are to be marketed. This marketing period extends from January (for the very earliest crops) through the rest of the summer, autumn, and winter until August. There is little winter rainfall. The soil does not freeze to any great depth; there may be surface penetration of frost before the sun melts it during the day, but there is no permanent freezing. Thus, there is no clamping or other intermediate storage of potatoes, as in Europe. They are left in the ground and lifted, sorted, and bagged as required for market. Planting is in rows 36 to 45 inches apart, the widest rows (45 inches) being those of farmers who like to earth up very high for the storage period. Spacing between plants in the row is 16 to 22 inches. Many growers start earthing up when the plants are very small as a precaution against tuber moth.

The climagram for Bethal suggests that with a 120-day growing period and with the abundant rain and favorable temperatures, late plantings would be made up to mid-January to obtain crops maturing in April before the frosts. But, in fact, the second half of the long season favorable for the growth of potatoes is little used, owing to the incidence of blight.

Around George, 240 miles east of Cape Town, rain is well distributed throughout the year; the climate is temperate, and near the coast the area is free from frosts. Potatoes are grown the year round, and blight is severe, especially in the autumn and early winter. There is a constant carryover of infection from one crop to another.

Around Cape Town the climate is notably different from that at George and also from that in the Transvaal; it closely resembles that of Western Australia. The summers are dry, hot, and windy. The cropping period is from March to October or November, utilizing the winter rains. Severe blight epidemics occur over the winter and spring and are the limiting factors in potato production, which has now fallen to a relatively small amount.

BLIGHT EPIDEMICS IN THE TRANSVAAL HIGHVELD

In the 1955-56 season the potatoes, all Up-to-Date except for a very few Kennebec, were planted in September and October and were closing across the drills by about the end of November. On December 18-20, blight was

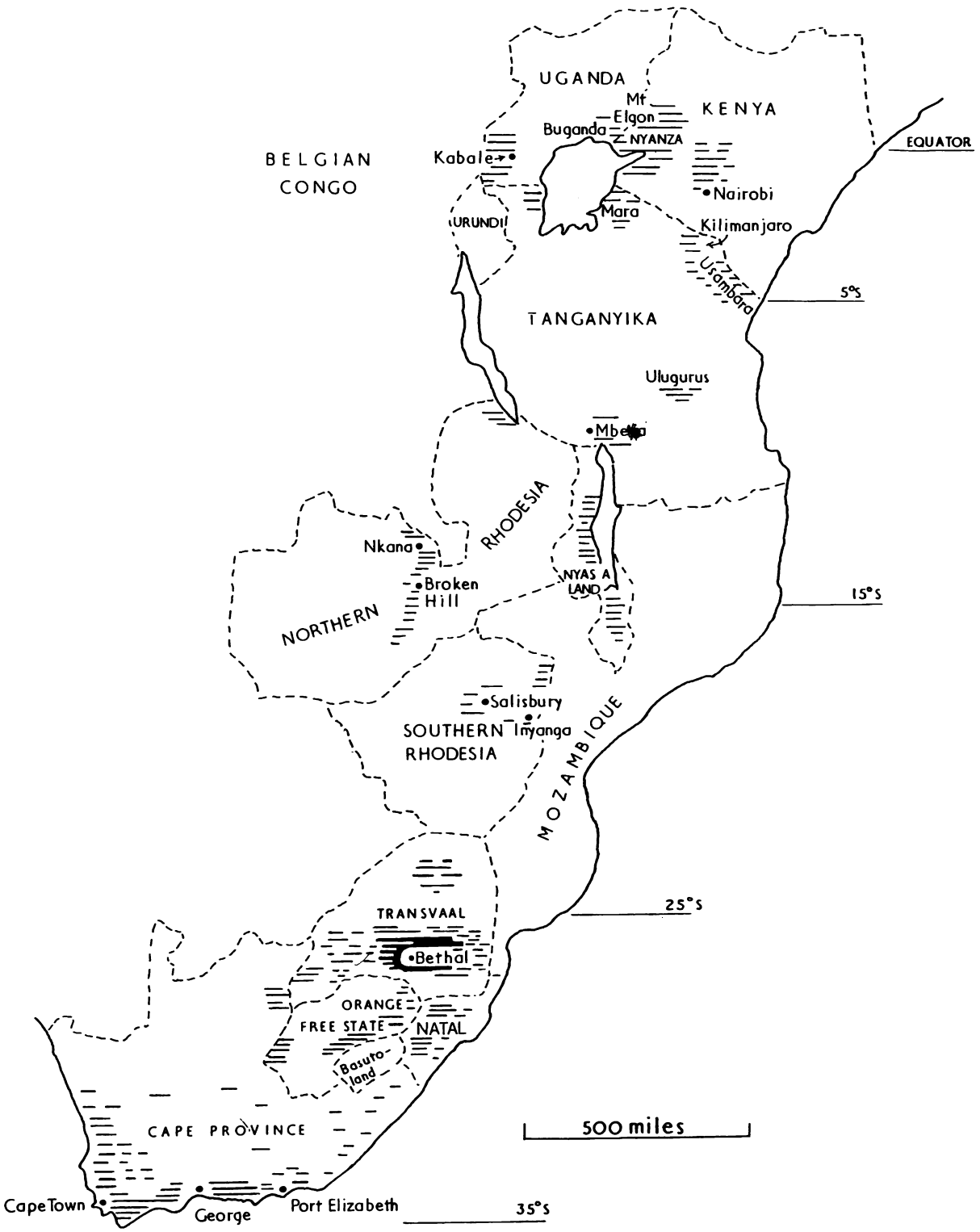


FIGURE 80.--Key map of East and South Africa: Shading indicates areas where potatoes are grown.

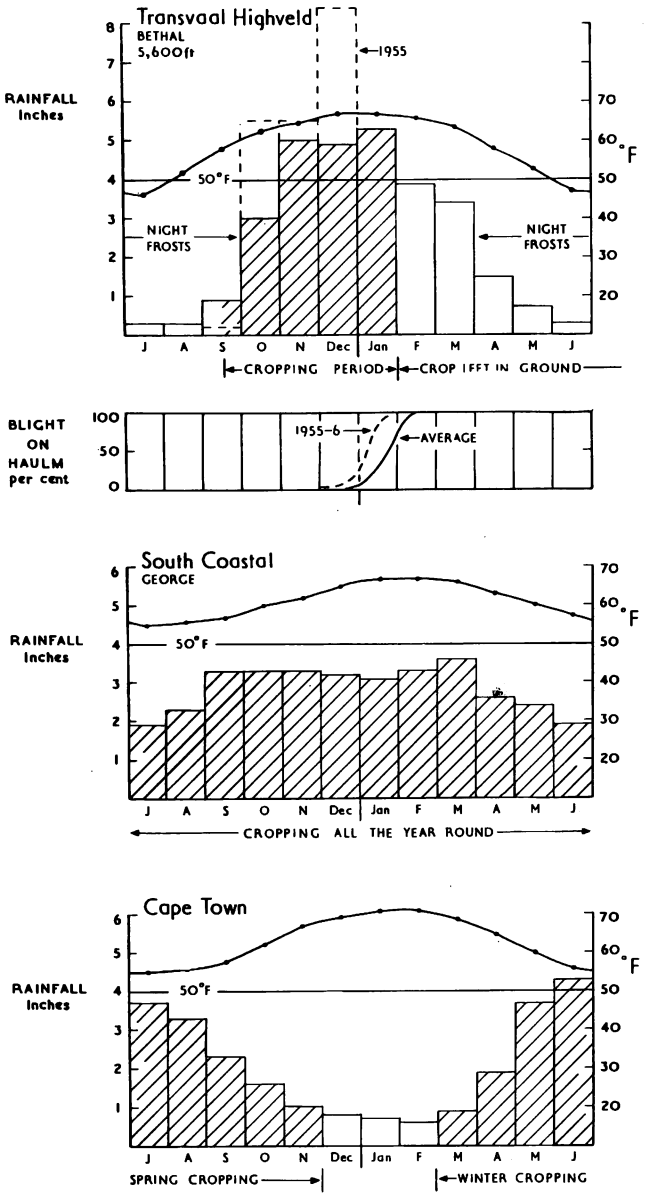


FIGURE 81.--Long-term average monthly rainfall and mean temperatures in relation to potato cropping for three centers in the Union of South Africa, with blight curves for the Transvaal.

found scattered over the whole area, and by January 12, 1956, only a few green leaves were left. The weather then cleared and further spread of blight was stopped. On December 20, the estimated crop for the whole area was 2,300,000 bags of 150 lb. each. After the epidemic the actual yield was 1,850,000 bags. Of the drop, 350,000 bags, or 15 percent of the expected yield, was attributed to loss by premature defoliation; and 100,000 bags, or about 4-1/2 percent, to rotting of the tubers in the ground from blight infection and other causes. The loss in individual fields depended on the age of the crop at the time of the blight attack.

The rainfall and mean temperature figures for the season were:

Month:	Rainfall (inches)	Mean temperature °F.
September.....	0	57
October.....	5.5	60
November.....	5.3	63
December.....	8.4	64
January.....	1.3	65

The 1955-56 season was worse than average for blight, the attack being earlier than usual; this may have been associated with the high rainfall in December, but there were also dull and overcast conditions in late December, continuing into January. The progress of the disease was stopped by the dry weather later in January, and the few leaves then remaining green were not further attacked.

Precise information is not available for previous years. In general, blight starts toward the end of December and does not reach the 75 percent stage until the end of January, when growth is over in most of the crops. Indications of the probable mean blight progress curves for most years, and for the bad blight year 1955-56, are given in the climagram (fig. 81). The estimated loss of 15 percent of the crop by defoliation in 1955-56 is fairly consistent, with some 2 to 3 weeks' loss of growth in this particular year.

In most years the loss from blight is slight in crops planted as early as possible (in September and October), as these are already dying down (in January) before much defoliation by blight occurs. The major loss arises from the fact that the incidence of blight renders it impossible to utilize the second half of an otherwise excellent season for potato growing. The market quality of potatoes left in the ground from January deteriorates by sprouting and other causes by July; and were it not for blight, second plantings would be made in December or January to mature before the first frosts at the end of April and to provide supplies of potatoes in good condition after relatively short storage, to supply the winter market. The result is a scarcity of good potatoes on the market from July onward. Crops planted in December or January would be cut down by blight while the plants were still small, and thus there would be little or no yield. Experience now being won in the high valleys of Mexico (q.v.) seems to point a way toward overcoming this loss of the second crop.

SOURCES OF INFECTION

On the Transvaal Highveld it cannot be assumed that primary sources of blight infection are always present to start an epidemic when weather conditions become favorable for its development. As the climagram indicates, there is almost always abundant rain and favorable temperatures for blight from October

onward. Although many of the earliest planted crops are well forward and in flower by November, no blight has ever been seen in that month. In the 1955-56 season, despite exceptionally heavy rain during October, November, and December (49 inches in 11 weeks at Harrismith) and squelching fields, no spot of blight was found in the Highveld up to December 31.

The seed from the Highveld crops saved for planting in the following year is riddled off from the ware, or taken from crops specially intended for seed. In either case it is lifted late, and it is often stored with a light straw covering under the dense canopy of evergreen trees, which gives adequate protection from the frosts. It may be that this combination of circumstances--the late harvesting of seed after it has lain during the autumn in warm soil and the temperate winter climate--is unfavorable to the survival of Phytophthora infestans in the local seed, so that in some years there is little primary infection from this source.

It is possible that the first infection may come in from other areas. It is known that the disease occurs in winter crops of potatoes and tomatoes in the frostfree areas near the east coast. Some support for this idea comes from the fact that blight epidemics normally occur in summer crops in the coastal province of Natal before there are any outbreaks far inland, in the main production area of the Highveld.

Lastly, there is undoubtedly some blight infection in imported seed. Much seed is still imported annually, mainly from Scotland. Because of the opposite seasons, the imported seed arrives late, and is mostly planted from the second half of November onward, fully 2 months after the planting of the local seed, and this might explain the timing of the blight epidemics, which commonly begin, not in November as might be expected from infection in the local seed, but in December.

CONTROL MEASURES

Spraying plays practically no part in Highveld farming. At least one farmer with a large acreage and proper equipment sprays regularly and says it pays him, but the spraying is basically with DDT to control tuber moth. Zineb is added for blight, but a part of the advantage may come from control of early blight, Alternaria solani, which is very common, and sometimes more injurious than the late blight caused by Phytophthora infestans.

Some seed of Kennebec, an R_1 resistant variety, has been introduced, but in 1955-56 it suffered almost as severely from blight as the Up-to-Date variety. Two R_1R_2 types (Onikwa 52 and Onikwa 53) have been tried in the Cape Province, but are not promising. Blight races 1; 1,2; 3; and 4 are certainly present in the Union, and skepticism is felt about the value of varieties containing the R-genes, singly or in combination. A note on three sorts of resistance to late blight by Van der Plank (1957) distinguishes between (1) R-gene resistance; (2) field resistance associated with late maturity (as in Voran and in the Dutch Robijn now grown in Kenya); and (3) field resistance not associated with late maturity (as in Sebago).

On the whole, the only important control measure in the Highveld has been to plant early for blight escape; but this is effective only at the cost of a sacrifice of supplies for the late market, which commands the best price. Attempts are being made to breed varieties of about the same maturity as Up-to-Date but with tubers having a longer period of winter dormancy. One variety of this kind is already under test and shows promise. It is considered that breeding to this end may in some ways be an easier task than breeding for disease resistance, which is also under way.

Dr. Van der Plank thinks the Highveld area may be so isolated from airborne infection in other areas and have storage conditions so unfavorable for the survival of the fungus in the tubers, that epidemics might be suppressed by growing only local seed or by heat treatment on the Jensen principle of imported seed to insure its complete freedom from blight infection.

Against this there is the fact that the humidity conditions, as apart from rainfall and temperature, of the Highveld have not yet been investigated. It is possible that records of blight-weather spells by Bourke's Irish Rules (see section on Chile) or of Beaumont periods (see England and Wales) might reveal that the relatively late outbreaks (in December) are due to a general absence of critical blight weather before that time, rather than to any lack of the very few and widely scattered primary infectors that are necessary to start an attack over a wide area (see Van der Zaag, 1956).

SUMMARY: UNION OF SOUTH AFRICA

In the Transvaal Highveld, the principal potato-growing area of the Union, the major loss from blight is a loss of the whole of the second half of an otherwise ideal potato-growing season. Late-planted crops could be used to provide potatoes for the winter market if the disease were controlled. Even with restriction to early planting for disease escape, losses are still occasionally severe, as for example in the 1955-56 season when the loss was about 20 percent of the expected crop. The frostfree areas of the Southern Cape, the only part of the Union with adequate winter rainfall, should be the natural source of out-of-season crops; in the past it was usual for Cape potatoes to be sent in quantity to northern markets in the winter. For many years, however, blight has limited potato production in this area, and the Cape now imports potatoes from the north. In Natal, crops of both the January and the September plantings are severely attacked in some years, and the damage is of particular consequence in seed crops for the Transvaal.

Conditions of potato growing in Southern Rhodesia (fig. 80), where according to F.A.O. (1955) there were some 5,000 acres in 1952, with a production of about 16,000 tons, are in some respects similar to those in the Transvaal, but higher temperatures in the winter months permit cropping all the year. G. R. Bates reports that more than half of the Southern Rhodesia crop is produced within a radius of about 35 miles of Salisbury. Since blight became established in that locality in 1952-53, there has been an increasing tendency to explore new areas for potato growing, and quite substantial amounts are now grown in the Midlands, around Bulawayo, and on the high ground between Salisbury and Umtali. Both seed and ware are also grown throughout the mountainous eastern districts, where there are humus-rich friable soils. The tubers have an excellent keeping quality--a characteristic rare in other areas of Southern Rhodesia.

CLIMATE AND CULTIVATIONS

The rainfall pattern in the Salisbury area somewhat resembles that at Bethal (fig. 81). There are 6 dry months and 6 rainy months. The rains start with thunderstorms in mid-November, increase to January and February, which is the wettest period, and end in March, with a few thunderstorms in April. May is dry, and the weather then remains dry until mid-November. July is the coldest month, but here the mean July temperature (56° F.) is well above the 50° level, in contrast to that at Bethal (46° or 47°).

Three potato crops are grown during the year--the main, or summer crop, which is usually planted in November with the onset of the rains, and harvested in February; a first-irrigation crop, planted in March and harvested in June; and a second-irrigation crop planted at the end of July and harvested in October. Frosts normally occur in June and July.

For irrigation crops a typical rotation is potatoes, followed by maize--for two seasons at least--during the summer, and wheat or barley in the succeeding winter, followed by green cropping or summer fallow. Potatoes are grown usually every third or fourth year on the same land, but the rotation is now being widened. Until recently, the variety grown has been almost invariably Up-to-Date, which is very susceptible to blight but has a strong consumer preference, is well adapted to the latitude, and has a fair tolerance to leaf roll. It is also drought resistant.

BLIGHT INCIDENCE: 1946-53

J. C. F. Hopkins, who was at Salisbury from 1926 to 1953, has told the authors that there were no records of potato blight in Southern Rhodesia until 1946, when it was found on Up-to-Date in the Enterprise district of Salisbury, on a first-irrigation crop about May 10. In the particular crop of 13 acres on which it was then found, there had been 13 irrigations before flowering, and with 2 inches of rain in May, conditions were unusually wet. Although most of the foliage was killed, little if any loss of crop occurred, and all the tubers were well developed. A little blight was seen on neighboring farms that year. It is not known how the blight was introduced; the affected crop was grown from local seed. Potato supplies for troops during the war may have brought in the disease.

Nothing further was seen of blight after 1946 until 1951-52. In 1952 there was a severe attack in the eastern seed-growing area about Inyanga (fig. 80), and by 1953 the disease had spread to the main Salisbury area. Dr. Hopkins conducted a seed-potato growing scheme (summer crops) on the mountains about Inyanga, and between 1940 and 1947 there was no blight in the area. In 1949-50 the Portuguese started potato growing with imported seed just over the Mozambique border, at over 7,000 ft. in the mist belt near Manika. Blight attacks became very severe, and it is possible that southeasterly winds during the winter spread the disease across the country.

EPIDEMICS SINCE 1953

G. R. Bates and W. E. Kerr have reported that blight has been severe every year in Southern Rhodesia since the first general epidemic in 1953. This has been due mainly to a succession of very wet summers. In the summer, or main, crop, overall blight losses have been estimated as never less than 25 percent, and occasionally they have reached 50 percent. Individual summer crops on some farms have been a complete failure. In each of the 5 seasons blight was noted in the Salisbury district between December 20 and January 10, except in 1956-57, when, following an unusually early and prolonged rainy spell in mid-November 1956, the disease appeared before the end of that month.

The pattern of infection among the first-irrigation crops has varied considerably. In 1953 and 1954 it was sporadic and losses did not exceed 10 percent. Subsequently, losses of up to 30 percent have occurred. This has been due to very wet seasons with extensions of the rains into May or even June, and also to a tendency among the Salisbury growers to plant the first-irrigation crop earlier and earlier, with the result that the summer and first-irrigation crops have overlapped. Irrigation is mainly by the furrow method, although overhead irrigation is becoming more common. With furrow irrigation, blight tends to attack

the stems and leaf stalks rather than the leaves; but this may perhaps be a characteristic of the potato variety, for stem lesions are very common on Up-to-Date, even when it is grown under natural rainfall in the southwest of England.

No blight has yet been observed on the second-irrigation crop, but this matures during the hottest period of the year and the keeping quality of the tubers is poor.

CONTROL

All attempts to control blight by spraying have failed on the summer crops, chiefly because of difficulty in obtaining adequate protection under conditions of torrential rain. More promising results have been obtained on the first-irrigation crops, particularly with the dithiocarbamates.

A fair amount of work has been done on resistant varieties. Little prospect of success is expected until more attention is devoted, as it has been during the past 2 years, to cultural practices and the choice of varieties for the various croppings according to their several cropping characteristics. R-gene resistance has proved a failure for summer cropping conditions in the varieties tested (Kennebec, Pentland Ace). Better results have been obtained with field-resistant varieties, such as Furore, Voran, Robijn, and in particular, Pimpernel; but all these have their disadvantages, and search is continuing for more acceptable field-resistant sorts. Recent records show that blight races 0; 1,3,4; 3,4; 4; and 1,4 are present in summer crops, and races 4 and 1,3,4 in irrigation crops.

Disease-escape methods are being used and explored. The seed crops along the eastern border, which once were threatened with extinction because of the devastating blight attacks, are now planted much earlier to escape the most dangerous blight-period (December-January). Elsewhere in the country the main (summer) ware crops can be planted before about mid-October only where supplementary irrigation is available. Field trials over the past 2 seasons have shown the value of planting in the third week of September under such conditions, and heavy yields have been obtained. Ulster Prince is being tried for very early summer planting to escape blight.

EAST AFRICA

The problems of potato growing in East Africa have been reviewed by Moreau (1944b), who has given an admirable account of the particular localities in the mountains of Northern Rhodesia, Nyasaland, Tanganyika, Kenya, and Uganda where the crop is grown, as well as a critical study of rainfall and temperature conditions. The production of potatoes over the whole of this vast area is small and very localized, and with some exceptions, the "English" potato is a minor crop, providing but a small part of the native diet. In Uganda in 1955, for example, there were 500,000 acres of beans, 520,000 of cassava, 1,585,000 of coffee, 425,000 of groundnuts, 380,000 of maize, 1,218,000 of millet, 220,000 of peas, 1,414,000 of plantains, 582,000 of yams and sweetpotatoes, and only 15,000 acres of the "English" potato, or Solanum tuberosum. Most of the potato cultivations are primitive, and often they are a luxury vegetable that the natives can sell for a good price despite the small yield, which is often less than that of the earliest "new" potatoes in Europe. Cans of such potatoes are frequently sold by natives at the roadside to passing long-distance lorry drivers.

Nevertheless, with good husbandry excellent crops of S. tuberosum can be raised in suitable areas, and the cultivation of this crop is becoming more important. Moreau (1944b) concluded that the short-day conditions were of no practical consequence, and that there was no reason to suppose that S. andigenum potatoes would do any better than suitable varieties of S. tuberosum. According to F.A.O. (1955) the potato acreage in recent years has been about 12,500 in Kenya, 2,500 in Tanganyika, 15,000 in Uganda, and 2,500 in Northern Rhodesia. Mean yield figures are scanty and are not too reliable, but actual yields probably range from 1 or 2 tons per acre in native cultivations interplanted with beans, to 4, or very exceptionally, even 8 tons per acre with good European husbandry. Potato blight has invaded most parts of East Africa only within the past 20 years. Watts Padwick (1956) has attempted to assess the approximate losses now caused by the disease from data received in response to a questionnaire sent out as part of a Colonial Plant Disease Survey. For all parts of East Africa he has put the percentage loss at 10 percent or more. For the purposes of the present study, Kenya has been considered at some length, as typifying the equatorial mountain cultivations. The sections on Uganda, Tanganyika, and Northern Rhodesia are therefore shorter.

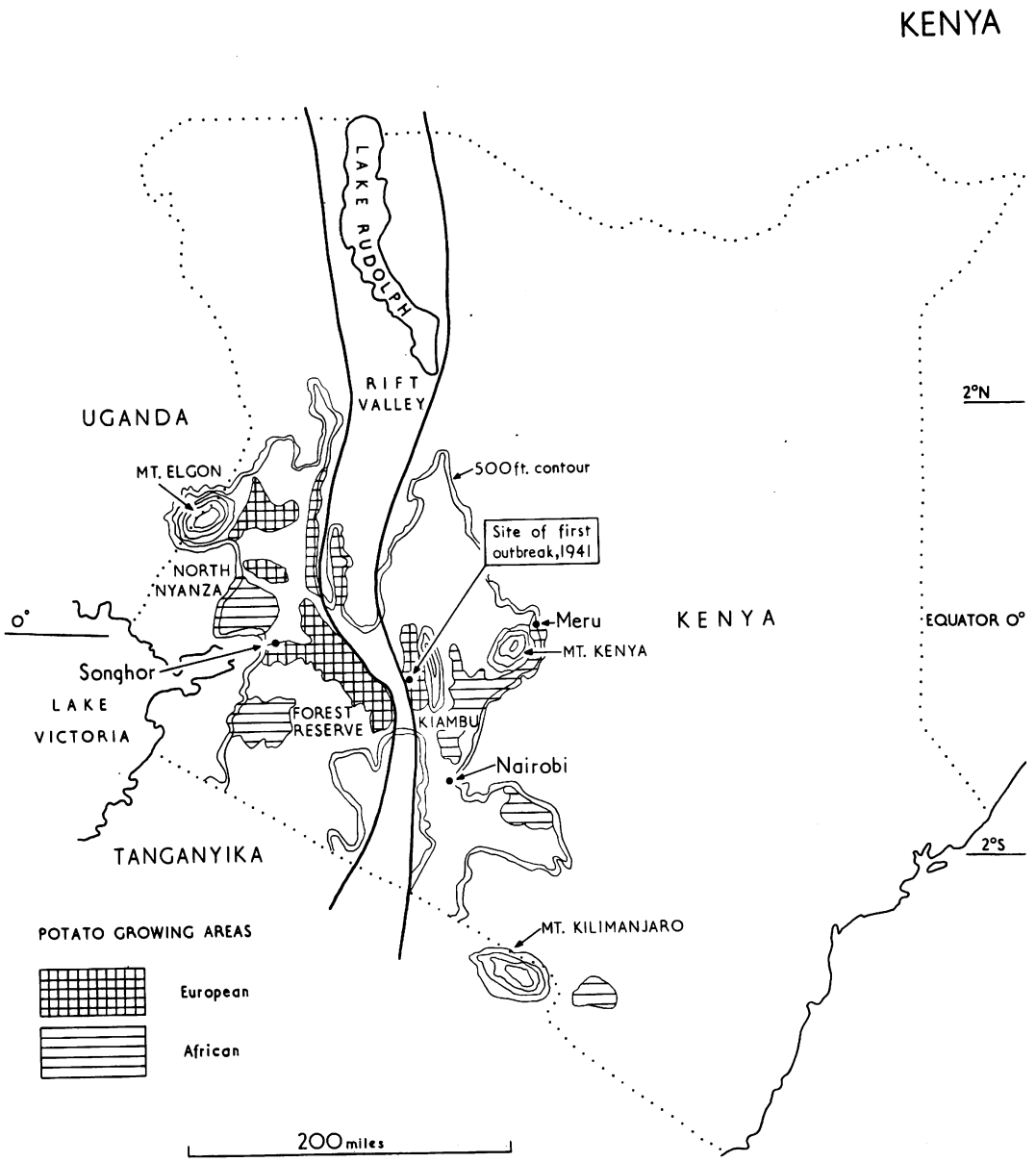


FIGURE 82.--Key map of Kenya, showing principal potato growing areas and localities referred to in text.

Potatoes have probably been grown in Kenya for as long as the Highlands have been settled by Europeans. The acreage, however, is relatively small and yields are low. According to F.A.O. (1955) the mean area for the crop in the years 1948-52 was about 12,500 acres, with a mean production of about 21,000 tons, or 1 3/4 tons per acre. With a population of about 6 millions, the annual consumption of potatoes, together with other starchy roots, was estimated at only about 20 lb. per person.

Blight was first observed in Kenya in 1941 by R. M. Nattrass, to whom the authors are indebted for a first-hand account of the disease in Kenya from its beginnings up to the present time.

DISTRIBUTION OF POTATO GROWING AND CLIMATIC CONDITIONS

As shown by the key map (fig. 82), potatoes are now grown on both sides of the Rift Valley at altitudes between 6,000 and 9,000 ft., between latitudes 2° N. and 2° S. of the Equator. The cultivation is in both native and "settled" areas within this altitude range. In all native areas the potatoes are produced as a food and as a cash crop. There is some specializa-

tion in potato growing here and there by European farmers, but this is an indication of inclination rather than topography. Almost all the area between 6,000 and 9,000 ft. is suitable, but the best parts lie within 7,000 and 8,500 ft.

The climagrams (fig. 83) illustrate the mean rainfall and temperature conditions at two centers, respectively, west and east of the Rift Valley. These figures show the general pattern of the rainfall, but the actual precipitation in individual months is exceedingly variable. East of the Rift there are two plantings. One, the "long rains" crop, is planted in March and lifted about July, and the other, a "short rains" crop, is planted in October or November and lifted about February. The "short rains" crop is often light, as the rainfall is considerably less than that in the "long rains" crop. West of the Rift the rains are heavier and more evenly distributed over the year. There is one planting in April or May, with lifting in August or September.

During the rains at the higher altitudes, especially east of the Rift, there are periods of mist and much drifting light rain in addition to the heavy falls. So far as temperature is concerned, there cannot be said to be any regular succession of spring, summer, autumn, and winter. The seasons are dependent upon the advent of rains, and it is only lack of rain that stops potato cropping at any time of the year. The mean temperature lies between 60° and 65° F. the whole year round, and the controlling temperature variation in the highlands is the diurnal range, which becomes excessive on all days when clouds are absent. The mean diurnal range at Nairobi, however, is 18° (52° to 70°) in August. It rises to 23° or 24° only in January and February.

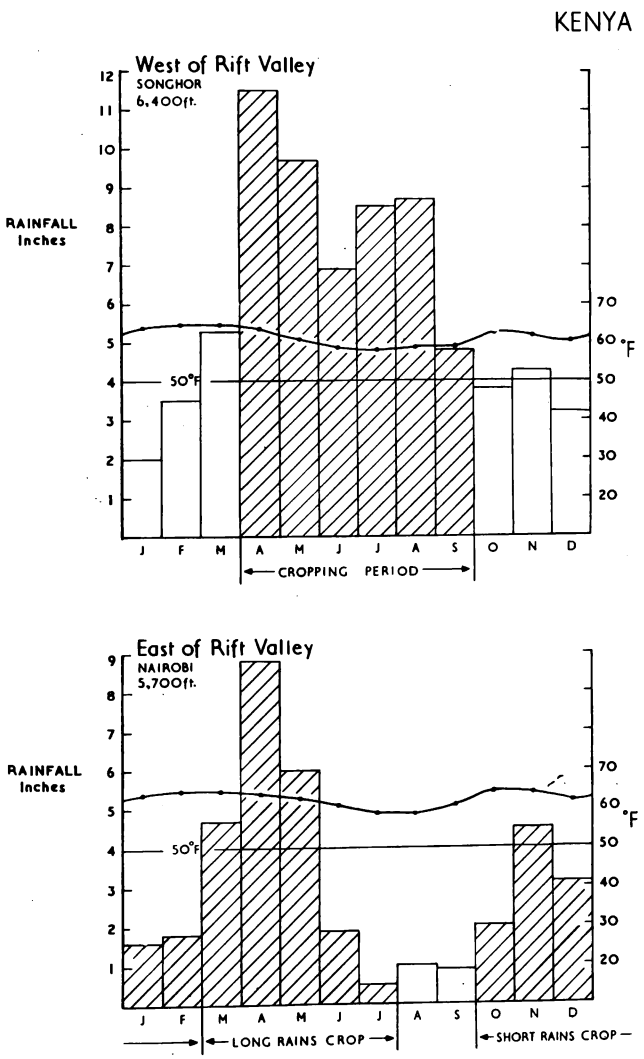


FIGURE 83.--Long-term average monthly rainfall and mean temperatures in relation to potato cropping, west and east of the Rift Valley in Kenya.

THE BEGINNINGS OF BLIGHT IN KENYA

Dr. Nattrass first found the disease in May 1941, about the middle of the east Rift on the "long rains" crop (see climagram). The focal point appeared to be on high land at about 8,000 ft. near the eastern escarpment of the Rift Valley 60 miles north of Nairobi (see key map). The affected variety was Kerr's Pink, in a crop for which imported seed had been planted. On his return to Nairobi, Dr. Nattrass found the disease in a garden at 7,000 ft., about 20 miles west of the city. Within the following few weeks reports of the "new disease" began to come in from practically all the potato-growing areas east of the Rift, particularly from the Aberdares Range and Mount Kenya--a large tract of country including extensive areas of Kikuyu reserve. By the middle of November, to quote one agricultural officer, "the disease had assumed epidemic proportions over the whole of this area; squatters' shambas were heavily infected, and the crops in many parts, almost, if not wholly, a failure."

The disease did not appear across the Rift Valley until a year after the original outbreak; the first notification of the disease on the west escarpment was in June 1942. A month later it had reached the foothills of Mount Elgon on the Uganda borders. From this point it spread westward into Uganda and eventually into the Belgian Congo. Southward, Tanganyika was reached in the same year (1942). One isolated area in the Usambaras in Tanganyika held out until 1943, although heavy attacks occurred in the closely settled slopes of Mount Kilimanjaro. In 1944 the Tanganyika plant pathologist reported that the disease was present in all the important areas of the Territory.

SOURCE OF THE FIRST INFECTIONS

Until 1939-45, potato growing was almost entirely confined to African production, although one or two European farmers had imported seed and grown commercial crops from time to time. With the low prices then prevailing, however, commercial production of potatoes by Europeans was much restricted or even nonexistent. Apart from squatters' production on European farms, which supplied most of the European market demand, there was (and still is) some growing of potatoes at higher altitudes as a native food crop to replace maize. The native crops were not pure varieties but mixtures of odd sorts long since gone out of cultivation by Europeans. At the time of the blight outbreak a number of Europeans were growing what had then become a lucrative crop on account of Service demands. Kerr's Pink was the favorite variety, and a large consignment of it was imported from the United Kingdom for the 1941 crop. This extension of potato growing coinciding with an exceptionally wet season in 1941 may possibly have given rise to circumstances more favorable for the introduction of blight than there had ever been before. Dr. Nattrass is convinced that if blight had developed on any previous occasion in Kenya, it would almost certainly have become endemic and could scarcely have escaped observation. Except at high altitudes, there are no frosts to kill the haulms; once potatoes have been grown on any piece of land it is practically impossible (with ordinary cultivations) to prevent groundkeepers coming up. They grow like weeds and may persist for years.

CONTROL MEASURES

The onset of the new disease in 1941 caught the Europeans unprepared for any direct control measures, and native cultivators were in any case unable to do anything about it. The effect was devastating on the European Kerr's Pink, and some of the miscellaneous native varieties were completely destroyed. Two of these native varieties, however, the "Kinongo Kerai" (since identified as Northern Star) and another, known locally as "Kigezi Blue" (later identified as Skerry Blue), showed considerable resistance to the disease. The first step therefore was to advise that these two varieties should be collected and multiplied with all possible speed.

The importation of blight-resistant hybrids for test under the local conditions began in 1943, and this testing, centered at the Scott Agricultural Laboratories at Nairobi, has continued since that time. In the early days a suggestion from Reddick and others that Kenya should produce its own short-day potato was investigated, and some breeding work was done with Solanum andigenum. Beyond the raising of some fantastic hybrids with the ordinary domestic varieties this achieved nothing. The main work has been with Black's R-gene resistant hybrids from Scotland, of which about 60 have been tried up to the present time. These R-resisters were at first very successful, being immune from attack by the blight races 0 and 2,4, then the only races that appeared to be present. Some of these varieties were grown on a fairly large scale, and although they were eventually attacked, they are still in cultivation. As new blight races appeared, seedlings with more genes for resistance came from Dr. Black, and were tested against them. So far the blight races identified from Kenya are 0; 2,4; 4; 1,2; 2; and 1,3,4. (See fig. 16 for these race designations.) Race 3,4 has also been identified from Kenya, but on tomato. Some of the above races were found for the first time in material from Kenya.

In 1950 Phytophthora infestans was found on the leaves of perennial woody Solanums (S. indicum, S. panduraeforme, and S. incanum) in widely separated localities of bush and forest (Nattrass and Ryan, 1951). The races of the fungus so far identified on these wild shrubs are 2,4 and 4. S. incanum is susceptible to some races but resistant to others; another species, the treelike S. aculeastrum is susceptible to all races. The importance of these wild hosts is that they flourish in the wetter forest regions where blight conditions are very favorable, and they can act as a perennial source of infection.

A number of Black's resistant varieties have been distributed over the country in both European and African areas. They have proved to be resistant to the dominant blight races and are now in considerable demand. Others are still being tested, and the two most promising varieties to suit the local conditions are a R_1R_2 and R_3R_4.

The most popular commercial variety in Kenya at the present time, however, is the Dutch Robijn, which was introduced from John Clarke in 1945 and has no R-genes. It stands up to blight better than most varieties in Kenya, other than the R-resisters, and it has largely replaced Kerr's Pink. Dr. Black has informed the authors that Robijn was bred from Roode Star x Preferment, and that it is a variety with a fairly high field resistance, which seems to suit the Tropics, as it has also done well in trials in Southern Rhodesia. On a scale from 1 to 5 for field resistance in which 1 denotes completely resistant and 5 completely susceptible, Dr. Black has placed Robijn, from the results of his trials, at 3.5, which compares with 3 for Voran and 4 for Kerr's Pink. It is thus more resistant than Kerr's Pink, and, presumably like Kerr's Pink, it is tolerant of the short-day conditions. Kerr's Pink, so extremely popular in Ireland, appears suited

equally well to the extreme long-day conditions of Iceland (see Iceland section) and to the extreme short-day conditions in Kenya. The second most widely grown variety in Kenya is now the native Kinongo. A few European growers plant a little Majestic and Up-to-Date.

Protective spraying as a means of control has been considered and full directions have been issued (Nattrass, 1944) for the conduct of the operation, both with freshly prepared bordeaux mixture and with cuprous oxide and copper oxychloride preparations. Only a very little spraying has been done, and the real hope of control is through the introduction of resistant varieties. Blight has been a serious disease on tomatoes in Kenya ever since its introduction, and it is on tomatoes that control by spraying has real possibilities. A full account of the disease on tomatoes is given in Nattrass (1950).

COURSE OF EPIDEMICS AND MAGNITUDE OF LOSSES

In Kenya the potato plants may be attacked at almost any stage of growth, and conditions are too variable over the range of potato-growing areas for any estimate of loss of crop from the date at which the haulm is destroyed. The worst blight years have been 1941 (the first year of attack), 1946, 1951, and 1955. No surveys have been attempted to establish the actual timing of the attacks or the extent of losses in various years; indeed, such surveys would be extremely difficult to carry out, owing to the scatter of the cultivations and the many factors other than blight contributing to low yields. In general, it can be said that slight attacks tend to coincide with partial failure of the crop from lack of rain; while with abundant rain and luxuriant crops the blight attack becomes severe.

The introduction of potato blight has certainly not prevented the continuation and expansion of potato growing in Kenya; it has merely introduced yet another factor contributing to the variability of production in various years and districts. The situation in 1951 to 1955, 10 years or more after the first epidemics, may be seen from the notes on potato production in the Annual Reports of the Department of Agriculture. In 1951 excessive rains reduced yields in the Nyanza Province and blight was prevalent, both there and in the Central Province. The Dutch Robijn showed greater resistance than other varieties to the adverse conditions and to blight.

In 1952, owing to the failure of the short rains, plantings were small in the Nyanza Province. In the Central Province there was a shortage of planting material created by the heavy blight attacks of 1951, and throughout Kikuyuland the short-rains crop suffered a good deal from blight. In Meru good crops were harvested. In 1953, yields were heavy in the Meru district and moderate elsewhere. In the Nyanza Province a fair crop was harvested. Owing to dry conditions, blight was less severe than usual, and planting of Robijn was increasing. In 1954, the crop did well in the Central Province, with Kiambu coming into production again. Production in Meru slumped for security reasons. Blight and paucity of resistant seed were reported as the limiting factors to increased production. Yields in Kericho were above average. Stocks of Robijn were being built up gradually in all districts. In 1955, a steady increase of acreage was reported in the Central Province, except Meru. Long-rains crops yielded well in all districts but short-rains crops were severely hit by blight. Production was increasing in Nyanza, where the output at Kericho had quadrupled since 1950. Sales from African areas increased from 687 tons valued at £14,410 in 1954 to 800 tons valued at £17,300 in 1955.

SUMMARY: KENYA

Blight was first found east of the Rift Valley in 1941, and by 1942 it had appeared in both European and African cultivations in the equatorial highlands on both sides of the Rift. Mean temperatures between 60° and 65° F. all the year round, with heavy and variable rainfall, double cropping and perennial groundkeepers, all favor the incidence of the disease; but attacks are very variable from district to district and season to season. Much work has been done on the determination of blight races, and Kenya has been found to be a country in which much specialization of the fungus can occur. Several races have been found on solanaceous forest trees and shrubs. R-resistant varieties have been extensively tested, many have gone down under local conditions, but some are still of value and others of promise. Robijn, a variety with no R-genes but with some useful measure of field resistance has largely replaced Kerr's Pink as the most popular commercial variety.

UGANDA

The authors are indebted to Margaret A. Keay, of Makere College, Kampala, for a review of the available information for Uganda.

Potatoes are grown entirely by African peasant cultivators, and the acreage is very small compared with that planted to other crops. At one time there were some potatoes in Buganda, but the climate in this central province is the

TABLE 101.--Potato acreage in Uganda, 1946-55

Year	Western Province	Buganda	Eastern Province
	1,000 acres	1,000 acres	1,000 acres
1946	1.7	1.5	--
1947	2.1	1.1	--
1948	4.3	2.4	0.4
1949	6.1	.7	.7
1950	7.9	.7	4.0
1951	8.0	--	4.4
1952	8.9	.8	2.5
1953	9.0	--	2.6
1954	9.2	--	3.1
1955	11.0	--	4.1

least suited for them, and cotton and coffee provide all the cash crops required. At the present time the largest acreage is in the Kigezi district in the Western Province, at altitudes of 5,000 to 7,500 ft., but there is also a smaller acreage at the same altitude range in the Eastern Province near Mount Elgon. Table 101 shows the acreages in the three provinces over the 10 years 1946-55, as given by the Annual Reports of the Department of Agriculture.

According to the Annual Reports, blight spread rapidly into Uganda after it was first found in Kenya in 1941, and in 1942 and succeeding years it destroyed much of the crop in the Kigezi district. In 1948, when the rainfall at Kabale in this area was 30.2 inches, as against the long-term average of 39.2 inches, there was less damage. In 1945 and 1946 the disease was recorded at Kawanda, near Kampala. Although blight appears to be a serious factor in reducing yields in Uganda, and particularly in Kigezi, it has not prevented a steady increase of potato growing in that area, and this is clearly brought out by the acreage figures. The increase is attributable partly to greater consumption of potatoes by the African producers themselves, partly to their need for a cash crop, and partly to a greater demand for potatoes from an increasing urban population. Under good conditions yields are 2 to 3 tons per acre, but most yields are probably lower, owing to the poor standard of peasant cultivation.

The long-term average rainfall and mean temperature conditions for Kabale in the Kigezi area are shown in figure 84. As at Nairobi in Kenya, the rainfall distribution is typically bimodal. There are two cropping periods--planting in April for lifting in August before the September rains; and planting in October for lifting in February before the March rains. In some places the main rains occur about March-April and in other places that are quite near they may be in October-

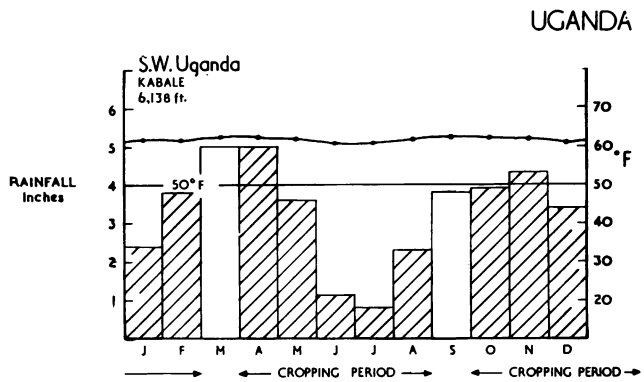


FIGURE 84.--Long-term average monthly rainfall and mean temperatures in relation to potato cropping at Kabale, in southwestern Uganda.

November. Mean temperatures are somewhat lower than at Nairobi, being between 61° and 63° F. in every month of the year. The district is, moreover, notorious for its mists. It is hilly, with very steep slopes to the valleys, the bottoms of which are filled with swamps. The valleys are narrow and there is considerable shadow effect. A very high incidence of cloud occurs; the mean total amount of cloud, on a 0 to 10 scale, at 14.30 hr. of daylight being from 7.5 to 8.5 in every month of the year. Apart from the high diurnal range of temperatures (from 49° to 74°, averaged over the year), the climate would appear to be almost ideally favorable for blight.

No information is available to indicate the timing of the epidemics, or their varying severity in differing years. Potatoes were introduced into Kigezi about 1913, and they are considered to have done better before blight arrived. Some part of the increased acreage may be due to the need to plant more acres to compensate for blight losses, but the main reason for the increase is because more potatoes can be sold.

Control by spraying is out of the question for the very poor subsistence cultivators. The small plots are scattered over a wide area, and it would be burdensome in the extreme to carry spraying or dusting equipment up the precipitious slopes. The variety Toro Blue (probably the old variety Skerry Blue) has shown a useful degree of field resistance. Blight on tomatoes has now been reported in Uganda. Baldwin (1956) records it at Kawanda near Kampala, where he found it late in 1954, but not in 1953. Dr. Keay found it on tomatoes on Makerere Hill in the second half of 1954 and again in 1955.

TANGANYIKA

According to F.A.O. (1955) the acreage of potatoes in Tanganyika is very small indeed, the figure given for 1948-50 being only about 2,500 acres, with a production of about 2,000 tons. E. A. Riley, at Lyamunga, reports that the real extent of potato cropping is probably quite unknown. The cultivations are mainly by Africans, and are located in areas about the Usambara and Ulugurus Mountains, Kilimanjaro, Meru, the Porotos Mountains near Mbeya, Bukoba, and North Mara by Lake Victoria. (See key map, fig. 80.)

Blight first occurred in the territory in the Kilimanjaro area in July 1942, following the outbreak in Kenya in 1941, and it spread rapidly to other areas in Tanganyika, practically wiping out potato growing in the Usambara.

Control has been attempted by spraying, but this is almost impracticable under the conditions of peasant cultivation, and nothing is known of the circumstances that lead to outbreaks. A number of fairly resistant potato varieties were introduced into Tanganyika from Kenya about 1945, including one labeled "Blight Resister No. 914." This later went down with blight, and Dr. Black in Scotland found blight race 1,3 on it. Before this only races 0, 1, and 2 had been recorded. After 1945 eight of Dr. Black's R-resistant varieties were introduced from Scotland. One of these, 1521 (c), has withstood blight so far and has resulted in a revival of potato growing in the Usambara. Seed is being multiplied there for distribution elsewhere. Dr. Black has told the authors that this seedling when tested with race 1,2,3,4 was graded 1 for field resistance, and this bears out its performance in Tanganyika, where it has now been grown for 7 years with 2 crops each year and no blight has appeared on it.

In the Annual Report of the Department of Agriculture for 1955 it is stated that the main potato markets in Tanganyika are Dar es Salaam and Tanga, and that these are supplied from the Ulugurus and Usambara Mountains, respectively. Potatoes are a staple food of Africans in the Porotos and Ukinga Mountains of the southern Highlands, where some 7,000 tons were said to have been produced in 1955. There was no export market, but some were sold in tins to drivers of long-distance transport. The quality of the native-grown potatoes has never been good, partly because of blight and partly because the crop is usually allowed to grow from tubers left in the ground without any further cultivation. Nevertheless, the native growers expect a very high price, and in some seasons they lose their market, because it is cheaper to import potatoes from South Africa.

Moreau (1944b) records that in trials in the Kilimanjaro area potatoes of native type yielded 3 tons per acre, while in the Ulugurus up to 5 tons were obtained with Abundance, and in the Usambara Mountains even 8 tons with Arran Chief.

NORTHERN RHODESIA

Riley (1955) has reported that potato blight was first found in Northern Rhodesia at Nkana, on the Copperbelt, by Mr. Hadfield of the Nkana Mine garden on April 19, 1955. On that date it was seen on the foliage of tomatoes but not on potato plants nearby, which were then quite young (about 6 weeks). The disease progressed rapidly on the tomatoes, and later the potatoes (Up-to-Date) were affected. Complete destruction of the 4 acres of tomatoes and 2 acres of potato haulm ensued. The temperatures during the period 12 to 19 days before the outbreak were about 81° F. daily maximum, and 55° daily minimum (mean 68°), and there had been much cloudy weather.

A. Angus, at Mount Makulu Research Station, Chilnga, has informed the authors that the disease appeared again, on an epidemic scale in 1956. It was found on the Copperbelt at Nkana on potatoes and tomatoes on April 1, and at Luanshya on potatoes on March 3. It was also found on potatoes at 2 places and on tomatoes and potatoes at 1 place in the Broken Hill area between April 4 and May 18, 1956; and on tomatoes at 3 places and on tomatoes and potatoes at 1 place in the Lusaka district, between April 18 and September 26, 1956.

Moreau (1944b) notes that potatoes were grown along the railway line from Choma to Broken Hill (latitudes 17° to 14° S.) at altitudes between 3,200 and 4,500 ft. The disease would now appear to be established in this area, and also further along the railway to Nkana. In Northern Rhodesia there is also some potato growing at latitude 9° S. near Abercorn. F.A.O. (1955) puts the total potato acreage of Northern Rhodesia at about 2,500 acres in 1953, with a production of about 2,000 tons.

Few potatoes are grown in West Africa, but the first occurrence of blight in native cultivations of the crop in the highlands of Bamenda, in the Southern Cameroons, 6° N., so graphically described by T. A. Russell (1954), is one of the incidents of special interest in the recent history of the disease about the world. J. M. Waterston at Ibadan and J. D. Tallantire and his colleagues at Buea provided information supplementing that given by Russell and carrying the story up to 1956.

As recounted by Russell, potatoes are to be found mostly above 6,000 ft. in small tilled patches carved out of the prevailing grassland. The cultivation is very primitive and is done entirely by the women of the tribes with no other tool than a hand hoe and a stout knife. In the area to be planted the grass is burned at the beginning of the dry season, about the end of November, and the surface soil is scraped into raised beds, commonly about 6 feet by 4 feet. In this loose soil the potatoes which have been saved for seed are planted with the first rains in March, and seed of other crops such as maize and kidney bean, is often inter-planted. The first crop is taken in July, and the second crop, planted in late August, is harvested in December. Yields of 2 tons per acre are regarded as good.

Figure 85 shows the location of the area and figure 86 the rainfall and temperature conditions in relation to the croppings. The climagram is for 1952, but the general pattern of rainfall and temperature has been similar in succeeding years, except that the months with the heaviest rainfall (reaching 15 inches

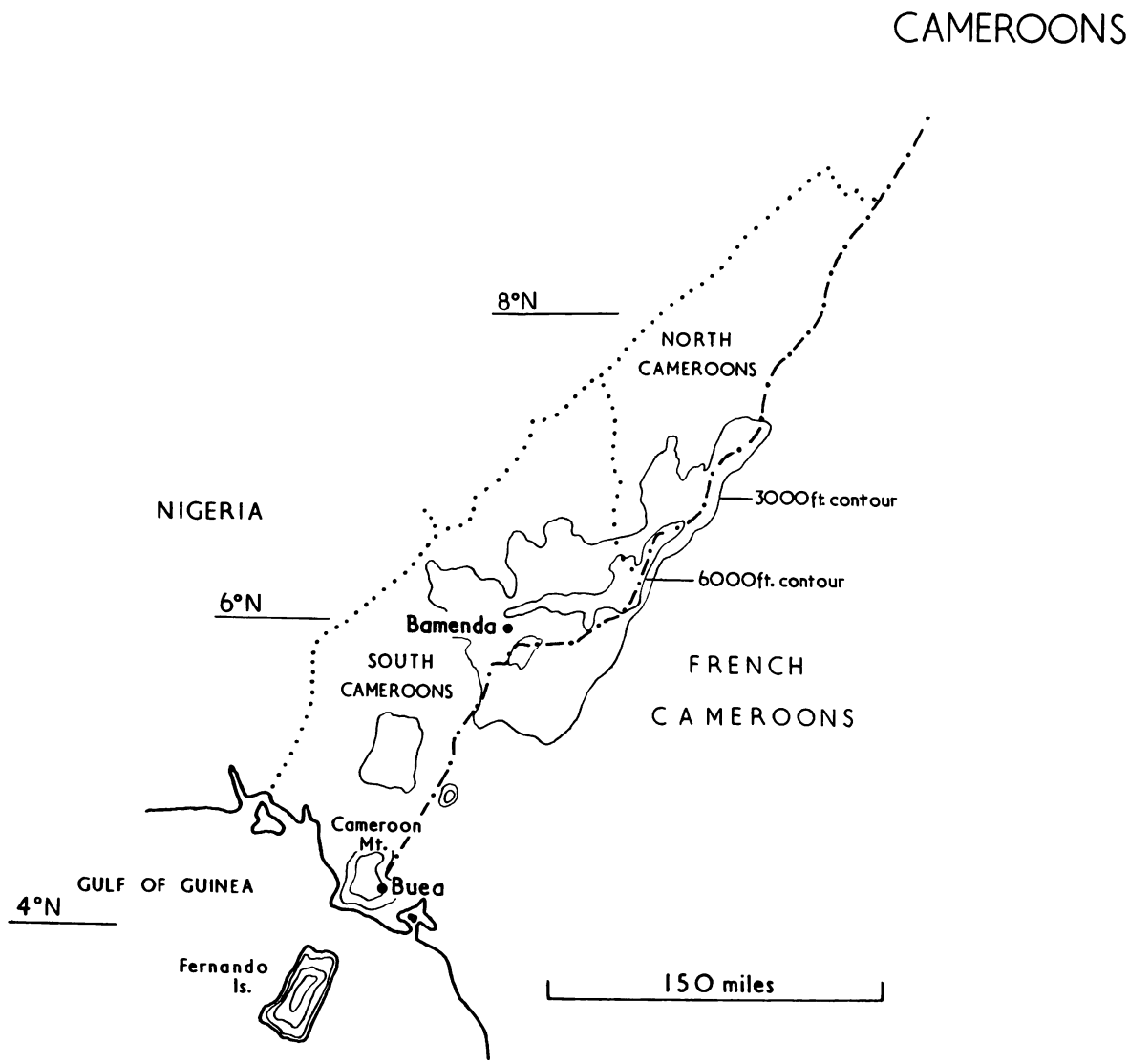


FIGURE 85.--Cameroons, West Africa, showing the Bamenda locality.

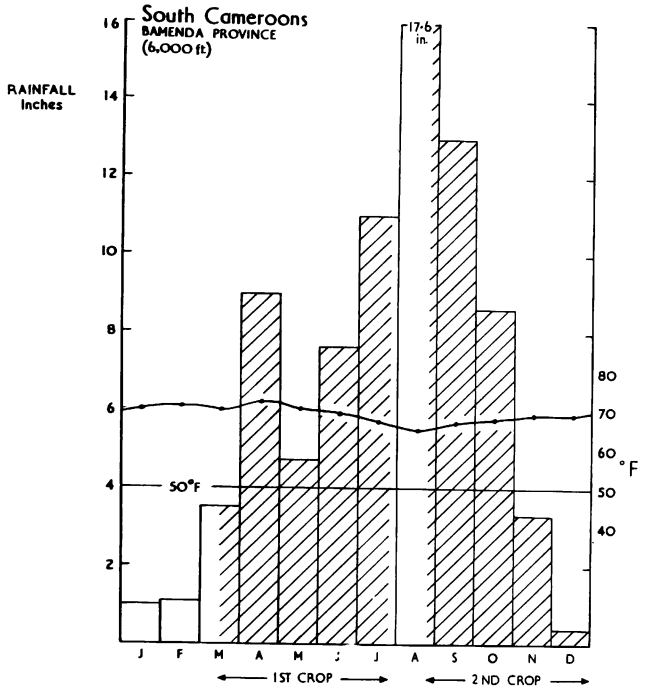


FIGURE 86.--Monthly rainfall and mean temperatures in relation to potato cropping in Bamenda Province, South Cameroons, 1952.

or more) have been sometimes in July, sometimes in June, or sometimes in September. There is a dry period from December to February. The mean temperature is near 70° F. for most months of the year, falling slightly in May or June to September with a low of about 65° in August. The mean diurnal variation in May and June is about 15° (from 60° to 75°). Comparisons with the climagrams for Kenya and Uganda (figs. 83 and 84) show that the conditions are similar to those in other equatorial mountain regions where blight now occurs, but mean temperatures in the Cameroons are distinctly higher, except in the June-September period. Rainfall and temperature figures for May and June in each of the individual years 1952-56 are given in table 102.

Potatoes were probably brought to Bamenda and the adjoining land about Dschang in the French Cameroons during the German occupancy of the territory before 1915. Since then, they have been adopted by the native tribes as an important part of their diet. Until 1952 the crops were free from the disease, but in May of that year there was a report of destruction of the first crop by a disease starting near the French boundary and sweeping over Bamenda Province. The symptoms suggested Phytophthora infestans, and during a visit in November 1952, the presence of the fungus was confirmed in every plot of potatoes throughout the area. Russell was able to ascertain that the disease appeared in the French part of the Cameroons in 1951, a year earlier than on the British side. Some ware potatoes had been imported from France, and occasionally some of these had been planted. There was therefore a possibility that the disease was brought in from Europe. Mr. Tallantire supplied the data in table 102, which show the incidence of the disease on the British side since 1952.

In the early crops, lifted in July, weather conditions in May and June probably determine the severity, or rapidity, of the blight attack. In 1956 the dry June may have been partly responsible for the light attack, but in the other years no obvious differences in rainfall or mean temperature can account for the differences, which were probably due to variation in humidity conditions. With the very high rainfall, and no doubt much mountain fog, mean temperatures up to 70° F. in May and June do not appear to have restricted the development of the disease.

POSSIBILITIES OF CONTROL

Russell records that spraying with 1 percent bordeaux mixture at 10-day intervals

TABLE 102.--Incidence of blight and climatic conditions in South Cameroons, West Africa, 1952-56

Year	Blight incidence	Rainfall		Mean temperature	
		May	June	May	June
		In.	In.	°F.	°F.
1952.....	Disease appeared and crop wiped out.....	4.8	7.6	70	69
1953.....	Widespread attack and heavy losses.....	5.9	14.8	70	67
1954.....	Widespread attacks destroying early crops, September plantings not so badly affected.	10.3	9.2	68	67
1955.....	Attack started in late May, 2 or 3 weeks later than usual. For the first time (since 1951) fair-sized tubers were on sale in the markets.	9.0	18.6	67	65
1956.....	The lightest attack so far since the disease was recorded.	8.1	1.8	66	67

over the growing period failed to prevent the destruction of the crop. With such heavy rainfall it may be impossible to protect the foliage without an altogether uneconomic number of applications. Control by spraying or dusting is hardly a suitable measure for adoption by impoverished and backward tribes.

The introduction of resistant varieties appeared to offer more hope of success. In March and April 1953, a number of R-gene resistant seedlings or varieties from Scotland, Canada, and the U.S.A. were planted at the Government Farm at Bambui within a field of the local susceptible variety. The B.M.S. key was used for the assessment of blight on the trial plots, and on June 16, 1953, where the local variety (planted March 26 to April 8) showed 50 to 95 percent blight, most of the resistant seedlings showed only 0.1 to 5 percent. The score in Kennebec, Pungo, Placid, Canso, and Keswick from the U.S.A. and Canada was then 0 percent, and in Cherokee 0.1 percent. Later news from Mr. Tallantire in 1956 indicates that of the 18 varieties tried only 2 of Dr. Black's seedlings from Scotland, 1521(c) and 1521(d), have shown real promise of standing up to the disease and have given yields of up to 2 tons per acre.

SUMMARY: CAMEROONS

Blight, probably introduced from Europe, attacked primitive potato cultivations in the highlands of the Southern Cameroons for the first time in 1951-52, causing almost complete loss of the crops. In subsequent years the severity of the attacks has decreased, possibly owing in part to some natural selection of the more field-resistant types in the native varieties. Two R-gene resistant seedlings have shown promise in trials. The crop is important, but even a good yield is only about 2 tons per acre.

INDIA

Although the potato acreage in India (fig. 87) has been increasing during recent years, potatoes are still a relatively unimportant food crop. In 1950, for example, the total area of cereals (rice, millets, wheat, etc.) in India was 193 million acres, as against just over half a million acres of potatoes (Russell, 1954).

Figure 87.--Key map of India.

Potatoes are grown for the ware market. They remain something of a luxury crop, owing to their low yield, which averages approximately 2-1/2 tons per acre. The average consumption of starchy roots (principally potatoes) is 24 lb. per head per year (F.A.O., 1955), but actual consumption varies considerably over the country, as the growing of potatoes is concentrated in relatively few areas and transport facilities from these areas are not good.

DISTRIBUTION OF POTATO GROWING AND VARIETIES

R. S. Vasudeva, who has provided much of the information for this section, has included details of the acreages of potatoes grown in the different Indian states during the season 1954-55. These were as follows:

State:	1,000 acres
Uttar Pradesh	244
Bihar	106
West Bengal	105
Assam	73
Other States	137
Total	665

None of the other States, after Assam, grew more than 21,000 acres of potatoes. Thus, production is seen to be concentrated in northern and northeastern India. Of the potato crop 95 percent is grown on the plains of northern India. The remaining 5 percent is grown in the hills, up to a height of 9,000 ft., partly to provide a source of seed for some of the plains' crop. Important hill-growing districts are around Simla and Darjeeling in the north, and the Nilgiri hills in the south. An account of potato-growing methods for the plains and hill crop in the Uttar Pradesh has been given by Mitra (1954). According to Pal and Pushkarnath (1951), 16 local and 38 European potato varieties have been identified under cultivation in India. The main varieties, covering the greatest acreage, are Phulwa, Darjeeling Red Round, Up-to-Date, Magnum Bonum, Gola, Satha, Great Scot, and Italian White Round. The poor quality of much of the seed of these varieties is one of the reasons for the generally low level of potato yields.

CLIMATIC CONDITIONS AND CROPPING PERIODS

The most striking feature of the Indian climate is the rainy summer monsoon. The monsoon rains occur throughout the country, but with a wide range in duration between different localities. In general, winter is a dry or very dry season. The potato crop on the plains is grown during the winter months, as summer temperatures are too high for successful cultivation (see climagram for Patna, fig. 88). Incidentally, even the winter temperatures are too high for potatoes on the low ground in most of peninsular India, and this partly explains the concentration of potato growing in the north of the country. Two crops of potatoes are grown on the plains. The first, planted shortly after the monsoons in September or October and lifted from December to March, is the more important. This is known as the "winter crop" and is planted with seed from a previous plains' crop, which has been stored during the summer. Formerly, storage was in sand in thatched mud houses, when losses through storage rots were very great, but this method is now being rapidly replaced by mechanically operated cold storages. The second plains' crop--the "summer crop"--is grown from December to April, and the source of seed is usually the hills' crop. Both crops on the plains are grown under short-day conditions and have to be irrigated. These factors tend to militate against high yields.

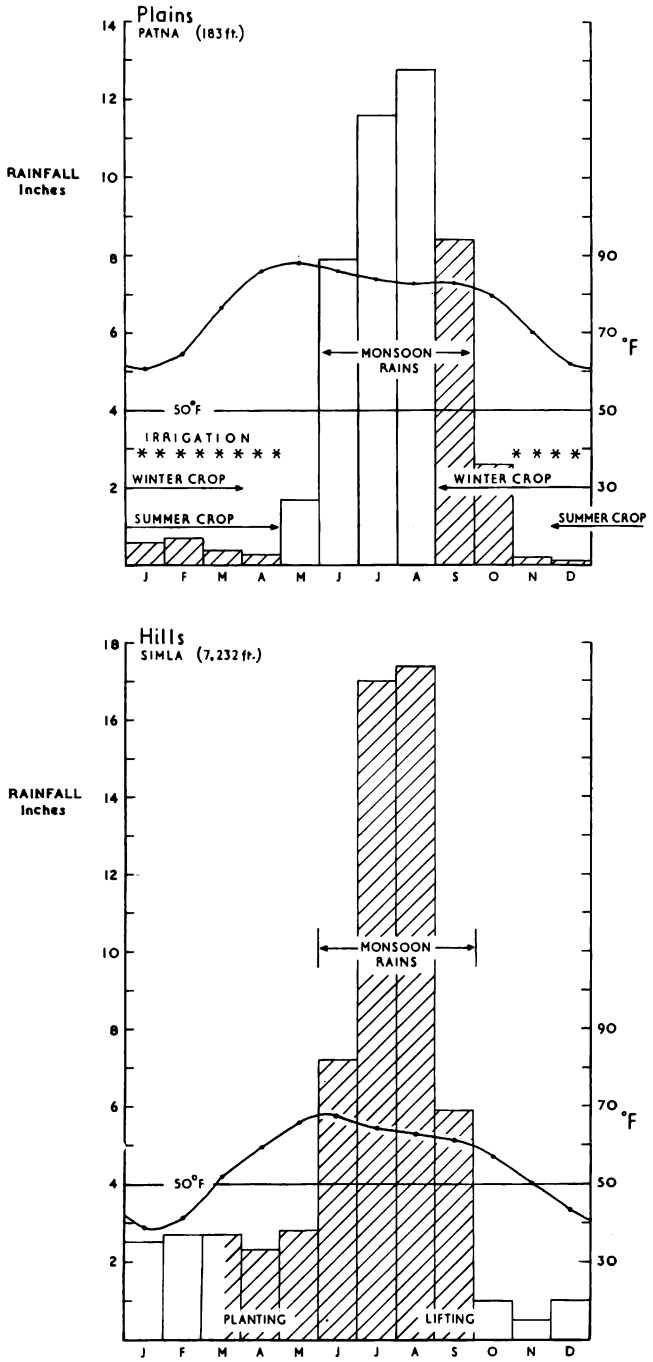


Figure 88.--Long-term average monthly rainfall and mean temperatures in relation to potato cropping on the plains and in the hills of northern India.

In the lower hills (3,000 to 4,000 ft.), where irrigation is possible and snowfall is either absent or over very early, potatoes are planted in February and lifted in June for the ware market. At higher elevations (5,000 to 9,000 ft.), where the seed crop is produced, the growing season is during the summer monsoon period (see climagram for Simla, fig. 88). Planting takes place in late March or April and lifting is in August and September. This seed cannot normally be used for the "winter crop" on the plains, owing to dormancy difficulties.

DISTRIBUTION AND FREQUENCY OF BLIGHT EPIDEMICS

Blight was introduced into India sometime between 1870 and 1880 in seed potatoes from Europe. In the north, it was first observed near Darjeeling in 1883, and the disease spread rapidly to other potato-growing areas in the hills and soon became prevalent in the Khasi, Sikkim, and Nepal hills (Butler, 1918). The presence of the disease in the Simla hills was detected as early as 1902 (Butler, 1903). Since then blight has been widely spread throughout the entire sub-Himalayan region, wherever potatoes are grown, from Simla in the northwest to Darjeeling and Assam in the northeast. The disease causes heavy losses year after year, being particularly severe in the northeastern hilly tracts, where the monsoons break early and are of longer duration.

In the plains of northern India, the disease was first recorded in the Hooghly district of West Bengal in 1900. It was observed for the first time in Bihar at Bhagalpur in 1913; the first record of blight in the plains of Uttar Pradesh was not made until 1943, when it occurred at Meerut and Dehra Dun (Lal, 1948). Until recently, the only source of blight inoculum in the plains crop was infected seed from the hills; the high summer temperatures during the storage period of the plains seed crop did not allow the carryover of the fungus from one plains crop to the next (Dastur, 1948; Lal, 1948). Blight epidemics occurred only occasionally. The introduction of cold storage for the seed has enabled the disease to bridge the summer gap on the plains. In 1949, a severe attack of blight was recorded in a "winter crop" of Phulwa at Hapur in Uttar Pradesh. This variety is confined to the plains, and the source of inoculum from which the crop became infected was undoubtedly carried over in the seed kept in cold storage during the summer. Since then, sporadic infection as well as severe epidemics of blight have been reported from many localities in the plains, including Meerut and Hapur, Allahabad, Benares, and Patna. In the Patna area, in particular, which is an important potato-growing center, blight appears almost every year, and sometimes causes severe damage. There would appear to be a strong connection between the more frequent outbreaks during recent years and the introduction of cold storage for the seed crop (Vasudeva and Azad, 1952a).

BLIGHT ON HAULM AND BLIGHT LOSSES

HILLS: There is no systematic survey data on the timing of blight epidemics in the various

hill districts. Vasudeva and Azad (1952b), however, have given details for one center of blight progress on sprayed and unsprayed potatoes during a severe blight year (1949) and a year (1948) when the disease was slight. Their trials in these 2 years were held at the Central Potato Research Institute Sub-Station at Kufri near Simla, situated at a height of 8,500 ft. Figure 89 shows the blight progress curves on the control plots and on the plots sprayed with burgundy mixture--the most successful of a number of different spray

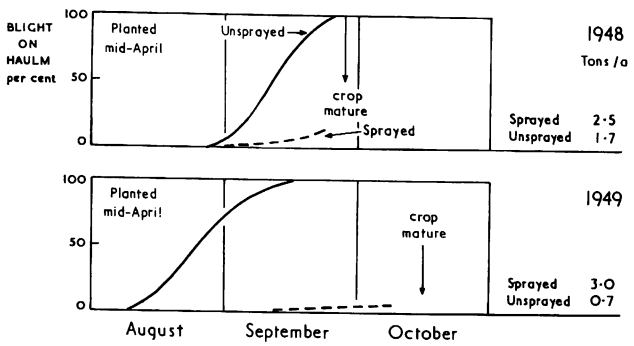


Figure 89.--Progress of blight on sprayed and unsprayed Darjeeling Red Round potato, with corresponding total yields in tons per acre, Kufri near Simla, India, 1948-49.

treatments. In both years, the yields of the sprayed potatoes given in figure 89 represent approximately the full potential yields in the absence of blight. In neither year was the 75 percent blight stage reached on the sprayed plots before the haulm died down naturally, and spray treatments were applied by hand, so causing the minimum of damage. The loss of growth due to blight (i.e., the period between the 75 percent blight stage and the time that the tops matured) was about 2 weeks in 1948 on the control plots. In 1949 it was about 6 weeks. This premature defoliation led to crop losses of 32 and 77 percent, respectively, for the 2 years. The yield losses seem very high when considered in relation to the number of weeks' growth lost, but it may well be that in crops such as these, where the potential yields are very low (2-1/2 to 3 tons per acre), bulking at the end of the growing season is relatively very rapid. It would be interesting to see the results of bulking rate trials carried out under these conditions.

PLAINS: Information is very scanty. Dr. Vasudeva has told the authors that at Patna, where the Central Potato Research Institute is situated, blight generally makes its appearance in the second half of December. By February, when the daily temperatures begin to rise, its further progress is stopped. The time that the disease is likely to cause damage is confined to about 1 month, from mid-December to mid-January. Majid (1952) has stated that during the season 1950-51, blight caused losses in parts of the plains of Assam ranging from 10 to 65 percent of the potato crop; protective spraying increased crop yields by 0.7 to 1.6 tons per acre.

Little attention appears to have been paid in any part of India to the problem of losses due to blight in the tubers, and information on the extent of these losses is lacking.

BLIGHT AND WEATHER DATA

HILLS: The long-term average rainfall and temperature figures for Simla are shown in figure 88. Total annual rainfall at this center is 63 inches, of which over 80 percent falls during the potato-growing season. This is typical of the hill districts, where potatoes are grown. Rainfall, particularly during July and August, is very high, although there are considerable fluctuations in amounts of rain from year to year. The very high rainfall at this time accounts for the almost annual occurrence of severe blight conditions in the hills. In table 103 humidity and temperature data supplied by Dr. Vasudeva are given for the 1948 and 1949 cropping seasons at Kufri. The figures were obtained by averaging daily readings made at 9.00 hours and 17.00 hours (Indian summertime) of wet-bulb and dry-bulb thermometers fixed in the potato-trial plots. Details of blight progress there in these years have been shown in figure 89.

TABLE 103.--Humidity and temperature data at Kufri, India, May-October, 1948-49

Month	Average relative humidity		Mean monthly temperature	
	1948	1949	1948	1949
	Percent	Percent	°F.	°F.
May	25	48	71	66
June	42	59	69	67
July	82	89	66	63
August	96	86	62	62
September	88	87	61	60
October	89	74	57	56

The bad blight year occurred in 1949. Higher relative humidities and lower temperatures during the first half of the growing season in 1949 as compared to those in 1948 no doubt partly explain the earlier appearance and greater effect of the disease in that year. But, a proper analysis of the 2 years on the basis of critical humidity periods, such as those of Beaumont (1947) or Bourke (1955), is required to make a worthwhile comparison of blight-weather relationships. Table 103 does, however, show the sort of variation in humidity and temperature conditions that occurs from month to month during the potato-growing season in the Indian hill districts.

PLAINS: Potatoes are grown under irrigation during the dry winter months (climagram for Patna, fig. 88). Apart from being very much less serious under these conditions than it is in the hill crops, blight is more readily controlled by chemical methods.

CONTROL MEASURES

No exact information exists on the extent of control measures practiced against blight in India, but it must be remembered that potatoes are still largely grown under rather primitive conditions, and it is unlikely that many of the growers are able to undertake a spray program against the disease. The problem can only be seen in its proper perspective against the background of the present low yields of potatoes. These are due to numerous causes, among the most important of which are the virus-infected seedstocks, poor cultivations, and variation in water supply for irrigation. Until the general level of potato yields has been raised appreciably, there can be little point in the widespread adoption of blight-control measures in the plains area. In the hill districts, however, measures could be adopted, but these districts account for only 5 percent of the total potato area.

Trials on the control of blight with spray and dust materials under hill conditions have been reported by Vasudeva and Azad (1952b) for the Simla Hills, and by Choudhuri (1954) for the Darjeeling district in West Bengal. The variety chosen in all the trials was Darjeeling Red Round, which Choudhuri describes as being very susceptible to blight. Satisfactory control of the disease was obtained in 1948 and 1949 near Simla by 7 fungicidal applications given at 10-day intervals (see fig. 89). At Darjeeling a good control was obtained by applications at 6- to 8-day intervals, during the 3 seasons 1950-52. Even so, the final yields on the sprayed plots in these 2 sets of trials were very low--in no case better than 3.1 tons per acre--due to causes other than blight. It becomes obvious that the farmer can meet the cost of an intensive spray program, at this low level of output, only if he receives a very high price for his potatoes, which in effect makes the potato a luxury crop. Potato-growing conditions in the hills of India are very similar to those in the high valleys of Mexico, which have been described in this study. In both areas control is very difficult, owing to heavy and frequent rains that wash the fungicides from the leaves. However, Dr. Niederhauser and his colleagues of the Rockefeller Foundation at Toluca, Mexico, have shown that blight can be controlled by an intensive spray program. The sprays are applied to field-resistant potato varieties and yields of up to 17 tons of potatoes per acre have been obtained there. The value of varieties that show a high degree of field resistance does not yet appear to have been fully appreciated under the Indian conditions.

For the plains, information is required on the need for spraying in the different areas, but the problem of control is nothing like so serious as in the hill districts. The use of cold storage to keep the plains' seed during the summer months has greatly increased the amount of blight inoculum present in the plains' crop, and thus the liability of the crop to infection. The cold storages have so many advantages over the older methods of storage, however, that any return to them is out of the question.

SUMMARY: INDIA

Potatoes are a relatively unimportant crop, and yields are low. Blight is serious in the hill districts, and although these districts provide only a small percentage of the total crop, they are an important source of seed potatoes.

AUSTRALASIA

NEW ZEALAND

New Zealand is normally self-supporting in both ware and seed potatoes. The total acreage of potatoes is small, about 20,000 acres per annum; but the population of the two islands is only 2 million, and with almost all the potatoes going to the ware market, this provides for an annual consumption of potatoes of about 100 lb. per head. This level of consumption is comparable to that in the U.S.A. The average potato yield for the country is 5.9 tons per acre (F.A.O. statistics).

POTATO DISTRIBUTION AND VARIETIES

The most important maincrop potato-producing areas in New Zealand are in Canterbury (chiefly around Christchurch), in the South Island and Wellington (Palmerston North area) in the North Island (fig. 90). Apart from Wellington, the North Island grows principally early and midseason potato varieties, and there is an important early-growing district at Pukekohe, near Auckland. In the South Island, there is another early growing district near Nelson. A full account of potato growing in the various parts of New Zealand has been given by Claridge (1945).

Figures provided by P. W. Smallfield of the New Zealand Department of Agriculture at Wellington are shown in table 104, which gives the average potato acreages for New Zealand on a land-district basis.

The potatoes grown in New Zealand are largely varieties that originated in Great Britain. More recently, a number of varieties have been introduced from the U.S.A., and some of these are now widely grown. According to Mr. Smallfield, 4 varieties have made up 71 percent of the total potato acreage during recent years. These have been: Aucklander Short Top (31 percent); Arran Chief (18 percent); Dakota (14 percent); and Arran Banner (8 percent).

Aucklander Short Top is a selection from Sutton's Supreme. It is an early maincrop variety that shows some resistance to blight. Leitch (1947) has given a description of the principal potato varieties grown in the country and their behavior under New Zealand conditions. R-gene resistant varieties have not been grown commercially anywhere in New Zealand.

SOIL, CLIMATE, AND CULTIVATIONS

The crop is grown over a wide range of soil types, with the largest yields on the heavy, well-drained silt loams of the Canterbury area. New Zealand has a mild equable climate of the temperate oceanic or northwest Europe type. The sea has a marked effect on weather conditions, and there is a considerable variation in rainfall from district to district and in different years. The prevailing winds are from the west, and the wettest parts of the country lie principally in the west, very noticeably so in the South Island (see rainfall map, fig. 90, based on Stamp, 1944). Generally speaking, the potato crop is grown in the drier parts of the country, as in the Christchurch area of Canterbury, where the average annual rainfall is 26 inches. Climagrams for two potato-growing areas (Christchurch and Pukekohe) are given in figure 91.

Maincrop potatoes have a very long growing season in New Zealand (approximately 6 months). As the country is in the Southern Hemisphere, seasons are the reverse of those in the potato-growing regions of northern latitudes. Thus, in Canterbury, planting takes place in October (late spring), and lifting is in May (late Autumn). A full description of cultivation methods has been given by Leitch (1947). Potatoes are grown in ridges, 28 to 31 inches apart; in New Zealand, this has the additional advantage of protecting the tubers from attacks by the potato moth. Up to the present time, control of blight by spraying is

TABLE 104.--Potato acreage according to district, New Zealand

Land district	Acreage[1]
North Island:	
North Auckland	1,494
South Auckland	731
Gisborne	374
Hawkes Bay	1,075
Taranaki	134
Wellington	3,064
Total	6,872
South Island:	
Marlborough, Nelson, Westland	569
Canterbury	8,715
Otago	1,479
Southland	646
Total	11,409
Grand total	18,281

[1] 5-year average, up to and including 1954-55.

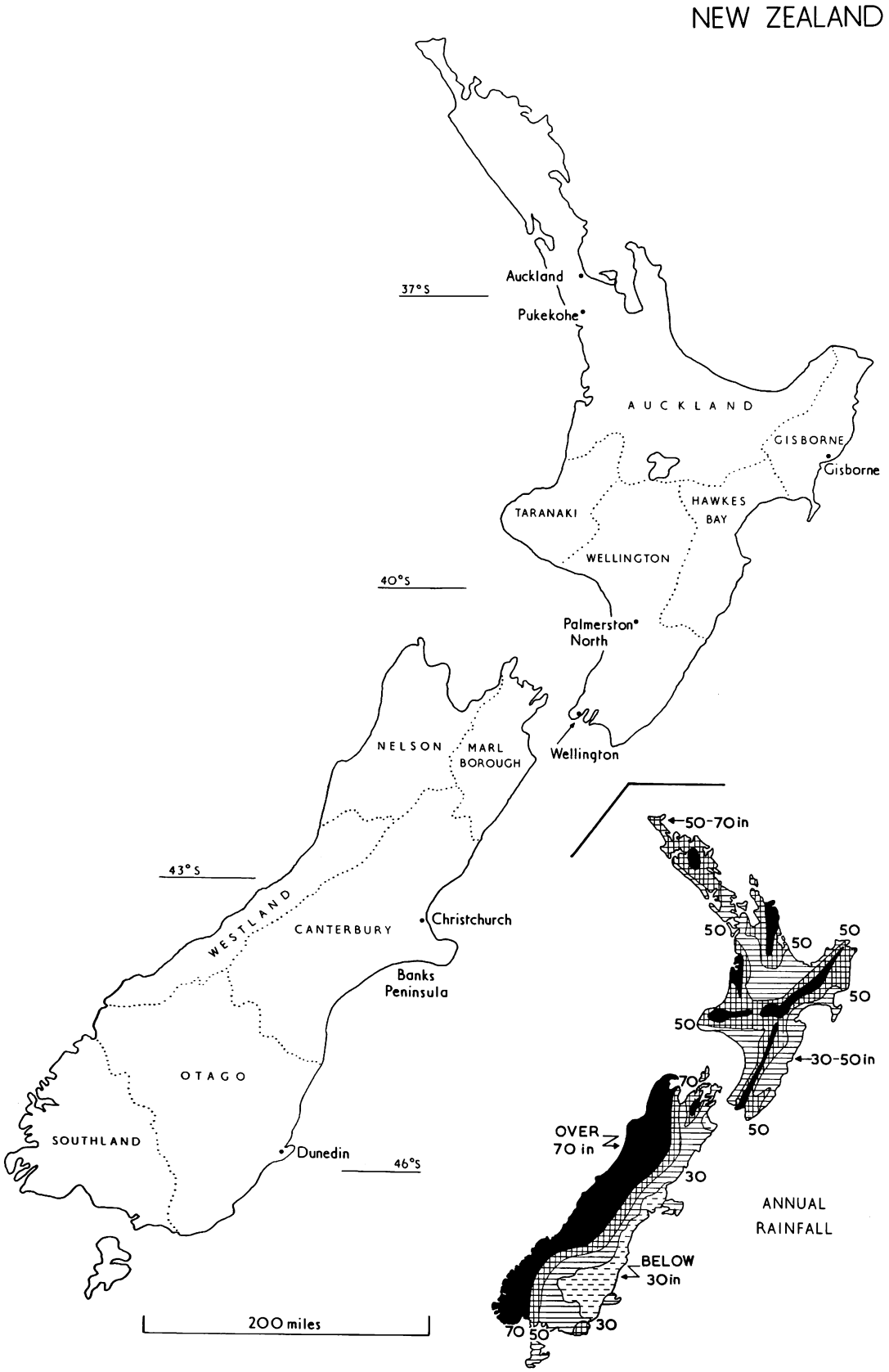


Figure 90.--Key map of New Zealand and annual rainfall.

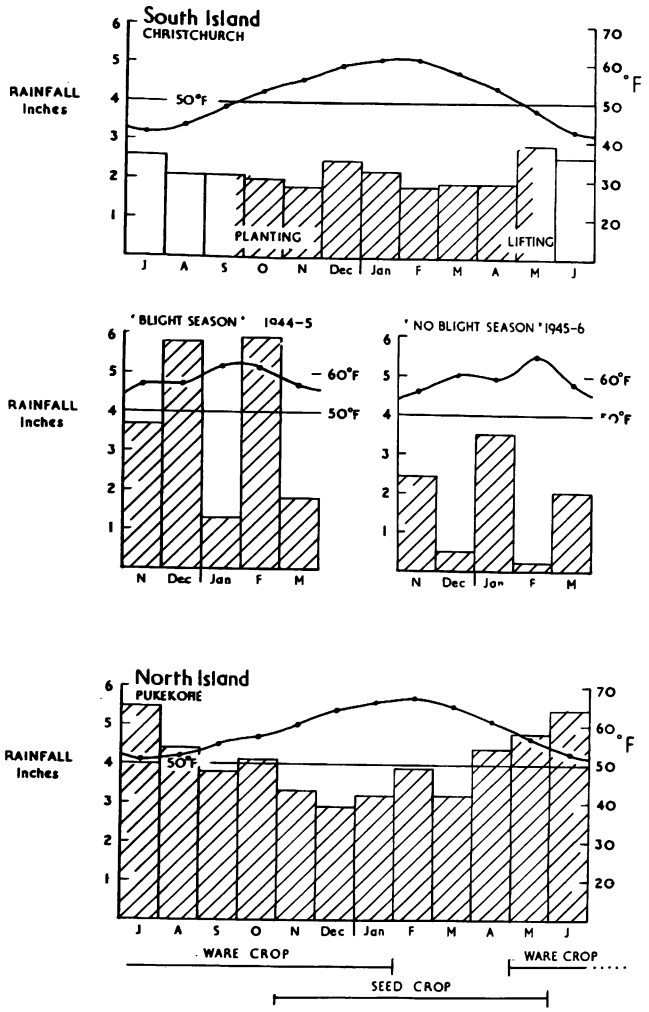


Figure 91.--Monthly rainfall and mean temperatures in relation to potato cropping for Christchurch and Pukekohe, New Zealand, and "blight" and "no-blight" seasons at Christchurch.

uncommon except in the Pukekohe district. The small amount of spraying is a reflection of the generally sporadic attacks of blight and the scattered fields of the potato crop, which has usually made it uneconomical for the farmers or contractors to invest in spraying machinery.

REGIONAL INCIDENCE OF BLIGHT

C. M. Driver, of the Crop Research Division at Lincoln, has provided an account of the incidence of blight in the various potato-growing areas. The disease occurs throughout New Zealand, but except in the northwest of the North Island, the attacks are sporadic and usually only toward the end of the growing season. Short notes on blight in the several districts are now given, and these are followed by more detailed accounts for important Christchurch district, where blight is not usually a problem, and for Pukekohe, where blight conditions are severe.

AUCKLAND: Blight is normally present throughout the year. Crops are regularly sprayed from soon after emergence until maturity.

GISBORNE: Blight seldom occurs, because of the usually dry spring and summer.

HAWKES BAY: The growing season is usually dry, but occasionally blight may cause some damage. Spraying is practically unknown.

WELLINGTON: Blight occurs in some areas in most years, but rarely is damage severe over a wide area. Sometimes it may occur in epidemic proportions during December, usually associated with very heavy rains and waterlogged soils, and thus considerable losses from causes other than blight. In 3 years out of 4, January and February are dry months with ample sunshine, so that blight does not develop. If blight does appear late, tuber infection may be high, as spores are washed into soil cracked by earlier dry weather. Until a few years ago, no spraying was done in this area, but new contract growers, who lease large areas of land solely for potato growing, have invested in spraying equipment.

NELSON and MARLBOROUGH: Blight attacks are infrequent, mild, and late in the season.

WESTLAND: Rainfall and humidity are high. Blight is always severe. Potato requirements for the district are small and it is cheaper to ship them from Canterbury than to attempt to control blight.

CANTERBURY: In general, summers are dry and blight is unimportant. Conditions are a little wetter in south Canterbury, so that blight occurs more frequently; even so, the main variety, Arran Chief, has sufficient resistance to carry it through the attack in most seasons.

OTAGO and SOUTHLAND: Rainfall is higher in these districts than in Canterbury. There are more days with rain and there is less sunshine. Blight can be severe on King Edward once in every 2 years or more. However, the most common variety, Arran Chief, is seldom killed early enough to affect the yield noticeably.

Christchurch District, Canterbury

An account of potato growing in Canterbury has been given by Dingwall (1953). He describes the Christchurch district as the land area lying between the rivers Waimakariri and Rakaia. Over half the potatoes produced in Canterbury are grown in Christchurch. The district concentrates on growing maincrop ware varieties, with some early varieties in sheltered situations near the coast. Farther inland, seed crops are grown and these form the source of certified seed for the ware areas.

Potato crops are widely scattered through the district. A high proportion are grown as a sideline and occupy only a small part of the farm acreage. The principal varieties are Aucklander Short Top and Dakota, which fluctuate widely in yield between dry and wet seasons. Driver quotes 4 to 6 tons per acre as a typical yield for Aucklander Short Top in a dry year. In a wet year, 14 tons per acre is typical for the same variety.

Potato soils are medium and medium heavy silt and sandy loams, which are usually well drained. Planting extends from late September to mid-November, with the majority of crops planted in October. Varying with variety and season, most crops mature between mid-March and mid-April. Harvesting starts in late April, and is carried out mainly in May.

Blight Epidemics and Losses

Blight is relatively unimportant in the Christchurch district. During the last 20 years, the disease has been severe enough to cause extensive damage in only 2 seasons. These have been 1935-36 and 1944-45. Every third or fourth year, blight appears during February or March. Progress of the disease is usually slow (except in odd pockets), so that a crop noticeably affected (10 to 25 percent leaf damage) may take a month to 6 weeks or longer to reach 75 percent damage or more. The extra rainfall associated with blight attacks results in greatly increased yields, so that, in general, yields are much higher in a blight year, and this, despite the fact that very few growers make any attempt to control the disease.

Tuber blight is not a serious problem. In general, there is very little in the earlier maturing varieties and usually not more than 10 percent on the late varieties (often nil). There may be a few crops on heavy, poorly drained soil where losses are high, but probably most of the loss is attributable to waterlogging rather than blight.

Results of a survey of tuber infection in the soil, made at the end of the bad blight season, 1944-45, have been reported by I. D. Blair of the Canterbury Agricultural College, Lincoln, in a article entitled, "Late Blight of Potatoes in North Canterbury, 1945." Table 105 presents some of the data from this survey.

It will be seen that heavy tuber blight losses occurred in 1944-45. Such years, however, have a frequency of only about 1 in 10 in the district. Two of Blair's conclusions from this admittedly small survey are worth quoting: (1) Dakota was less severely affected by tuber decay than the other varieties listed, whereas Arran Banner showed the heaviest infection; and (2) the amount of tuber loss that occurred was related to different soil types. The heavier and damper loams were associated with more disease than the sandy loams.

Infection of the tubers at lifting time by contact with blighted haulm is extremely rare. Most crops have matured some time before lifting, and the small importance attached to this problem is a reflection of the long growing season and also the long period over which harvesting is possible. In fact, another problem often arises. This is a strong weed growth, which makes lifting difficult. Dingwall (1953) says that some growers adopt the practice of quickly grazing off this growth with sheep before lifting.

Blight and Weather Data

The long-term average temperature and rainfall figures for Christchurch, together with the planting and lifting times of potatoes are shown in figure 91. A marked feature of the disease in the district is its generally slow progress on the potato haulm after its first appearance. Hot drying Föhn winds blow across the district from the northwest during the summer, so that even after heavy rains, the haulms may be rapidly dried. In addition, temperature conditions may not be too favorable to blight. The diurnal range of temperature during the summer months is from 15° to 20° F., and cold nights with temperatures dropping below 40° are common, with occasional nights when the temperature goes below freezing. Conversely, high daytime temperatures, up to 90° are frequent; periods of

TABLE 105. --Distribution of tuber blight infection among certain potato varieties, North Canterbury, 1944-45

Variety	Crops examined	Range of infection between crops	Average tuber infection
	Number	Percent	Percent
Dakota	15	0-19	5
Aucklander Short Top	16	1-42	15
King Edward	4	7-34	15
Arran Banner	13	11-77	34
Inverness Favourite	5	5-20	11
Aucklander Tall Top	3	1-30	17

low humidity are also common. Hence, blight is continually receiving severe checks.

In figure 91, temperature and rainfall conditions from November to March in a blight season (1944-45) and a no-blight season (1945-46) are compared. In 1944-45, blight was first reported at the end of December, and most potato crops were killed by the disease around the end of February to early March. The very heavy rainfall in December and February was one of the main factors associated with the epidemic.

Control Measures

Protective spraying is uncommon. Driver says, "Spraying has not been done because it has not paid. No damage is caused (by blight) three years out of four. In the fourth or fifth year spraying may have the effect of increasing the surplus which cannot be sold." Potatoes are being grown increasingly under spray irrigation in the district. The change in the microclimate of the crop resulting from this is likely to give rise to conditions more favorable to blight, and protective spraying may become common practice. In this case, farmers are already well equipped with low-volume spraying equipment, which they use for weed control. Destruction of the potato tops before lifting is generally unnecessary, but occasionally a 10 to 12 percent solution of sodium chlorate is used for this purpose.

Pukekohe District, Auckland

This district, centered on Pukekohe Hill, concentrates on market garden crops. Outdoors tomatoes are grown during the summer months. The area is almost frostfree throughout the year, and potatoes are grown in the winter to supply the early ware market. Dawe (1951) has described potato growing at Pukekohe. He says that during recent years, approximately 600 to 700 acres have been grown annually for the ware market. In addition, some 200 to 250 acres for seed are grown each year during the summer. The main reason for this home seed production is the difficulty in getting seed from elsewhere in New Zealand in time to plant the early winter crops. Some difficulty may be experienced in breaking the dormancy period of seed tubers and one method that has been used successfully is dipping them in a carbide solution.

Arran Chief is the most popular variety for the earliest crops. The use of a maincrop variety for this purpose is explained by short-day conditions under which the crop is grown. Northern Star (Gamekeeper) is the principal variety for the later crops. Yields vary according to the maturity of the crop and the month of lifting. Dawe gives 4 tons per acre as an average crop lifted in September.

The soils are basalts and, although heavy, are generally well drained. Figure 91 shows the long-term average weather conditions at Pukekohe, together with the planting and lifting times. Planting starts at the beginning of the winter (May), and continues into the spring; lifting takes place from August to January. The seed crop is usually planted in the early summer (November-December), following an early ware crop, and harvested the next April or May.

Blight Epidemics and Losses

Blight is present in the district at all seasons. Severe epidemics of the disease would almost certainly develop every year in the absence of protective spraying, which, however, is carried out by all ware growers from the time the potato plants emerge. Blight is less severe on the seed crop, which is grown in the summer or drier part of the year, and very often there is a time during the growth of this crop, when spraying can be curtailed.

There are two main reasons for the severity of blight in this district. These are the weather conditions, and coupled with them, the presence of ample sources of blight inoculum throughout the year. The sources of inoculum are (1) the potato crops, themselves; (2) groundkeepers; (3) tomatoes; (4) home gardens; and (5) weeds. Potatoes are being grown throughout the year, very often on the same field, so that there is a constant carryover of the disease. Unharvested potatoes sprout very rapidly and groundkeepers are extremely common. Driver writes that "Large acreages of tomatoes are grown from November to May. Although in general tomato blight races may be different from potato blight races, yet the latter may carry over quite well on the tomatoes, which often follow potatoes." Large numbers of home gardens throughout the district often grow potatoes for the greater part of the year. In June 1955 Joan M. Dingley found blight infecting a common New Zealand shrubby weed, Solanum aviculare, in native bush near Auckland. Many other infected plants of this species have since been found and by May 1957 it had been shown to be susceptible to blight races 0; 1; 4; 1,3; and 2,4; collected in New Zealand (Brien and Dingley, 1955; Driver, 1957).

There are no published records of blight progress on unsprayed potato haulm for the Pukekohe district. However, Taylor (1945) has given some data for unsprayed plots of King Edwards derived from a series of spraying trials carried out in the Auckland district (site unspecified) between 1940 and 1945. Some of his results are set out in table 106.

In each season, blight appeared very early. The speed with which the tops were killed,

TABLE 106. --Blight attack on unsprayed King Edward, Auckland district, 1940-43

Year	Date of planting	Date of blight appearance	Later observations
1940-41	Oct. 15	Nov. 14	Dec. 27, plants severely infected.
1941-42	Sept. 15	After Nov. 14	Dec. 8, plants severely infected.
1942-43	Sept. 16	End of Oct.	Dec. 1, most plants killed.

however, was not particularly fast in view of the obvious smallness of the plants, except perhaps in 1941-42. Conditions in these trials and those for the important early ware crop at Pukekohe are not strictly comparable, since the trials were planted in the spring, whereas the early crop is planted in the autumn and winter. They do give a good idea of the sort of blight conditions facing the Pukekohe seed crop, which is usually less severely attacked by the disease than the ware crop.

Tuber infection before lifting is not a problem in the district. Crops are usually dug quite clean. This is, no doubt, in part a reflection of the good control of blight achieved on the tops, but Driver has further suggested that the high copper content of the soils in the area, brought about by frequent copper spray applications, is protecting the potato tubers from blight infection. He says "...potatoes may be grown 4 to 6 times in six years on one area. Tomatoes may have been grown for several of those years, so the total number of sprays received over that period could quite well be as many as 80 to 100, and is unlikely to be below 40." If this supposition is correct, it falls into line with work reported by Skaptason, Peterson, and Blodgett (1940), from Long Island, New York, and referred to in the U.S.A. section of this study.

Infection of tubers at lifting is also of little importance. Driver writes, "One would expect some tubers to become inoculated from the haulm at harvest but transport has been coordinated so that potatoes harvested one morning can be in the shops in Wellington, 400 miles away, by the next morning. Consequently a high proportion of the potatoes would be eaten within 4 to 5 days of harvest, not allowing tuber blight a chance to develop."

The serious blight problem at Pukekohe is therefore the foliage attack. This, however, would be so devastatingly severe each year in the absence of spraying as to make potato growing impossible.

Blight and Weather Data

Mean temperature and rainfall figures for Pukekohe are given in figure 91 in relation to the growing seasons of potatoes. There is a consistently high rainfall each month during the winter and spring, when the bulk of the early crop is being grown. For the 6 months, May to October, total rainfall averages 28 inches. Though rainfall is heavy, it tends to come in short, heavy showers, with dry, often sunny periods in between. This has an important bearing on blight control, as it is unusual even in the wettest season to have periods longer than 3 days when spray equipment cannot work. Mean temperatures during the growing season of the early crop are low. On the other hand, humidities are high--in part, a reflection of the long-night and short-day growing conditions.

Control Measures

The early crop is sprayed from emergence onward at approximately 4- to 8-day intervals until shortly before lifting. Up to 10 sprays may be given over the growing season. The potatoes are lifted while they are still very immature, at a time when the tops are meeting in the drill but have not yet made spraying difficult. Driver states, "If for any reason, harvesting is delayed longer than this, and the weather is wet, blight becomes very difficult, if not impossible to control. However, this seldom happens, growers tending to plant a succession of crops if they want to harvest over a period, rather than planting one area and harvesting a portion at a time."

The most commonly used spray material is copper oxychloride applied at the rate of 5 lb. in 100 gallons of water per acre. It is possible to produce satisfactory early crops of potatoes by these control measures under the very severe blight conditions at Pukekohe. But the cost of control is very high, and only economic because of the correspondingly high value of the early crop. It seems unlikely that maincrop ware potatoes could be produced economically in such an area, particularly in view of the difficulty of controlling blight once the potatoes have met in the drill.

SUMMARY: NEW ZEALAND

Blight is not generally a serious disease in the country. The bulk of the maincrop potatoes are grown in the drier areas. The Pukekohe district in the northwest of the North Island is an example of an area where blight is very bad; but the production of a valuable out-of-season potato crop justifies an intensive and expensive control program against the disease.

Potatoes are grown in Australia at all seasons of the year and under a wide range of soil and climatic conditions. The acreage is relatively small. During 1939-45, the area approached a quarter of a million acres, but in recent years it has been about 125,000 acres. The only major outlet for the potato crop is the ware market; but annual consumption of potatoes is low, around 110 lb. per person, which compares very closely with the position in the U.S.A. The average yield is also low, no more than 3.5 to 4 tons per acre (F.A.O. statistics), and there is little sign that present-day yields have improved appreciably over those obtained during the late 1930's. Bald (1941) has stated that one of the major problems of potato growing in Australia is lack of water supply. This is due to an unequal distribution of the rainfall, rather than insufficiency in the total amount, in the areas where potatoes are grown. In addition, there is a generally high rate of evaporation from the soil.

DISTRIBUTION OF POTATO CROP; CLIMATIC CONDITIONS

The most important potato-growing areas are in the more temperate parts of the country (fig. 92). Victoria, with about 40 percent of the total Australian acreage, is the largest potato-producing State, followed by Tasmania with 25 percent. Figure 93 includes climagrams for centers in these two States. The main potato-growing season is during the summer months (October to April), and potatoes are grown both under coastal conditions and at higher elevations; for example, in the Central Highlands of Victoria, around Ballarat.

New South Wales, with 15 percent of the potato crop, and Queensland, with 9 percent, come next in order of importance. In northern New South Wales and Queensland, climatic conditions are subtropical, and the main potato-growing season is in the winter or summer, depending on elevation. On the coast near Grafton, New South Wales (climagram, fig. 93), potatoes are grown during the winter. Summer temperatures, which average over 75° F. for each of the 3 months, December to February, are too high for potato growing. On the tableland near Glen Innes (climagram, fig. 93), which is on the same latitude as Grafton, the main potato-growing season is during the summer.

Potatoes are not an important crop in Western or South Australia. In Western Australia, early potatoes form a high proportion of the crop, and these are grown during the winter and spring months. A summer crop is grown in South Australia, mainly under irrigation.

POTATO VARIETIES, SOIL CONDITIONS, AND CULTIVATIONS

According to White (1952), the most important variety now grown in Australia is Sebago, which was imported from the U.S.A. shortly before the Second World War. Sebago has displaced Carman (Green Mountain) and Snowflake, which used to be the leading varieties in Victoria and South Australia; in New South Wales and Queensland, Sebago has displaced Factor (Up-to-Date). Sebago shows a high degree of field resistance to blight, and in this respect it is superior to the older varieties it has replaced. Other important varieties in Australia are Sequoia, Monak, and Adina. In Tasmania, Bismark (early) and Brownell are still the chief varieties.

Most potatoes in Australia are grown on soils derived from basalts and adjacent transitional soils. These are generally fertile, often very deep, and permeable despite a high clay content. Bald (1941) has described in some detail the relation of soil type to potato growing in the country. Methods of cultivation vary between districts; in general a surprisingly large amount of cultivation, in particular planting and lifting, is carried out by hand labor. Cutting of the seed is general, and the crop is grown in wide rows (30 to 36 inches). Potato growing under temperate conditions in Victoria has been described by Mattingley (1954); details of the cultivation of the crop under the subtropical conditions of Queensland are given by Cartmill and Bechtel (1951). An important pest of potatoes in Australia is the potato moth (Gnorimoschema operculella). Caterpillars of this moth feed both on potato leaves and the tubers. The crop is sprayed or dusted with DDT to prevent caterpillar damage, and, in addition, good earthing up of the rows prevents the moths from laying their eggs on the tubers. This latter preventive cultivation serves also to protect the tubers from blight infection.

FREQUENCY OF BLIGHT EPIDEMICS

Not much attention has been paid to potato blight, and the disease is usually considered of little economic importance. According to Bald (1941), it is much less serious in Australia than in most other countries where potatoes are grown. G. C. Wade, Tasmania; S. Fish, Victoria; C. J. Magee, New South Wales; and J. H. Simmonds, Queensland, provided the following notes on the incidence of the disease in their respective States.

TASMANIA: Potato blight was first officially recorded in Tasmania in 1907, and a history of the disease in the State is given in an article by Oldaker (1947). Since 1947, it has caused fairly general losses in the 1947-48 and 1952-

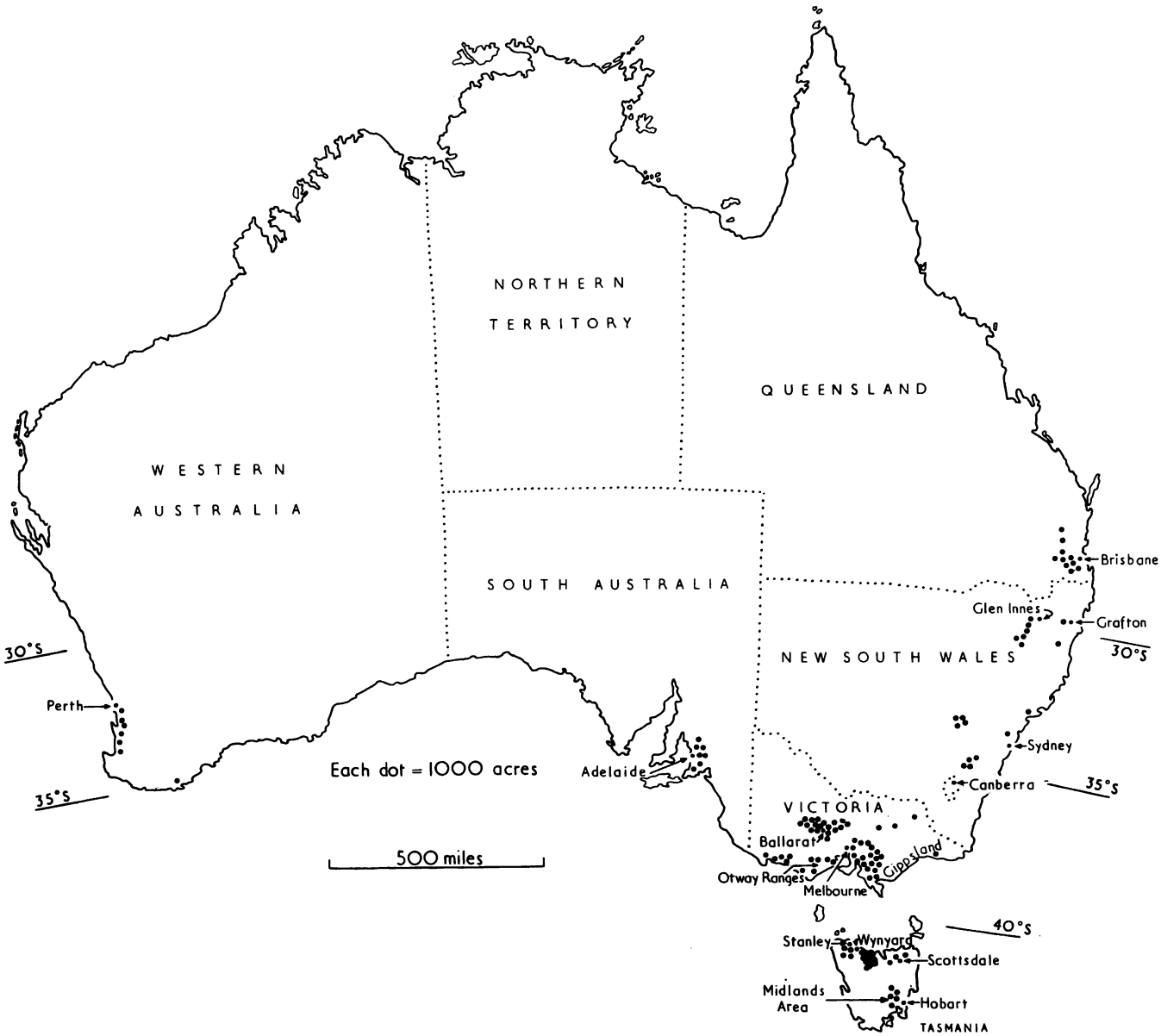


FIGURE 92.--Key map of Australia, showing distribution of potato growing and localities referred to in text.

53 seasons. In 1955-56 it was probably more generally serious than ever before, causing heavy losses in all districts, including many districts where it had previously never caused sufficient damage to be noted. Except in a few localities, blight causes economic damage only in about 1 year in 5 in the important potato-growing districts of the northwest coast, while outbreaks rarely occur in the midlands and south. Attacks are most frequent in the Table Cape district near Wynyard, and the Scottsdale district in the northeast.

VICTORIA: Isolated occurrences in individual crops are reported nearly every season, but the disease very seldom becomes of any economic importance. It is reported most frequently from the Otway Ranges and South Gippsland.

NEW SOUTH WALES: Losses from potato blight in New South Wales are as variable as the season and the locality in which the crop is grown. Whether loss will occur in any locality seems to depend on weather conditions, the presence or absence of inoculum not being an obvious conditioning factor. In seasons favorable to blight it appears to become well dispersed in the air spora. Annual Disease Survey Records show that outbreaks

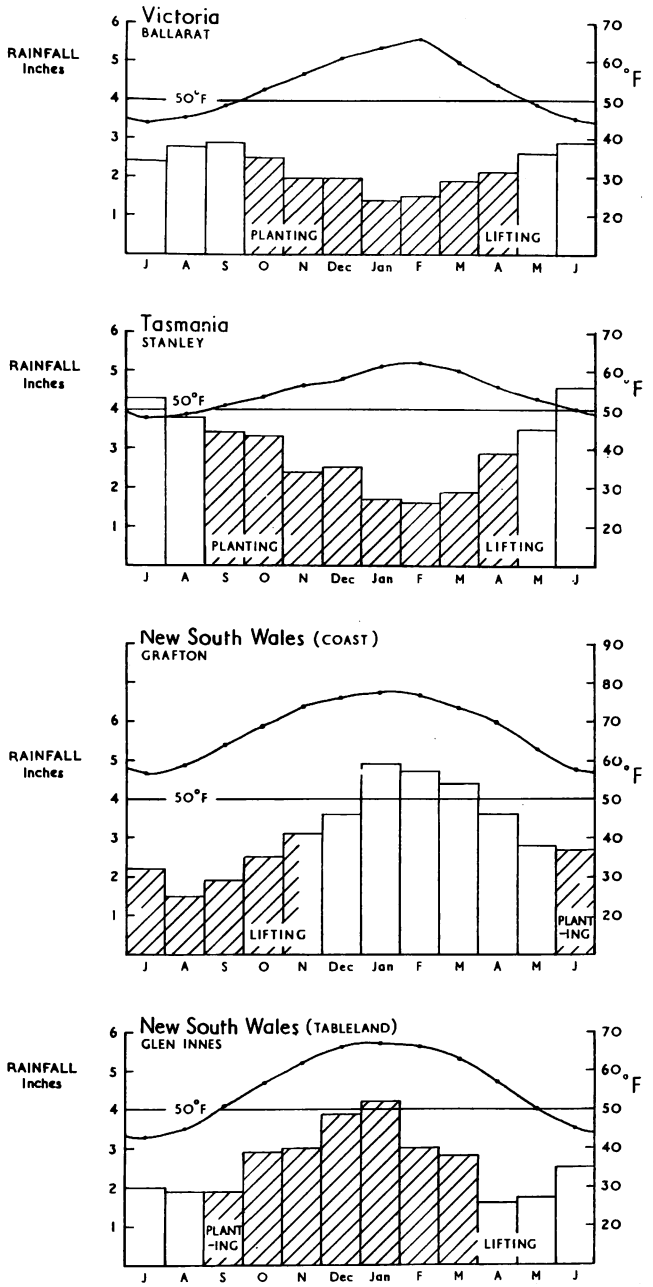


FIGURE 93.--Long-term average monthly rainfall and mean temperatures in relation to potato growing periods for four centers in Australia.

occurred in coastal districts of New South Wales in 10 of the past 25 years (1930-31 to 1954-55). In the same period in upland or tableland crops, it was important in only 5 seasons, and in one of these it was recorded only on the northern tablelands.

QUEENSLAND: The main wet period occurs during the summer when potatoes are not normally grown, or, if they are, temperatures are too high for blight. The winter and spring is normally dry. The appearance of blight is therefore sporadic and restricted to the somewhat rare occurrence of suitable weather conditions.

OTHER STATES: Blight is of little or no importance in the greater part of the potato-growing areas in Western and South Australia. Cass Smith (1952), however, has reported that serious outbreaks of the disease have sometimes occurred in the winter-planted crop near Perth during the period August to mid-November.

LOSSES FROM BLIGHT

The small importance attached to blight by Australian growers and research workers is reflected in the paucity of precise data about the effects of the disease on the haulm and tubers. G. C. Wade and S. Fish have provided details of blight progress on unsprayed potato crops, grown in "blight" years at particular centers in Tasmania and Victoria. Details of these two crops are shown in table 107. These records are, so far as is known, the only ones of their kind available for the whole of Australia.

At Toolangi the period between planting and the 75 to 90 percent blight stage was 128 days. This is about the normal length of the growing period of Sebago, when it is grown in the U.S.A., although it may well have a somewhat longer growing season in Australia. The 13-ton yield of this crop, however, shows that the effect of blight on yield was not very serious.

The observations on the crop at Wynyard were made during a series of spraying trials, which have been reported by Williams, Wade, and Cartledge (1956). Bismark is an early variety, and the length of time between planting and 75 to 90 percent haulm destruction in the crop referred to in table 107 was 101 days. The unsprayed crop yield of 2.7 tons per acre compares with a mean yield of 6.2 tons per acre for the different spray treatments employed in this particular trial. The haulm on the sprayed plots was destroyed mechanically 112 days after planting, so that there was only approximately 11 days' difference in effective growth between the 2 sets of plots, but this resulted in a fall in crop yield of over 50 percent on the unsprayed plots. To some extent this loss of yield was caused by tuber infection. Digging of the trial was delayed until all blighted tubers had rotted in the soil, so that it is not possible to say how important this was. G. C. Wade has stated that blight was probably more serious in the 1955-56 season than in any season since its introduction into Tasmania. In similar trials carried out at Wynyard in 1953-54 and 1954-55, blight caused no losses.

It is impossible to make any accurate estimates of the losses caused by blight in

TABLE 107. --Data on blight in Tasmania and Victoria, Australia, 1954-56

Area and variety	Year	Date of planting	First appearance of blight	Date of 75 to 90 percent defoliation by blight	Yield
Toolangi, VICTORIA:					Tons/acre
Sebago variety.....	1954-55	Dec. 20	April 1	April 27	13.0
Wynyard, TASMANIA:					
Bismark variety....	1955-56	Sept. 26-30	Oct. 30	Jan. 5	2.7

Australia, on the basis of the available evidence. All that can be said is that overall losses caused by the disease are very small. Nor is it possible to apportion the losses that do occur between yield losses resulting from premature defoliation and tuber blight losses. The good earthing up that the crop is given in Australia against potato tuber moth and the generally long growing and long harvesting periods are factors operating against serious tuber blight infection. Bald (1941) has stated that, in aggregate, the losses caused in the Australian potato crop by early blight (Alternaria solani) are probably greater than those caused by late blight. The Australian potato growers show their lack of respect for both diseases by taking little or no protective action against them.

BLIGHT AND WEATHER DATA

The climagrams (fig. 93) for important potato-growing areas in Victoria and Tasmania indicate that low rainfall during the growing season is an important factor associated with the general absence of blight. Victoria and Tasmania together account for 65 percent of the total Australian potato acreage. At Ballarat, the average monthly rainfall is at or below 2 inches throughout practically the entire growing season; at Stanley, the average rainfall is below 2 inches for each of the 3 months, January to March, when blight is most likely to develop. The climagrams for New South Wales show that the coastal crop at Grafton is also grown during a dry period; the tableland crop at Glen Innes is grown during a relatively wet season. However, the frequency of blight years at Glen Innes is only about 1 year in 5, and it seems likely that high temperatures are limiting the disease there, despite the wetter conditions.

The absolute amount of rainfall is only a very rough guide to the likelihood of blight attacks, and in most of the potato-growing areas of Australia, total rainfall figures give an exaggerated idea of the amount of water available to the potato crop. This is because rainfall is poorly distributed. Heavy downpours are followed by considerable runoff from the soil surface. In addition, there is a high rate of water evaporation from the soil, associated with low humidity conditions. Low humidities are chiefly responsible for the relative unimportance of blight in Australia. Mean monthly humidity figures during the potato growing season for Melbourne and Ballarat in Victoria are shown in table 108.

The dry conditions under which potatoes are grown suggest the possibilities of irrigation as a principal method to improve crop yields. Both overhead and channel irrigation of the potato crop are practiced in parts of Australia. It is possible that a marked increase in overhead irrigation would affect the incidence of blight attacks.

TABLE 108. --Mean monthly relative humidity at Melbourne and Ballarat, Victoria

Month	Melbourne	Ballarat
	Percent	Percent
October.....	57	70
November.....	56	66
December.....	55	62
January.....	53	60
February.....	56	59
March.....	58	64
April.....	64	74

CONTROL MEASURES

The replacement of the old blight-susceptible varieties, Factor and Carman, by the more field-resistant Sebago has served as a partial blight control measure. It may well be that in large parts of Australia where blight is normally either absent or slight in its effect, such action in itself is sufficient control, especially as Sebago is resistant in the tubers as well as in the foliage. At any rate, very few Australian growers spray or dust their potato crops against blight. In Victoria, New

South Wales, and Queensland, growers generally consider spraying to be uneconomical.

In Tasmania, matters are different. Blight caused fairly general losses in the 1952-53 season, and as a result, the Potato Marketing Board asked the Department of Agriculture to investigate the control of the disease. Spraying trials were carried out in 1953-54, 1954-55, and 1955-56, and the results of these trials have been given by Williams, Wade, and Cartledge (1956). Some of the figures from these trials have already been referred to above. Blight was not serious in 1953-54 and 1954-55. Yield figures from the trial in this latter season indicated that a considerable reduction in yield can be caused by spraying with certain materials in a "no-blight" year. The yield on plots sprayed with bordeaux mixture was 30 percent lower than the yield on the unsprayed plots. In 1955-56 (a severe blight year), on the other hand, the unsprayed plots produced only 43 percent of the yield on the sprayed plots. In connection with the spraying trials in two of the seasons, the temperature-humidity rules of Bourke (1955) and Beaumont (1947) were tested for blight forecasting under Tasmanian conditions. The occurrence of blight-weather periods by these rules in relation to blight development at Wynyard is shown in figure 94. It was concluded that Bourke's Irish rules apply reasonably well, but that a major difficulty in making general forecasts of blight in Tasmania lies in the considerable variations in weather that occur over short distances. Blight forecasts were considered to be reliable only in the vicinity of the weather recording stations.

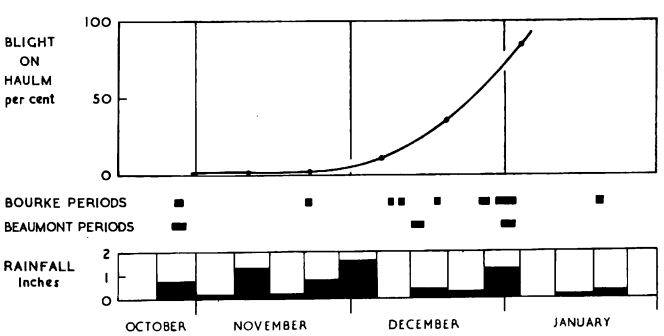


FIGURE 94.--Development of blight on unsprayed Bismark haulm in relation to Bourke periods (Irish rules), Beaumont periods, and rainfall at Wynyard, Tasmania, 1955-56. (After Williams, Wade, and Cartledge, 1956.)

In Australia, where severe blight outbreaks occur at infrequent intervals, the provision of reliable blight forecasting services for the main potato-growing areas would help considerably in preventing losses by the disease. Even in Tasmania, which is relatively compact, there are considerable difficulties in the way of doing this, owing to variations in climatic conditions; and, it must be admitted that in the larger States the present difficulties facing a forecasting service are almost insuperable. Until recently, a routine control program against blight, using copper sprays, would almost certainly have led to a net loss in potato yields, owing to the depression of yields in "no-blight" years. The position would be different if organic fungicides were used every year, although provision would have to be made to keep wheel-damage losses to a minimum. Potatoes are already grown in wide rows. However, Australian growers at the present time are making little use of any protective sprays. One reason for this is lack of suitable equipment; although low-volume sprayers, purchased primarily for weed control, are on the increase. It is possible that in some areas of the country, such as parts of Tasmania, a routine spray program, based on the low-volume application of organic fungicides, may be found to be economical.

Little work has been done on haulm destruction, as the need for this does not often arise. A recent account by the Tasmania Agronomy Division (1956) has stated that pentachlorophenol (P.C.P.) has proved an economical and effective chemical for haulm killing, in experiments that they have conducted. Testing the blight resistance of named and unnamed potato varieties, including material from the U.S.A. and Scotland that could be incorporated in a breeding program, has been carried out in Victoria. This work was reported by Chambers (1954) and (1955). The emphasis has been placed on the incorporation of major gene resistance in commercial varieties, but up till the present time no Australian blight-resistant varieties have come on to the market.

SUMMARY: AUSTRALIA

Potato blight is of small economic importance in Australia. This reflects the generally low rainfall and humidity conditions throughout most of the potato-growing areas. These conditions also lead to low yields. Chemical methods of controlling blight are rarely practiced.

CONCLUSIONS

The great interest of this study has been to see blight epidemics, not in the abstract or entirely from the viewpoint of plant pathology, but in their widest relations to the potato husbandry of the world, the provision of food supplies, the distribution of the crops, and the diverse climatic conditions under which potatoes are grown. It is not the intention to recapitulate the sectional summaries already given for each country, or to present any résumé of all the information that has been gathered together. The general conclusions or convictions of the authors that are reached are stated broadly, leaving the reader to fill in the innumerable necessary qualifications. Names of countries given in brackets indicate the preceding sections in which amplification of the various points, examples, may be found.

THE DEFINITION OF CLIMATIC CONDITIONS

The kind of climagram evolved in the course of this study may prove to be a useful device in other work on potato technology. Such diagrams enable quick visual comparisons to be made of some of the main conditions affecting both potato growing and the incidence of blight in different regions. With the climagram for an area, it is possible to see with fair certainty the period or periods of the year during which there can be potato cropping, and the favorability, or otherwise, of the area for both potato growing and for blight, at least as to mean temperature and rainfall. Diurnal range of temperature, distribution of rainfall, and humidity conditions are broadly dependent upon the type of climate, and day-length depends on the latitude.

EFFECT OF MEAN TEMPERATURE ON POTATO CROPPING

The entry of ascertained cropping periods on the climagrams in this study confirms by world survey the finding of Bushnell (1925) [Introduction] that maximum tuber production occurs over the mean temperature range of 59° to 64° F. A slightly wider range (58° to 65°) takes in most of the regions of the world where the highest potato yields are obtained. The 2 most important months for the bulking of maincrop potatoes, during which the mean temperatures lie within this range, are, in general the 2 months preceding the month of maturity. These are also the 2 months during which blight most seriously affects crop yield.

EFFECT OF RAINFALL ON POTATO CROPPING

Although lack of adequate rain limits potato cultivation in many parts of the world and the rainfall during the growing period is the principal single factor responsible for variation in yield from year to year in most of the great potato-growing areas, there is no such clear-cut relation between cropping and mean rainfall as there is for cropping and mean temperature over the world as a whole. The distribution of rainfall affects its utility, as also does the porosity of the soil and the rate of evaporation [Introduction]. The climagrams show that regions with the higher potato yields generally have, on a long-term average, 2 to 4 inches of rain during each month of the growing period [Belgium, Netherlands, Ireland, Prince Edward Island], but that potatoes are grown where the rainfall in some months reaches 15 inches or more [India, East and West Africa] and under irrigation in the virtual absence of rainfall, given suitable soil and temperature conditions [Western U.S.A., Peru, northern Chile].

DEFINITION OF BLIGHT EPIDEMICS

The losses caused by potato blight, both in reduction of total yield and by infection of the tubers, are consequences of the attack on the foliage. To define the incidence of blight in any area, the necessity is first to assess the course of the unrestricted epidemic on unsprayed foliage. If this is done over a sequence of years it becomes possible to determine the frequency with which epidemics of defined course and severity occur in the region. The modifying effect of control measures can then be ascertained by similar assessments on the treated crops.

The use of a standard key, such as the B.M.S. key [England and Wales], which defines the degree of attack by the approximate percentage of the total foliage killed by the disease, enables assessments of blight to be made quickly and easily in potato fields. Such assessments can be made in any part of the

world, and workers in other countries can understand what is meant by them. If these assessments are made at intervals over the growing period, the whole course of the epidemic may be plotted on a time scale. This progress curve will show the starting date of epidemic spread, the date at which further growth of the tubers is arrested, the period during which spores are washed down on to the soil and possibly will infect the tubers, and the amount of blight that is left on the haulm at lifting.

In the absence of such complete information, the eventual severity of the epidemic on the haulm may best be defined by the date at which the disease has almost completely defoliated the plants and therefore stopped further growth of the tubers. This stage is easily recognizable in the field, even from the air, and the date introduces the numerical element of precision.

DETERMINATION OF THE EFFECTS OF BLIGHT EPIDEMICS ON YIELD

Very frequently about the world, attempts have been made to base estimates of national losses from blight upon the results of sporadic spraying trials. Such trials, usually made for the purpose of comparing different spray treatments, tend to be carried out in the worst districts for blight and on the most susceptible varieties. By the tacit and usually wholly incorrect assumption that similar results would be obtained in all years and in all districts, grossly exaggerated and misleading figures are obtained.

In some countries [Northern Ireland, Denmark] spraying trials to a uniform plan have been carried out at many centers year after year over a long period, and the yields of sound and blighted tubers have been recorded. Such sequences of trials constitute excellent surveys of the consequences of blight epidemics. If carried out at enough centers they provide information on the average gain from spraying that could scarcely be surpassed. They are very laborious, however; they do not reveal the defoliation losses unrecovered by spraying, and unless they include systematic assessment of the disease on the foliage they provide no information on the courses of the epidemics in the several years--except perhaps by inference.

Following the work of Murphy [Ireland] in relating effects of spraying to the development of the potato plant, a method has been worked out [England and Wales] whereby the results of a few carefully conducted spraying trials with complete observations of the disease on the foliage, coupled with periodic liftings to obtain mean bulking curves for the principal varieties, can be used to interpret foliage observations made on a large number of crops over a very wide area. On test throughout England and Wales over the past 10 years, 1946-56, this method proved to give mean estimates of defoliation losses at least as accurate as those that can be obtained by lifting and weighing the produce from sprayed and unsprayed plots. Application of the principle of the method for the interpretation of available data from other countries [Netherlands, Republic of Ireland, Aroostook County, U.S.A.] indicates its general applicability. Similar methods are already in use in Poland and under trial in Norway.

The basic principle is to ascertain the time at which blight on the haulm has progressed so far as to stop further growth of the tubers (75-90 percent blight, according to the B.M.S. key) and then to read off the proportion of the potential yield normally present at this date from a mean bulking curve for the variety.

The mean bulking curve must be obtained for the variety in the region for which loss assessments are to be made, and it must be used in such a way that account is taken of the relative length or shortness of the growing season.

FREQUENCY OF "BLIGHT YEARS" IN DIFFERENT REGIONS

The incidence of blight on the potato haulm in any region is a product of two factors: The severity of the epidemics and their frequency. A "blight year" may be defined as one in which there is at least 3 to 4 weeks' loss of growth on maincrop varieties in a long growing season or 2 weeks in a short growing season, with a consequent loss in yield of 10 percent or more. The frequency with which such "blight years" occur is ranked in table 109 for some of the potato-growing centers of the world for which climagrams have been given.

This ranking shows clearly that not only are most of the world's potato crops grown where the mean temperature range in the 2 months preceding maturity lies within 58° to 65° F., but that the incidence of blight is also greatest within this range. There is little correlation between the frequency of blight years and long-term average rainfall, except at the extremes of the frequency scale. The centers fall, however, into quite distinct groups according to the type of climate. Blight years are most frequent in maritime areas and at high altitudes in tropical and subtropical countries where there is much cloud and mountain fog. Where maritime influences modify continental conditions, as in Denmark and northern Germany, blight years become less frequent; and where true continental climatic conditions prevail, as in the Warsaw and Moscow regions, the frequency is lowest.

TABLE 109.--Frequency of "blight years" in some potato growing centers of world, ranked in relation to mean temperatures and rainfall[1] in the 2 months preceding maturity of the maincrops

Frequency of "blight years" (years in 10)	Locations where mean temperatures in last 2 months before maturity were--		
	50° to 57° F.	58° to 65° F.	66° to 70° F.
10.....	.....	Mexico City, Mexico (6-1/2)	
9 to 7.....	.....	Kabale, Uganda (3)	
	.....	Songer, Kenya (8)	
	.....	George, S. Africa (3-1/2)	
	.....	Birr, Ireland (3-1/2)	
	.....	Penzance, England (3)	
	.....	Brest, France (2)	
	.....	Flushing, Holland (2-1/2)	
	.....	Malmö, Sweden (2-1/2)	
	.....	Charlottetown, P.E.I. (3-1/2)	
6 to 5.....	.....	Fens, England (2)	
	.....	Jutland, Denmark (3)	
	.....	Aroostook County, U.S.A. (3-1/2)	
4 to 2.....	.....	Cambridge, England (2)	
	.....	Berwick, Scotland (2-1/2)	
	.....	Ghent, Belgium (3)	
	.....	Gemert, Holland (2-1/2)	
	.....	Hanover, Germany (3)	
	Aberdeen, Scotland (3)..	Leningrad, U.S.S.R. (2-1/2)	
	.....	Moscow, U.S.S.R. (3)	
	.....	Warsaw, Poland (3)	
	Reykjavik, Iceland (2-1/2).	Stanley, Tasmania (2)	Glen Innes, Australia (3)
1 or less.....	Puno, Peru (4-1/2)	Christchurch, New Zealand (2)	Long Island, U.S.A. (3-1/2)
		Ballarat, Australia (1-1/2)	Red River Valley, U.S.A. (2-1/2)
	.....	.....	Saratov, U.S.S.R. (1-1/2)
	.....	.....	
	.....	.....	

[1] Numbers in parentheses after centers refer to inches of rainfall per month obtained from a long-term average for the 2 months.

INCIDENCE OF BLIGHT AND WEATHER CONDITIONS

Although weather conditions in the early part of the growing period affect the date of outbreak of blight, it is, in general, the conditions during the 2 months preceding maturity of the crop that decide the progress of the attack on the haulm and the amount of defoliation loss. This is shown by the blight progress curves available for different parts of the world, and it is substantiated under the previous head in these conclusions. Long-term average rainfall during these 2 months does not determine the relative frequency of blight years in different areas, but in any given area annual variations in rainfall profoundly affect both blight incidence and the level of crop yield. Rain provides water on the leaves in which sporangia of the blight fungus can germinate, and it assists spread of the disease by washing the sporangia about; but its greater effect, directly and indirectly, is to raise the relative humidity of the atmosphere about the plants. High humidity rather than rainfall is the main component of "blight weather," and the determination of the frequency and extent of occurrence of such weather demands detailed humidity observations [Netherlands, England and Wales, Ireland, Chile]. Average humidity records are of little value for indicating the prevalence of "blight weather," and if broad indications are required they are best derived from consideration of the locality, the altitude, and the general type of climate.

THE DUALITY OF THE DISEASE

The duality of potato blight, as a disease of the haulm and also of the tubers, complicates the estimation of blight losses and makes it difficult for growers to grasp the rationale of control measures. Sometimes, as among the Indians of Peru, the foliage and tuber infections are thought to be caused by two separate and distinct diseases. Often, and even among the most technically advanced of European and North American growers, there is a tendency to overestimate the importance of losses from blight in the tubers--which are immediately obvious and sometimes spectacular--and to forget the more insidious and unseen loss of yield due to premature defoliation. Very frequently, loss estimates for defoliation and tuber infection are lumped together and it becomes difficult or impossible to disentangle them for separate consideration.

THE DISEASE IN THE TUBERS

Estimates of tuber infection cannot be derived from climagrams or progress curves for blight on the haulm. These often show conditions under which tuber infection is likely to occur, but whether it occurs or not and the extent of its occurrence depend upon soil conditions, the thoroughness of the earthing-up, the tuber suceptibility of the variety, the time of lifting in relation to the blight attack on the haulm, and the weather conditions at the actual time of lifting. The incidence of tuber blight in relation to all these and other factors has been little explored. Two routes of tuber infection must be distinguished: Infection in the soil before lifting and infection at lifting in the presence of blighted haulm. Infection by the first route mostly becomes apparent by lifting, and as it is relatively easy to count or weigh the conspicuously blighted tubers at this stage, it is on this type of infection that most information is available. Infection in the soil before lifting may occur where there is any blight on the haulm to provide inoculum. It is therefore a very general consequence of blight epidemics on the haulm. Infection at lifting occurs only where blighted haulm is still present or sporangia are surviving in the surface layers of the soil. Infection at lifting is therefore an occasional consequence of blight epidemics on the haulm.

Where there is a long growing season, with time for blighted haulm to die down completely well before lifting, tuber infection before lifting is the main cause of loss. Where the growing seasons and harvest periods are short [Iceland, northern Sweden, Prince Edward Island, Aroostook County, U.S.A.] infection at lifting may predominate. It may also be a very serious source of loss in primitive cultivations.

Tuber infection before lifting tends to be greater in soils of high water-holding capacity, such as the sea clays of the Netherlands, than in drier soils, such as those of the great sandy plain of northern Europe. The distribution pattern and magnitude of losses from blight in tubers before lifting, with a long growing season, is exemplified by the results of detailed surveys in England and Wales. Here, even in a bad blight year, the mean loss, over the whole country, is only 3 to 4 cwt. per acre (less than 2 percent of the crop). This is made up by a very few crops with high losses, sometimes of several tons per acre, numerous crops in which the loss is moderate or slight, and well over half the crops with no loss at all. This pattern of distribution may be fairly general. Certainly throughout the world, occasional heavy and spectacular losses from blight in tubers tend to color the picture and give rise to an unbalanced impression of the relative importance of the losses caused by tuber infection and those caused by premature defoliation. Even in Ireland the mean loss from blight in tubers (in unsprayed crops) is less than a third of that due to premature defoliation, and in many regions the proportion is much less. In the Costa region of Peru, where coastal fogs favor infection of the haulm and there is little or no rain to carry spores down to the tubers, tuber infection is unknown.

Although the loss from blight in tubers may often be much less than that from premature defoliation, it tends to occur more constantly from year to year. Thus, quite a small general reduction in the level of tuber infection, as by the adoption of more tuber-resistant varieties, may be of more value to the national economy than much larger but sporadic reductions of defoliation losses in severe blight years [England and Wales].

COMPENSATORY EFFECTS ON YIELD OF BLIGHT EPIDEMICS AND RAINFALL

Throughout the great potato-growing regions of the world, in middle to high northerly latitudes, potato yields in "blight years" are not markedly lower than in years when there is little blight, and they may indeed be higher. This is perhaps the most striking single finding from the study: The compensatory effect of yield increase from the more abundant rainfall in the blight years. To some extent the good yields obtained in blight years are attributable to protective spraying. In some circumstances (see p. 204) protective spraying reduces

tuber infection, and this is part of the gain. But the overall effect of spraying may be much less than is generally supposed. In England and Wales, where the situation has been very fully analyzed, it is found that only about a third of maincrops are sprayed, and that even if all this spraying were fully efficient, it could not be responsible for more than 0.35 ton per acre increase of the mean national yield in a bad blight year; whereas the mean yield in bad blight years is about 8 tons per acre as against 7 tons in the drier years when there is little or no blight. On a long-term average over all types of seasons, protective spraying contributes only about 1 percent of the total potato production. The part of spraying in maintaining high yields in blight years is greater in Ireland, in the sea clay regions of Holland, and some other maritime regions where the frequency of blight years is higher and more spraying is done. In Aroostook County, U.S.A., where all the crops are sprayed, it is likely that yields in blight years might be lower than in no-blight years if no spraying were done. But in Denmark and Germany, where the amount of spraying done is much the same as in England and Wales, the contribution of spraying to the production in blight years is probably about the same. Certainly the general evidence shows that throughout the main potato-producing countries of the world, blight years are years of greater potential yield than the drier years when there is less blight. In other words, drought or shortage of rain is of far greater consequence than blight in reducing potato yields, and this is true not only in northern Europe and North America, but throughout the world as a whole.

ECONOMIC EFFECTS OF BLIGHT LOSSES: TROPICAL AND SUBTROPICAL REGIONS

Blight epidemics are occasionally catastrophic, and it has been common in the past to lay great stress on this fact. Even today, when blight first invades an area where an impoverished and backward peasantry has become too largely dependent on the potato for food supplies [Chile, Cameroons], there may be acute temporary privation. In some regions [Mexico, Africa] high incidence of blight may prevent potato cultivation in a number of districts where it would otherwise be possible, and thus deprive the population of a valuable supplement to other and more important food resources. Here and there the disease may cause the loss of part of an otherwise favorable growing season, with consequent loss of a valuable market [Transvaal]. In most of the recently invaded potato-growing areas, however, the disease has by no means led to any cessation of potato growing, and production has increased in spite of it [India, Kenya, Uganda]. The tropical and subtropical regions in which blight now causes the most spectacular occasional destruction are in general ones in which the potato is only a minor, and sometimes only a luxury, crop and in which potato yields are very low from causes other than blight. Not infrequently, in such circumstances, spectacular blight epidemics can do positive good, for by focusing attention upon the potato cultivations, they can lead to substantial improvements in the methods of husbandry, manuring, choice of variety, and suppression of virus diseases, which are the real needs of the area, and can have much greater effect upon the level of yield than all the losses from blight.

ECONOMIC EFFECTS OF BLIGHT: MAIN POTATO-GROWING COUNTRIES

The economic consequences of blight epidemics in the great potato-growing countries are conditioned by the salient fact that yields tend to be highest in the blight years and lowest in the years with least blight. They also depend upon the national utilization of the potato crop. In the majority of those countries with a high human consumption of potatoes the ware market is effectively buffered against shortages and surpluses by a heavy usage of potatoes for livestock feeding and manufacture. Peru is an exception to this. Where outlets for the use of surpluses are limited [U.S.A., Canada, England, and Wales], reduction of abnormally high yields by blight in some years may be positively advantageous to the national economy, though not to individual growers. Early defoliation may, however, lead to a high percentage of small, unsalable tubers [Aroostock County, U.S.A.]. Where there is a large and flexible usage of potatoes for fodder or industry, all reductions of yield by blight, even in the years when ware surpluses are greatest, may constitute real national loss. In the great potato-producing countries there is very little likelihood of any recurrence of famine due to potato blight, and shortages of potatoes, where they occur, are more likely to follow the dry years with little blight, than the wetter blight years. There may, however, be many blighted potatoes coming on the market after intermediate types of season, where the total yield is maintained but the tuber infection is heavy.

In all years and in all countries there is a national loss chargeable to blight equivalent to the total cost in labor and materials of all the spraying done; and in years with little or no blight there may be quite a serious loss due to reduction of an already light crop by mechanical and phytotoxic damage from unnecessary spraying. Where blight causes a

yield reduction regularly every year, or almost every year, there is a national loss equivalent to the acreage that has to be planted to compensate for the proportion of the regular loss not recovered by spraying--and spraying, where it is done, is rarely more than 50 percent efficient. The economic consequences of blight are thus highly complex. They benefit some and cause hardship to others; indeed, they involve the whole structure of society, and they certainly cannot be expressed in terms of tons per acre.

COURSE OF ESTABLISHMENT OF BLIGHT IN NEW AREAS

Since 1935 potato blight has invaded a number of countries where it was previously unknown [Chile, Peru, Kenya, Rhodesia, Cameroons]. The introduction has almost certainly been brought about in each case through the importation of infected tubers in seed or ware. The courses of establishment of the disease in the new areas throw light on the first epidemics in Ireland and other parts of Europe in 1845-46, and they have followed a fairly constant pattern. First, there is a period of a year or two when the disease is present here and there among the crops of the new country, but it passes unnoticed or unrecognized. Then comes a year in which weather conditions are unusually favorable for the infection of the tubers--it may be a late attack causing no very great loss from premature defoliation. Then by ill-fortune the following year is also one in which the weather is favorable for blight, and favorable this time for an early attack. Many blighted tubers have been planted in seed saved from the previous season; there are many foci of infection; and the epidemic spreads over a wide area, causing spectacular destruction of the haulm and heavy loss of crop. At this stage there is alarm, the impoverished peasants who have been subsisting in greater or less degree on the potato suffer acutely, and commissions of inquiry are set up--usually too late to prevent lifting of the crops while blight is sporing profusely on the diseased haulm, with consequent further widespread infection of the tubers.

In the following years the disease then acts as an instrument of natural selection among the potato varieties that have become indigenous in the country. The more blight-susceptible sorts gradually pass out of cultivation, and this process is aided by the importation of more resistant sorts from other parts of the world. In the meantime there may be quite a run of years during which weather conditions are unfavorable for the recurrence of a severe epidemic [Chile]. Alarm then subsides, and during these years the disease becomes endemic over the whole terrain; always with sufficient foci to start up the disease again on an epidemic scale when the weather is favorable. Sooner or later, according to the climate, the next severe epidemic does occur, but with less susceptible varieties; with some spread of education about the nature of the disease, the losses are less than in the first year of epidemic attack. The cultivation of potatoes then goes on, losses are considerable from time to time, but it is usually a case of better blight than lack of rain, and the extent of the cultivation comes to depend rather upon market demands and the general suitability of the area for potato growing than upon the incidence of blight. Some old and popular varieties continue to be grown no matter what their blight susceptibility.

CARRYOVER OF BLIGHT FROM SEASON TO SEASON

The climagrams for various parts of the world show clearly the gaps between cropping periods in which the fungus must survive. In some areas [George, S. Africa; Pukekohe, New Zealand] potato growing goes on throughout the year, and new potato foliage is always subject to infection by airborne sporangia from older crops in the vicinity. In other areas [Kenya, East and West Africa] where there are two cropping periods in the year, the short gaps between them may be bridged by potatoes left in the ground and growing on like weeds. Blight on solanaceous trees and shrubs [Kenya; New Zealand] may also have a bridging effect. In some hot regions [Plains, India] where potatoes can be grown only in the winter, the fungus must survive a summer gap, with temperatures that may be lethal to the mycelium in the tubers, but the introduction of cold stores for the seed in the summer has made survival possible. In other regions where potatoes are grown in the winter [Southern States, U.S.A.], tomatoes, for which the optimum temperature range is higher than for potatoes, may bridge the summer gap. In still other areas [Transvaal; Australia] the winter gap includes a period, sometimes of several months, during which the tubers are left in the ground, in warm or hot soil, which causes more or less complete rotting of any with blight infection, thus effecting their eradication. Oospores of the blight fungus have now been found in potato foliage in one country of the world [Mexico], and is conceivable that these spores, if they survive in leaf debris, may play some part in the carryover of the fungus.

In the great northern potato-growing regions of the world (northern Europe, U.S.A., Canada) there is a long winter gap during which there is no foliage on which the fungus can survive,

and so far as is known this gap is bridged solely by survival of mycelium of the fungus in some of the infected tubers. The proportion of the infected tubers, in which the fungus does survive is very small [Netherlands, England and Wales]; most, but never all, of the infected tubers are riddled out of seed stocks; and the infected shoots arising from blighted tubers planted are generally few and far apart. Greater concentrations of blighted tubers occur in cull piles [U.S.A.] or in waste heaps left by clamp sites [England and Wales], and thus the probability of primary foci occurring in growth from such heaps is high. The proportion of infected plants among groundkeepers also tends to be high, as some of these arise from blighted tubers rejected at lifting. In many districts where both early varieties and maincrop potatoes are grown, the infection appears first on the foliage of the early potatoes and these contribute to the first infection of the maincrops. Undoubtedly, the long period required for the buildup of infection after the winter break retards the onset of epidemic spread of the disease; there is some evidence that when the level of blight in the tubers is low in a dry year, the outbreak in the following year will be later than usual. But in the main there appears always to be sufficient inoculum to start a blight epidemic when weather conditions are favorable for its development. Although important progress has recently been made in the study of the early stages of blight epidemics [Netherlands, England and Wales], there is much about this phase of the disease that is still obscure.

EFFECTS OF VARIETAL RESISTANCE IN MODIFYING BLIGHT EPIDEMICS

That some potato varieties are more resistant to blight than others was observed during the first epidemics of blight in Europe in 1845-46. Ever since that time the choice, or the breeding and introduction, of varieties having some measure of blight resistance as one of their desirable qualities has been the principal factor in reducing the incidence of blight about the world. The introduction of Champion greatly lessened the severity of the blight epidemics in Ireland during the nineteenth century, and the same process is still going on. In recent years the substitution of Sebago for Up-to-Date in Australia, of Robijn for Kerr's Pink in Kenya, of Sebago for Green Mountain in Prince Edward Island, and of Alpha and Voran for indigenous varieties in Mexico are all cases in point. For whatever reasons these substitutions were made, and by no means all of them were deliberately made for the purpose of reducing blight losses, they have all had this effect.

During the past quarter of the century the long mooted idea of breeding potato varieties totally immune from blight by crossing the domestic potato with Solanum demissum and other wild species has been very strenuously explored [U.S.S.R., Germany, Scotland, Netherlands, U.S.A., Mexico, England and Wales]. The work has revealed that the blight fungus is not homogeneous, as was once supposed, but that it has a number of races or strains, differing from each other in the potato varieties that they can attack. New varieties, with S. demissum in their parentage, have withstood attack by all known races of the fungus for a time, only to go down eventually with other races not previously distinguished or perhaps not previously existent. The situation has been analyzed in genetical terms (see fig. 16, Scotland). The majority view of potato breeders now appears to be that R-gene resistance is not enough, and it may be of less value than the long familiar kind of partial resistance possessed to a varying degree by such varieties as Champion, Voran, Kerr's Pink, Alpha, and Sebago. This kind of resistance is now distinguished by the name of "field resistance." Although only a partial resistance, this is effective against all blight races. Its attractiveness to potato breeders has recently been enhanced by the discovery [Mexico] of an operative sexual phase in the blight fungus, which may be capable of producing an almost infinite range of new blight races.

A very important outcome of all the work with S. demissum is the discovery that, apart from R-gene resistance, this species also possesses field resistance in a very high degree, and that it may be used as a source of this quality in potato breeding for field resistance. The nature of field resistance, now it has been given this name, is under world investigation.

POTATO BLIGHT FORECASTING

A general relationship between the development of potato blight epidemics and the occurrence of wet or humid weather has been recognized since the famine years of the last century, but it was not until the formulation of the Van Everdingen rules [Netherlands] in the mid-1920's that real progress was made in the attempt to define specific meteorological conditions that would provide warnings of blight outbreaks for the purpose of spray timing. The work was advanced by the researches of Crosier in the U.S.A. on the humidity and moisture requirements of the blight fungus, published in 1934 [Introduction], and by the derivation, over the period 1929-39 of the simple Beaumont rule [England and Wales].

In the past decade much practical success in regional forecasting has been achieved by the application of the Beaumont and other temperature-humidity rules--notably those of Post and Richel, Bourke, and Wallin--in ways already summarized in this study under the countries concerned [Netherlands, England and Wales, U.S.A., Irish Republic, Germany]. The essentially different cumulative-rainfall method of Cook has also been successfuly employed in eastern Virginia, and with certain modifications Hyre has found it successful under test in some Northeastern States [U.S.A.].

In general critical weather periods for the development of blight have now been empirically defined, and the recording of them has been reduced to fairly simple and practical procedures. Critical periods, according to one system or another, can now be recorded in most parts of the world, but the way in which the observations are to be interpreted and used to form the basis of a valid forecasting system can be worked out only by investigation and experience in the country concerned. Account must be taken of the number and distribution of the weather stations available, the nature of the terrain, and the phenology of the crops.

Effective and extensive collaboration between meteorologists and plant pathologists is a prime requirement in the development of a forecasting service, as the meteorological findings (whatever criteria of "blight weather" are employed) must be checked and correlated with the results of adequate field surveys of blight outbreaks in the region to be served.

The use of synoptic weather maps and air-mass analysis [Irish Republic] may find an application in many parts of the world, where forecasting has to be attempted for a wide area with no very close network of weather stations.

PROTECTIVE SPRAYING: MATERIALS

The fungicides employed for potato spraying have changed during the past quarter of a century. Up till the early 1930's the use of bordeaux or burgundy mixtures was universal. Preparations of copper oxychloride and of cuprous oxide then began to come on the market, having the advantage that they greatly simplified the preparation of the spray fluid in the field, but the disadvantage that they did not give such lasting protection of the foliage. Bordeaux and burgundy mixtures, in point of retentivity under rain, are still unsurpassed. The copper oxychloride and cuprous oxide sprays made great headway, nonetheless. The introduction of low-volume potato spraying in the late 1940's--following the development of light low-volume machines for the application of MCPA and 2,4-D weedkillers to cereals--was greatly to the advantage of the new sprays, as they were suitable for application at low volume while bordeaux and burgundy mixtures were not. By the 1950's practically all the potato spraying in England and in Holland was being done with cuprous oxide or copper oxychloride. In the meantime, the use of organic sulfur fungicides, chiefly zinc or manganese dithiocarbamates, had largely superseded copper oxychloride and cuprous oxide in the U.S.A. It was found that under the prevailing conditions in the U.S.A.--with frequent applications, high temperatures, and much insect damage conducive to copper injury--the dithiocarbamates controlled the epidemics satisfactorily, and their use led to increased yields. By 1957 the dithiocarbamates had taken a place among the available potato spraying materials of the world; they were replacing copper oxychloride to a considerable extent in the Netherlands, at least for the first sprayings, and they were just being launched on the market for potato spraying in England and Wales.

PROTECTIVE SPRAYING: EXTENT OF USE

The amount of protective spraying done in various parts of the world depends upon the nature of the terrain, the frequency and severity of the losses caused by blight, the value of the crop, and the amount of technical development in the country concerned. The method is impracticable in primitive cultivations, up steep mountains, and in areas where torrential rains may wash off the spray deposits as soon as they are applied [East Africa]. It is employed to best advantage in maritime areas where there is a high level of yield, and where without it there would be heavy defoliation losses almost every year [Netherlands, Ireland, Prince Edward Island]. It is used, sometimes to excess, where cultivations are very fully mechanized, and numerous applications already required for insect pest control make it easy to incorporate fungicides [parts of U.S.A.]. The need for spraying against Colorado beetle [France] may also promote its adoption.

The value of spraying as a routine measure is uncertain and its use is local and discretionary in countries where there is an irregular alternation of blight years and years with little or no blight [Germany, England and Wales]. It is in such countries that blight survey and forecasting work is most needed, to distinguish the localities in which spraying is profitable and to save wasted expense and crop damage in years when it is not. In such countries there is a strong tendency to spray

only the more blight susceptible and valuable varieties. In general there is a tendency for less and less spraying to be done as the climate becomes more and more continental, and the need decreases [U.S.A., northern Europe]. But, in the absence of guidance from objective and impartial blight surveys, there is also a decided tendency for the amount of spraying done to be influenced as much by the commercial enterprise of spray manufacturers and spraying contractors as by the incidence of blight.

PROTECTIVE SPRAYING: EFFECT ON CONTROL OF BLIGHT IN TUBERS

Although it is common to regard protective spraying as a measure for the reduction of defoliation losses rather than for the control of blight in the tubers, one point that emerges from this study is that protective spraying sometimes effects a very considerable reduction in tuber infection. In some countries [Ireland, sea clay regions of Holland] the available figures show that protective spraying generally about halves the mean percentage of blighted tubers in the crops. Where spraying unduly prolongs the growth of partially blighted haulm at the end of the season, it often has the opposite effect; but in some countries, especially those with a short growing season [Iceland] and in some seed-growing areas [Scotland, Brittany], protective spraying appears to be used for the main purpose of preventing tuber infection. There is a very noticeable preference for the use of copper rather than organic sulfur fungicides for the later applications where the reduction of tuber blight is an objective; in Ireland strong applications of burgundy mixture are recommended for this purpose.

It is understandable that if protective spraying is continued late in the season and is so effective that it keeps blight off the haulm entirely, there will be no inoculum to wash down to the tubers and their infection will be prevented. This ideal state of affairs is rarely attainable in practice, and despite all practicable spraying there will almost inevitably be some blight on the haulm toward the end of the season in a blight year. Then the effect of the spraying would appear to be one of degree, the longer blight is kept off the haulm by protective spraying, the shorter the period during which sporangia can wash down and infect the tubers. The greater persistence of the copper sprays, and particularly of bordeaux and burgundy mixtures, in part explains the preference for copper rather than for the dithiocarbamates, as copper sprays provide the longest possible protection of the haulm from the last spraying and therefore the greatest possible avoidance of the chance of tuber infection. There is evidence [Prince Edward Island; Long Island, U.S.A.; Pukekohe district, New Zealand] that the direct application of copper fungicides to the soil or accumulation of copper in the soil after years of protective spraying with copper may kill sporangia washing down to the soil, and therefore effect a direct protection of the tubers. If this is, in fact, an important part of the action of late copper applications in reducing tuber infection, then the inferiority of the dithiocarbamates for this purpose becomes understandable, for they may break down and lose their potency as fungicides when in contact with soil.

Where the growing period is short, and haulm destruction some 10 days or a fortnight before lifting would entail a considerable sacrifice of crop, reduction of tuber infection by late protective spraying with copper may be a better technique. But it has the disadvantage that it may leave the haulm green and with blight sporing on it at lifting, and thereby lead to infection of the tubers when they are exposed. Perhaps with copper in the soil, the usually stipulated 10 to 14 days' delay between haulm destruction and lifting is not necessary, and haulm destruction much nearer the date of lifting would suit the case. This is a matter for investigation.

HAULM DESTRUCTION

Removal of blighted haulm before lifting to prevent infection of the exposed tubers is one of the oldest of blight control measures, but destruction of the haulm by chemical or mechanical means is a comparatively new technique. It is now employed extensively in North America, the Netherlands, Great Britian, and to some extent in other European countries, and particularly on seed crops. The principal materials now employed are sodium and potassium arsenites, sulfuric acid, sodium chlorate, DNC, and other di-nitro compounds. Mechanical haulm-cutters and pulverizers are also in limited use.

Haulm destruction is employed on seed crops to prevent translocation of viruses from the haulm to the tubers and also for the limitation of seed size. It is often also useful on ware crops as a farm practice for clearing the ground in preparation for lifting.

As a measure for the reduction of blight infection of the tubers it is of most value where partially blighted haulm would otherwise be surviving at lifting. This most commonly

happens where the growing season is short (under continental conditions and at high latitudes) and the method is certainly used on a very large scale in North America at the present time for the purpose of preventing tuber infection at lifting. It has the disadvantage that a period, generally taken as 2 weeks, has to be allowed between haulm destruction and harvest. Thus, some sacrifice of an already short growing season has to be made if lifting is to be completed successfully within the limited harvesttime.

As a measure for the reduction of tuber infection in the ground before lifting--the chief need where there is a long growing season and most crops die down naturally well before harvest--haulm destruction is often disappointing [England and Wales, Netherlands]. Unless the risk of tuber infection in the soil is considerable, as when a variety very susceptible to blight in the tubers is being grown, it is generally uneconomic to employ haulm destruction for the purpose of preventing tuber infection before lifting. Good earthing up and the avoidance of tuber-susceptible varieties are better expedients.

CONTROL BY "DISEASE-ESCAPE" METHODS

One of the main findings of this study has been that the optimum conditions for potato cropping are in general also the optimum conditions for the incidence of blight. Opportunities for evading blight losses by moving to other production areas are therefore few. Sometimes it may be preferable to grow potatoes in areas where yields are low, rather than in those where yields would be much higher but for the heavy or catastrophic incidence of blight [Sierra versus the high valleys, Mexico]. Surface irrigation may provide the water required for good potato yields without giving rise to the humidity necessary for the development of blight on the foliage; thus, potato cultivation under surface irrigation in arid regions may be attended with disease-escape [Western States, U.S.A.,].

Planting of maincrops as early as possible and sprouting before planting [England and Wales], or "vernalization" [U.S.S.R.], may also effect an important measure of disease-escape, by obtaining as much of the crop as possible before weather conditions become favorable for epidemic spread of blight. Detailed study of the climagram for an area may help to reveal other possibilities. The choice of early-maturing, or early-bulking, varieties [Arran Banner, in Ireland; Bintje in France and the Netherlands] may contribute to the same end. But early-maturing varieties usually also sprout early and are not good keepers. The combination of early bulking and late sprouting, even if it is not attainable by breeding, could perhaps be secured by judicious use of chemical sprout-depressants. The opposite method of disease-escape by choice of variety is to grow certain late varieties, which are not generally attacked by blight until late in the season [Ackersegen, in Germany].

INDICATIONS OF SUBJECTS FOR FURTHER INQUIRY

In the course of this study the authors have inevitably found many matters concerning the epidemiology and control of potato blight on which there is a paucity of information in the world. Some of the directions in which further investigation appears to be most needed are as follows.

1. There is a need in most countries for systematically conducted field surveys of the incidence of blight, over a number of years, to establish the true losses caused by the disease and to guide control policy.
2. Such surveys can be made most economically by organizing countrywide observations of the disease on the haulm, and interpreting the findings in the light of periodic lifting and spraying trials at key centers. Aerial reconnaissance--with suitable checks from the ground--could be employed in this work.
3. More joint agronomic and plant pathological inquiry could be devoted to realizing the full potentialities of disease-escape methods of control.
4. In potato breeding there is scope for "improving" varieties popular for their quality, such as King Edward in England and Bintje in the Netherlands, by breeding in a greater measure of field resistance.
5. Breeding for tuber resistance deserves more attention.
6. The possibilities of breeding for disease-escape, e.g., for early bulking coupled with good keeping quality (without early sprouting), though perhaps intrinsically difficult, should be further explored.
7. Work in progress on the investigation of the mechanism and true nature of field resistance is of fundamental importance and should be extended.
8. There is need for further investigation of heat treatment of seed-potato tubers, to ascertain whether or not there is any practical possibility of eliminating in-

fection from seedstocks by this means and to reveal the effects of such treatment, at various times between lifting and planting, on dormancy breaking and sprouting. Such inquiries would be relevant to observed effects of natural heating on seedstocks in several parts of the world.

9. In regions of the world where blight is still absent or confined to small areas, a sharp watch should be kept for new outbreaks to prevent the dispersal of infected local seed, which generally precedes first and catastrophic epidemics.
10. Modern spray materials would be greatly improved if their capacity to resist washing off by rain could be brought up to equality with that of bordeaux and burgundy mixtures.
11. The possible efficacy of copper application to the soil as a means of reducing blight infection of tubers deserves critical investigation.
12. The whole question of the need for 10 to 14 days' delay between haulm destruction and lifting requires reexamination. There is also a dearth of real knowledge concerning the relations between soil conditions and tuber infection.
13. There is need for further study of the early stages of blight epidemics. Conditions governing spore dispersal, distances traveled by sporangia without losing their viability, and mechanisms of spread in the field have not been adequately explored.
14. The establishment of blight forecasting services is particularly desirable in countries where there is great variation in the incidence of blight from year to year. The purpose of such services should be as much to save unnecessary spraying and sprayer damage in years when the incidence is slight as to promote correct spray timing in those when it is likely to be severe.
15. The working out of a successful forecasting scheme in any country demands investigation of the significance of critical weather periods by direct blight survey in the field and is best linked with surveys proposed in paragraph 1.
16. The economics of chemical control need close examination in relation to the frequency of blight years and to the loss from crop damage in protective spraying, and from crop sacrifice in haulm destruction.
17. There is need for much more spread of education about the nature of the disease over the world as a whole. The need for more enlightenment concerning the interactions between haulm and tuber infection is not confined to backward countries.
18. In potato marketing and the organization of potato supplies, there is need for economic study of the opposed effects of rainfall and blight losses on potato yields.

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