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SOYBEAN DISEASES

Agriculture Handbook No. 302

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Caution

If pesticides are handled or applied improperly, or if unused parts are disposed of improperly, they may be injurious to humans, domestic animals, desirable plants, pollinating insects, fish, or other wildlife, and may contaminate water supplies. Use pesticides only when needed and handle them with care. Follow the directions and heed all precautions on the container label.

This handbook supersedes Circular 931, "Diseases of Soybeans."

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SOYBEAN DISEASES

By J. M. DUNLEAVY, *plant pathologist, Crops Research Division, Agricultural Research Service, and professor, Dept. Botany and Plant Pathology, Iowa Agricultural and Home Economics Experiment Station*; and D. W. CHAMBERLAIN and J. P. ROSS, *plant pathologists, Crops Research Division, Agricultural Research Service*

Annual losses from all soybean diseases have been estimated at 12 percent of the total crop. The severity of disease and amount of loss depend upon environmental conditions, such as temperature and humidity. Disease-free soybean fields in the United States are the exception rather than the rule, and it is not unusual to find fields with several diseases present. All diseases do not occur every year in a locality. A disease may be very destructive one year and not apparent the next.

All soybean diseases reduce yields. The amount of loss depends on the type of disease, the severity of the disease on each plant, and the number of plants infected. Yield reductions are not usually severe enough to be observed directly by the producer. For example, severe bud blight leaves no doubt in the producer's

mind that yield is being greatly reduced; but bacterial blight, downy mildew, and brown stem rot, which reduce yields as much as 20 percent, are not obvious on the basis of plant symptoms alone.

Some soybean diseases are now effectively controlled by use of resistant varieties. Other diseases, such as soybean wilt, bud blight, and brown stem rot, warrant control but cannot now be controlled easily and effectively.

Soybean diseases are caused by bacteria, fungi, viruses, and nematodes that depend on the plant for their nutrition. The constant feeding of these organisms on soybeans weakens the plants so that they do not grow properly and fail to produce maximum yields. This handbook presents information on diseases, various nutritional disorders, and miscellaneous causes of damage to soybean plants.

BACTERIAL DISEASES

Bacterial Blight

Bacteria are very small, single-celled organisms that can be seen only through a microscope. They sometimes grow so well on plant tissue that they can be observed as a thick, cream-colored mass oozing from infected tissue. Bacteria invade plants through natural openings or wounds. They divide and redivide so rapidly that great pressure is developed between cell walls, which soon buckle. The bacteria then enter the cells and destroy them.

Bacterial blight, caused by the bacterium *Pseudomonas glycinea* Coerper, is one of the most widespread diseases of soybeans. Bacteria splashed from soil or nearby diseased plants invade the leaves through stomata, the minute breathing pores on the leaf surface. The bacteria multiply rapidly and produce small, angular, wet spots (pl. 1, A) in about 7 days. The spots turn yellow and

then brown as the tissue dies. Many small infections sometimes run together; the resulting large dead areas may fall out. Diseased leaves may be severely torn by high winds during rainstorms. Heavy infection may cause dropping of lower leaves. Bacterial blight is likely to be most severe during periods of cool weather and frequent rain or dew. It is usually observed early in the season before plants flower. Under conditions ideal for the development of the disease, heavy infections of bacterial blight are known to reduce yields as much as 22 percent. Although these conditions are not often encountered in commercial fields, severe losses from bacterial blight can result when they do occur.

The bacteria that cause blight are seedborne. They survive in dead leaves from one growing season to the next. Planting seed from severely diseased plants or replanting seed in infested fields most commonly allows this disease to become established. If the environment is unfavorable for disease development, these practices do not always result in a diseased crop.

Bacterial Pustule

Bacterial pustule, caused by the bacterium *Xanthomonas phaseoli* (E. F. Sm.) Dows. var. *sojensis* (Hedges) Starr & Burkh., is present to some extent in most soybean-growing areas. In the North its prevalence and severity seem to vary considerably with the season, but in the South it is more uniformly severe when susceptible varieties are grown. Infection occurs in the same way as that described for bacterial blight. Spots produced by the bacteria are usually confined to the leaves. At first, they appear as small, yellowish-green areas with reddish-brown centers, more conspicuous

on the upper surface of the leaf. A small, raised pustule usually develops at the center of the lesion, especially on the lower leaf surface (pl. 1, B). This is the stage at which the disease is most readily distinguished from bacterial blight. The pustule and the absence of a wet appearance before the spot turns yellow distinguish bacterial pustule from bacterial blight. Many small infections sometimes run together; the resulting large dead areas sometimes fall out, giving the leaf a ragged appearance. Bacterial pustule losses as high as 12 percent have been measured.

The disease-producing bacteria are seedborne and overwinter in diseased leaves. The varieties Bragg, Clark 63, Hampton, Hardee, Hill, Hood, Lee, and Scott are highly resistant.

Wildfire

Wildfire, caused by the bacterium *Pseudomonas tabaci* (Wolf & Foster) F. L. Stevens, occurs only where bacterial pustule is found. The wildfire bacteria alone do not produce a disease in soybeans. They invade only the parts of the leaf already parasitized by the pustule bacteria. Light-brown, dead areas of various sizes, surrounded by broad, yellow halos, appear on the leaves (pl. 2, A). At times the dead spots are dark brown to black, with indistinct halos. In damp weather the spots enlarge and run together. Such severe infection can cause considerable loss of leaves.

The bacteria are seedborne. They may live for 3 to 4 months in dead leaves at the soil surface but are killed in a few weeks when covered with soil. This disease can be easily controlled by planting varieties resistant to bacterial pustule. Where resistant varieties are unavailable, wildfire can be controlled by using seed from

fields in which the disease was not present and by practicing crop rotation.

Bacterial Wilt

Bacterial wilt has long been an important disease of garden beans but only in recent years has it been recognized as a disease of soybeans. It is widely distributed throughout the soybean-growing regions of the United States. The disease is caused by a bacterium related to *Corynebacterium flaccumfaciens* (Hedges) Dows. and is seedborne. The bacteria occur both on and within the diseased seed. Bacteria within the seed cannot be reached by treating the seed with disinfectants or with chemicals without injuring the seed. Diseased seeds sometimes appear normal or sometimes show light discoloration, shriveling, or malformation (fig. 1). Severely diseased seed may be flat and irregular in outline, with seed coats covered with a fuzzy fungus growth. Such seed is usually dead and only spreads the bacteria when planted with disease-free seed.

Seedlings severely diseased by bacterial wilt are greatly stunted, and growing points can be killed. Main stems are frequently forked just above the cotyledons. Leaves are small and stems are thin and weak. Less severely diseased plants sometimes show only a depression in growth or slightly misshapen leaves. These plants usually have a fair to good pod set with only occasional unfilled pods. If, however, the weather becomes dry, many pods do not fill, the leaves become yellow, and the plants mature as much as 2 weeks early. Such weakened plants are subject to infection by many other disease-producing organisms. Pod and stem blight, charcoal rot, and fusarium blight are the most frequent secondary diseases; stem canker, anthracnose, alternaria

leaf spot, and phyllosticta leaf spot are observed less frequently.

Infected plants sometimes show netlike yellow blotches on the leaves (pl. 2, B). Severely infected plants may wilt and die at any time during the season. Depending upon the degree of severity and time of infection, stems may remain green and leaves may adhere to stems after pods mature. The veins along the upper edge of the pods may turn brown, and the pods may split as the seeds enlarge. Infection of green seed and pods sometimes results in brown, circular spots on the pod walls opposite the seed.

Most commercial seed is contaminated. Seed of some varieties appears more severely contaminated than others. Whether this is a measure of varietal susceptibility is not known. No resistant varieties are known, but there is a considerable range in susceptibility. Varieties Lee and Adams appear less susceptible than other varieties.

Soybeans from severely diseased fields should never be used for seed. Poor soil conditions, low temperatures, and heavy rains soon after planting increase the severity of infection. There is no effective method of controlling wilt. A search for wilt-resistant soybeans, followed by development of resistant varieties, seems to offer the only hope of controlling this disease.

Rhizobium-Induced Chlorosis

Chlorosis or yellowing of the upper leaves of young, actively growing soybean plants has been observed under some conditions. This chlorosis results from the interaction between a specific variety of soybeans and a specific strain of *Rhizobium* (nodulating) bacteria.

Under field conditions, seldom do more than two or three leaves

on an individual plant develop chlorosis (pl. 3, A), and these leaves develop a normal green color in 10 to 14 days. Chlorosis occurs during rapid plant growth when the plant is highly dependent upon nodule nitrogen. The variety Lee frequently shows chlorosis when grown on low nitrogen

soils in the South, whereas the equally susceptible variety Hawkeye seldom shows the condition when grown on the higher nitrogen soils common to the north-central area.

Field studies have demonstrated no yield reduction from chlorosis.

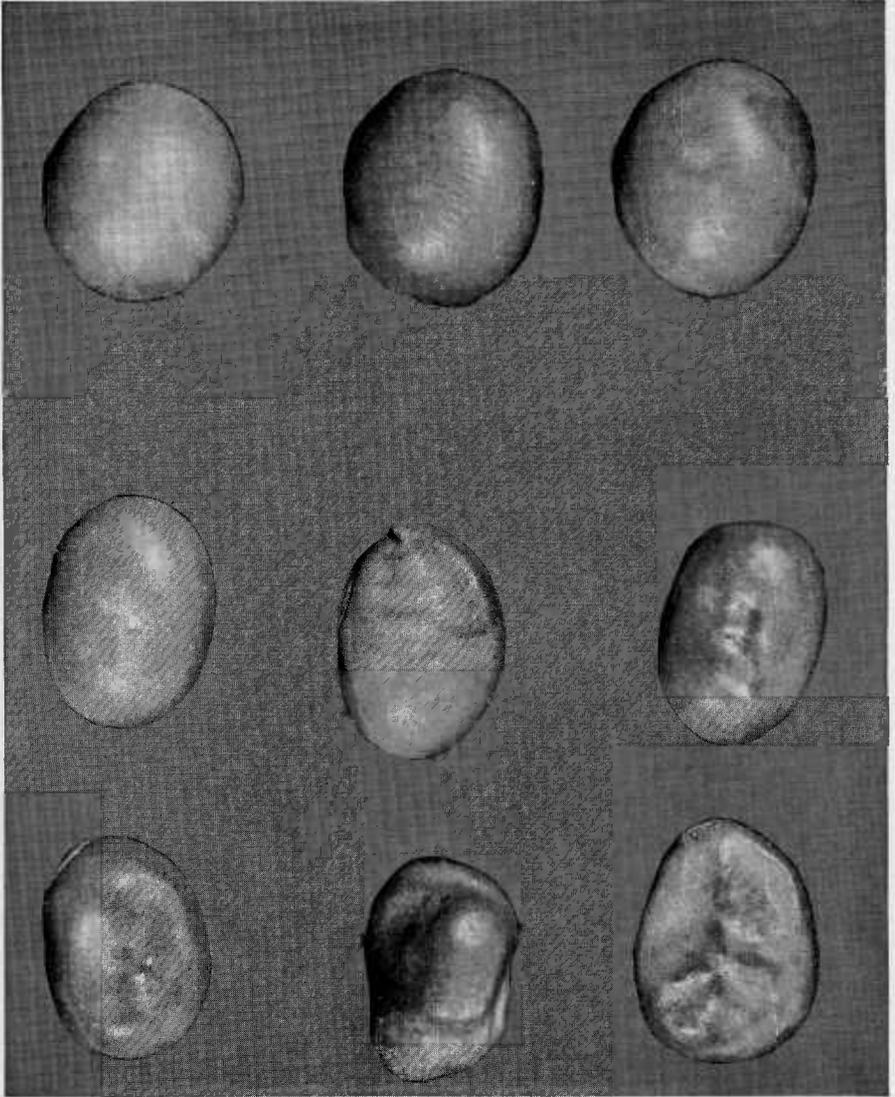


FIGURE 1. — Various degrees of seed distortion by the wilt bacteria (left to right, top to bottom). Seed at upper left is healthy; seed at lower right is flattened and dead.

FUNGUS DISEASES

Fungi, commonly called molds, are small, filamentous, branched organisms. Some fungi live almost exclusively on decaying organic matter and only occasionally invade living plant tissue with their threadlike structure. Others seem to thrive as well in living plant tissue as in decaying plant debris. Still another group of fungi can survive only in living plant tissue. Fungi enter plants either through wounds or natural openings or by direct penetration.

Diseases Affecting Leaves

Brown Spot

Brown spot, caused by the fungus *Septoria glycines* Hemmi, was formerly regarded as a disease of minor importance but has increased in prevalence in the Midwest in recent years. It appears early in the growing season on the primary leaves of young soybean plants as angular, reddish-brown lesions that vary from the size of pinpoints to one-fifth inch wide (pl. 3, B). As the plants grow, the fungus spores produced on the primary leaves spread and infect the trifoliolate leaves, stems, and pods. Heavily infected leaves gradually turn yellow and fall prematurely. Defoliation progresses from the base toward the top of the plant. In severe cases the lower half of the stems may be bare of leaves before maturity.

The fungus grows through the pod wall into the seed and is seedborne. Infected areas on the cotyledons furnish spores for subsequent infection of primary leaves. Soybeans from severely diseased fields should not be used for seed because seed treatment does not satisfactorily control brown spot. The fungus lives through the winter on diseased stems and leaves left in the field.

Greatest damage occurs where soybeans are planted every year in the same field. When this practice is followed, severe brown spot infection starts early in the season and one-half or more of the foliage may be lost before maturity. Crop rotation with at least 1 year between successive soybean crops should be used to reduce disease severity. None of the commercially grown soybean varieties are resistant to brown spot.

Downy Mildew

Downy mildew, caused by the fungus *Peronospora manshurica* (Naum.) Syd. ex Gaum., is one of the most common soybean diseases in the United States. It is characterized in its early stages by indefinite, yellowish-green areas on the upper surface of the leaves. In severe cases entire leaflets are discolored. As infection progresses, the diseased areas become grayish brown to dark brown and are surrounded by yellowish-green margins (fig. 2). Severely infected leaves fall prematurely. A gray fungus growth, sometimes called mildew, develops on the lower side of these diseased areas. Spores produced by the fungus spread the disease from plant to plant. In addition to these externally borne summer spores, thick-walled resting oospores develop within the leaf tissues. These spores overwinter in the fallen leaves and probably provide a source of infection for the next season's crop.

The fungus grows within the plant, invades the pods, and covers some seeds with a white crust of oospores (fig. 3). When such seeds are planted, a small percentage of the seedlings are infected. The first leaves to unfold on these seedlings sometimes are covered with mildew growth and provide centers of infection in the new

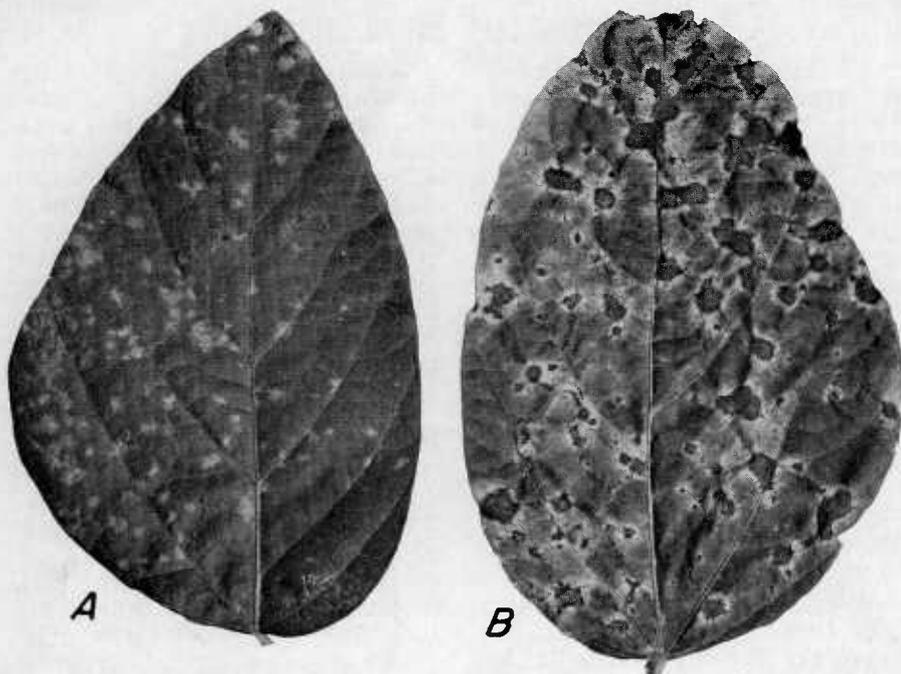


FIGURE 2. — Downy mildew lesions on upper surface of soybean leaflets: A, Early stage of disease; B, later stage.

season's crop. This type of infection also occurs when disease-free seed is planted in fields that contained downy mildew infected soybeans the previous year.

Downy mildew occurs in all soybean-growing areas. Under average conditions in Iowa it can reduce production 8 percent. Frequent dews cause more severe disease development and greatly increase the percentage of seed infested with oospores. Such seeds are smaller and this phase of the disease has been known to reduce yield an additional 6 percent.

Recent research has shown that 26 races of the fungus exist. These races are widely distributed throughout the soybean-producing sections of the country and usually only one or two races occur in a field. Soybean plants resistant to all known races of the

fungus have been found and improved; resistant varieties are being developed.

Target Spot

Target spot, caused by the fungus *Corynespora cassiicola* (Berk. & Curt.) Wei, is primarily a disease of soybean leaves; however, the fungus occasionally causes spotting of the petioles, stems, pods, and seeds.

On the leaves the spots are reddish brown, circular to irregular, and vary from pinpoint size when immature to one-half inch or more in diameter when mature. The larger spots sometimes form concentric rings of dead tissue, and the name "target spot" was suggested by this zonation (fig. 4). The spots of dead tissue are frequently surrounded by a dull-green or yellowish-green halo, thus resembling the wildfire disease;



FIGURE 3.—Soybean seeds encrusted with oospores of downy mildew fungus.

however, the wildfire spots are light brown or dark brown to black. Narrow, elongated spots are present along the veins on the upper leaf surface on highly susceptible varieties. The disease results in premature defoliation.

Spots on petioles and stems are dark brown and vary from mere specks to elongated spindle-shaped lesions. Pod spots are generally circular, about one-sixteenth inch in diameter, with slightly depressed, purple-black centers with brown margins. The fungus penetrates the pod wall in some cases and causes a small, blackish-brown spot on the seed.

Plant pathologists in Nebraska have reported that the fungus causes dark, reddish-brown lesions, which turn dark violet

brown with age, on the roots and stems of soybean seedlings. Lesions are particularly evident during cool, moist weather early in the growing season. Temperatures between 60° and 70° F. are optimum for disease development. Target spot is not considered a major problem in Nebraska since warm weather arrests disease development.

The target spot fungus also attacks cowpeas, cotton, and sesame. The foliage disease was first reported in the United States in 1945 and is generally distributed throughout the Southern States. So far, it has not been reported from the Corn Belt States.

Soybean yield losses caused by target spot were studied in Mississippi by growing susceptible and

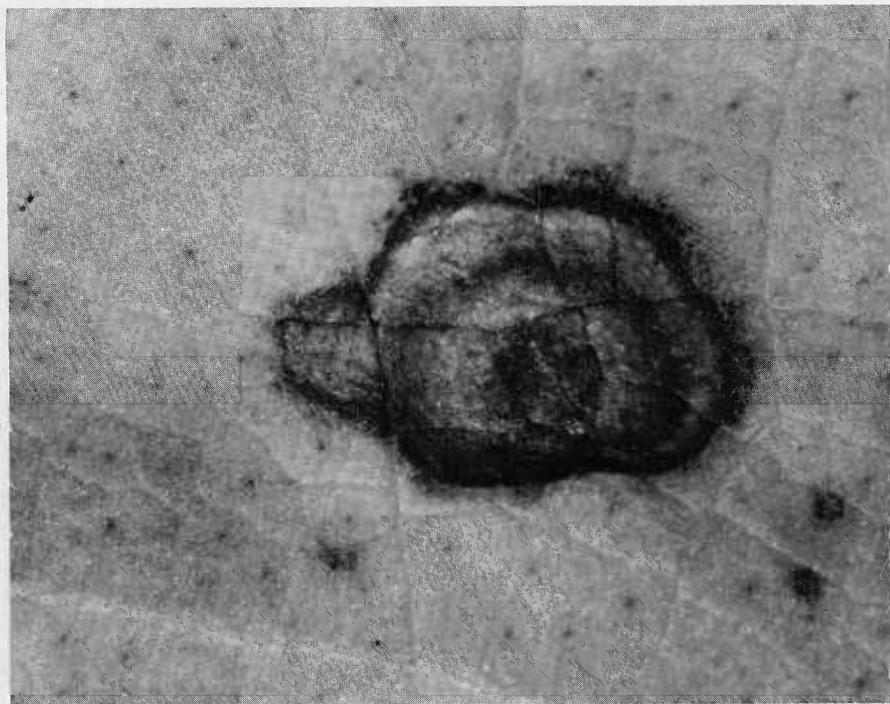


FIGURE 4. — Concentric rings forming target spot lesion on leaflet.

resistant lines. Yield losses ranged from 18 to 32 percent on susceptible lines. Nearly all varieties adopted for production in the Southern States are resistant.

Frogeye Leaf Spot

Frogeye leaf spot, primarily a disease of soybean leaves, is caused by *Cercospora sojina* Hara. When the fungus infects the leaf tissues, it causes an eyespot type of lesion composed of a gray or light-tan central area with a narrow, reddish-brown border (fig. 5). Heavily spotted leaves usually fall prematurely. Infection can also occur on stems and pods late in the growing season. The fungus sometimes enters the seed from infected pods.

The causal fungus overwinters in the seed and on leaves and stems from diseased plants. It may be introduced into fields through the

planting of infected seed. For this reason, seed for planting should not be saved from a crop severely infected with frogeye.

Although frogeye has been primarily a disease of the southern soybean-producing areas, it was prevalent in the southern half of Indiana up to 1950. At that time, the resistant varieties Lincoln and Wabash replaced the susceptible varieties Gibson and Patoka. In 1959, however, frogeye infection was found in Indiana on Lincoln and Wabash. This led to the discovery that there are two races of the fungus that causes frogeye, and Indiana workers have found that Kent and Lee are resistant to both races.

Phyllosticta Leaf Spot

Phyllosticta leaf spot, caused by the fungus *Phyllosticta sojicola* Massal., does not occur so regular-

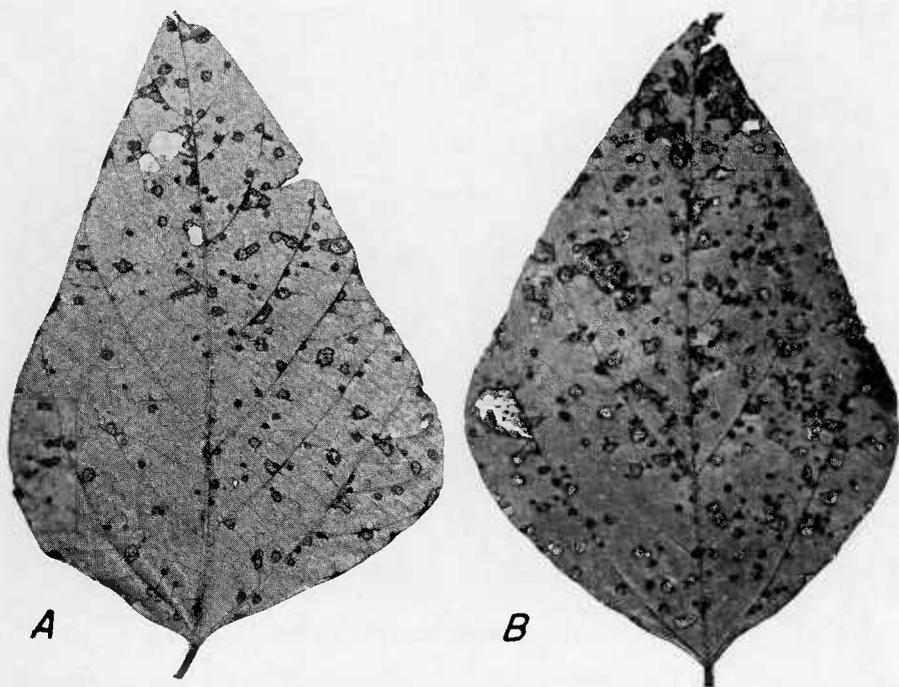


FIGURE 5.—Frog-eye lesions: A, Lower surface of soybean leaflet; B, upper surface.

ly as the bacterial leaf spots but sometimes causes severe damage in localized areas. The spots may be round to oval or indefinite in shape. On young plants, the spots form from the margin of the leaf inward. When first formed, the spots are dull gray; they later turn gray to tan with a dark-brown border (fig. 6). In general, the disease does not persist long after the third- or fourth-leaf stage of growth of the soybean plant. However, the disease has caused severe defoliation in certain areas, such as the Eastern Shore of Maryland and southeastern Missouri.

Lesions on the pods were observed in Maryland (1951), and infected seeds were found beneath the lesions.

Control measures for this disease have not been worked out. Resistant varieties are not available.

Powdery Mildew

Powdery mildew of soybeans is caused by one or more species of fungi. Early accounts of the disease name *Erysiphe polygoni* DC. as the causal agent. In more recent investigations *Microsphaera diffusa* Cke. & Pk. has been reported to cause powdery mildew. In the greenhouse the causal fungus spreads rapidly on susceptible varieties. In the field it does not appear to be adapted to prolonged survival; here it occurs only sporadically. In its early stages, powdery mildew may be recognized by the presence of small colonies of thin, light-gray or white fungus spreading rapidly on the upper surface of the leaf. Reddening of the underlying leaf tissue sometimes is evident. In time, the whitened areas of fungus enlarge but seldom coalesce to cover all the leaf surface. Many

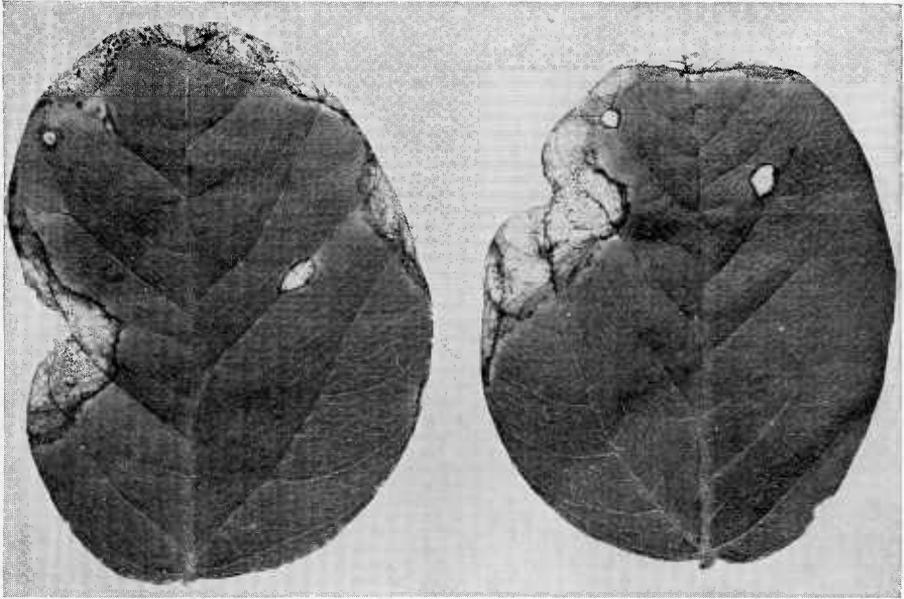


FIGURE 6. — *Phyllosticta* leaf spot lesions on primary leaves of young soybeans.

spores are produced, and the infected areas take on a white powdery appearance as though coated with flour. Heavily infected leaves soon turn brown and drop off.

Black Patch

On soybean leaves the black patch fungus, identified as *Rhizoctonia leguminicola* Gough & Elliott, causes small, circular to irregular spots that are buff at the center and have narrow, purplish borders. The spots resemble frog-eye leaf spot lesions, but the black patch disease can be recognized by the dark-brown to black aerial fungus strands on the surface of the spots. The disease is of minor economic importance, and so far it has been observed on soybeans in Georgia and Iowa only. The fungus attacks clovers and other forage legumes rather commonly. In no instance has the fungus been observed to produce fruiting structures on its host or in culture.

Alternaria Leaf Spot

Alternaria leaf spot, caused by a fungus of the genus *Alternaria*, is a common disease of soybeans in many parts of the United States. It is especially prevalent in the Midwest. Although young plants are occasionally infected, alternaria leaf spot is generally a leaf disease of plants nearing maturity and occurs too late to cause serious damage. The spots are brown with concentric rings, and vary from $\frac{1}{4}$ to 1 inch in diameter. The spots often coalesce to produce large dead areas on the leaf blade. Alternaria leaf spot resembles target spot, but it lacks the reddish-brown color and the yellowish-green halo that characterize target spot.

Small, brick-red spots on soybean leaves have been investigated at the Arizona Agricultural Experiment Station. These spots, caused primarily by sunburn or aphid injury, were found to enlarge and turn brown, and were frequently covered with a sooty-

black fungus growth. The fungus, described as *Alternaria atrans* Gibson, was considered to be a weak parasite.

Diseases Affecting Roots and Stems

Brown Stem Rot

Brown stem rot is caused by a soil-inhabiting fungus, *Cephalosporium gregatum* Allington & Chamberlain, which enters the soybean plant through the root and lower stem. Infected plants show no outward symptoms during the major part of the growing season. After mid-July, however, if the stem is split lengthwise, a brown discoloration can be seen inside the root and lower stem (pl. 4). The browning progresses upward in the stem as the season advances. In most seasons, the internal browning is the only symptom by which diseased plants can be recognized.

Leaf symptoms do not always occur but when they do, the leaf tissues between the veins turn brown and dry rapidly, usually about 3 weeks before maturity. The leaf tissues near the veins remain green for a few days, and then the entire leaf withers (pl. 5). A severely diseased field turns brown instead of turning yellow green as does a normally maturing field. Severely diseased plants may lodge.

Brown stem rot was first discovered in central Illinois in 1944. The disease occurs commonly through the North Central States and Canada, and was reported from North Carolina and Virginia in 1963.

Yield reduction due to brown stem rot depends upon the severity of infection in a field. When all plants are infected, the loss may amount to 25 percent. Fewer infected plants result in lower losses.

Yield losses caused by brown stem rot are not usually recognized by the grower because the symptoms of the disease (internal browning) are hidden; hence, the grower may attribute the loss to some other cause.

There are no resistant varieties. The only control measure known at present is a rotation in which soybeans are grown in a field only once in 3 or 4 years.

Stem Canker

Stem canker, caused by the fungus *Diaporthe phaseolorum* (Cke. & Ell.) Sacc. var. *caulivora* Athow & Cald., kills plants from mid-season to maturity. The disease is most common in the Midwest. Dead plants with dried leaves still attached may be the first indication of its presence. A brown, slightly sunken lesion girdles the stem, usually at the base of a branch or leaf petiole (pl. 6). These begin as small, confined areas on the stems. They are at first very superficial, and only the epidermis is involved. These spots enlarge and spread rapidly until the stem is girdled and the upper part of the plant is killed.

In the fall the stem canker fungus produces sexual fruiting bodies called perithecia on dead stems in the field. The spores produced in these bodies spread the disease the following growing season. The stem canker fungus is seedborne. Seedlings can be infected when disease-free seed is sown in fields containing diseased stubble. The variety Hawkeye is more susceptible than other varieties grown in the Midwest.

Phytophthora Rot

Phytophthora rot, caused by the fungus *Phytophthora megasperma* Drechs. var. *sojae* A. A. Hildeb., is one of the more recently discovered diseases of soybeans. It attacks the plant at any stage in

its development. Under certain conditions, it causes preemergence damping-off of the germinating seed, postemergence killing of seedlings, or a more gradual killing or reduction in vigor of plants throughout the season. Young plants, however, are most susceptible to killing.

When preemergence damping-off occurs, gaps of various lengths may appear in rows and the stand of plants may be so sparse that replanting is necessary. If seedlings are infected, the fungus produces a soft rot of the tender stem that kills the plants rapidly. In older plants, the first symptoms are yellowing and wilting of the leaves, frequently accompanied by a dark-brown lesion on the stem (fig. 7). The lesion may extend below the soil line, or it may be several inches above the soil line and extend upward into the branches. Leaves and stems are infected when splashed with contaminated soil. The lesion on the taproot is usually dark brown and the branch roots may be destroyed. Sometimes the brown discoloration is confined to the root tissue just beneath the bark.

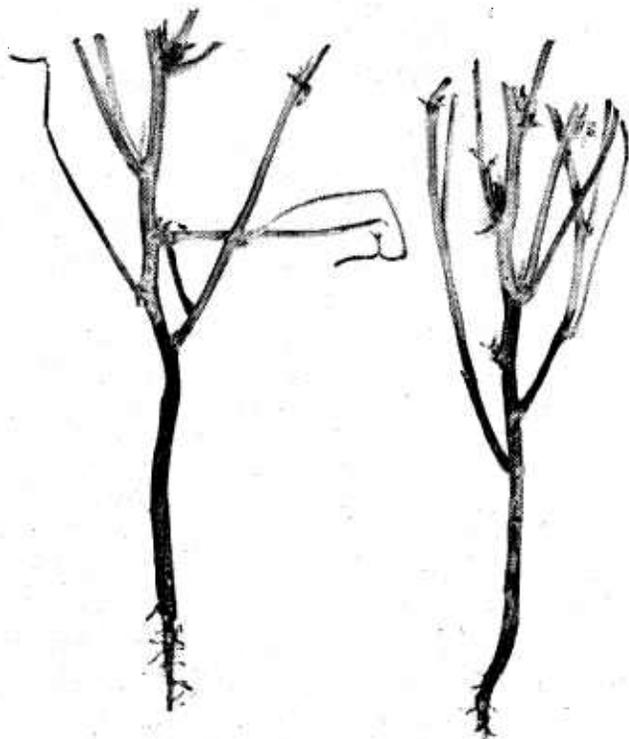


FIGURE 7. — Rot of lower part of soybean stems caused by *Phytophthora* fungus.

Phytophthora rot is especially noticeable in low, poorly drained areas of a field, but in wet seasons it also appears on higher ground. It is more severe on heavy clay soils than on the lighter soils. The disease occurs over most of the soybean-producing areas of the United States and Canada.

The variety Harosoy is very susceptible to this disease and is usually more severely damaged by the disease than some of the other varieties, such as Adams and Hawkeye. Blackhawk, Monroe, Crest, Ross, Henry, Harosoy 63, Hawkeye 63, Clark 63, Lindarin 63, Chippewa 64, and Madison are highly resistant.

Pythium Rot

Pythium rot, caused by the fungi *Pythium ultimum* Trow and *Pythium debaryanum* Hesse, can occur on soybeans at any time from the seedling stage to mid-season. When soybean seeds are planted in cold soil, the *Pythium* fungus can cause seed decay or kill the young seedlings before they emerge from the soil. It also causes damping-off of seedlings after they have emerged. The seedlings that emerge often have well-developed cotyledons but a dead growing point. This condition is known as baldhead.

In the early stages of infection of older plants, the first symptom is a water-soaked appearance of the outer tissues of the stem above the soil line. Later, these tissues turn brown and slough off. This gives the stem a shredded appearance. Wilting of the plant follows. The outer tissues of the large roots are soft, brown, and moist and slough off readily.

Pythium rot, like some of the other rots of the root and basal stem, is favored by cold, wet soil early in the growing season. Seed treatment does not control the disease in heavily infested soils but

does give some protection against seed decay. The *Pythium* fungi attack a wide variety of crop plants over most of the United States and Canada, and rotation is therefore of little value. There are no resistant varieties.

Rhizoctonia Rot

Rhizoctonia rot is caused by *Rhizoctonia solani* Kuehn, a widespread, soil-inhabiting fungus, which causes damping-off, root rot, and basal stem rot in a number of crop plants. Infection begins very early in the season. The young soybean plants develop a reddish-brown decay of the outer layer of the root and basal stem (fig. 8). Frequently this decay girdles the stem and the plant dies. The lower part of the taproot with its secondary root system is sometimes destroyed. As the upper 2 or 3 inches of soil dry out, the af-

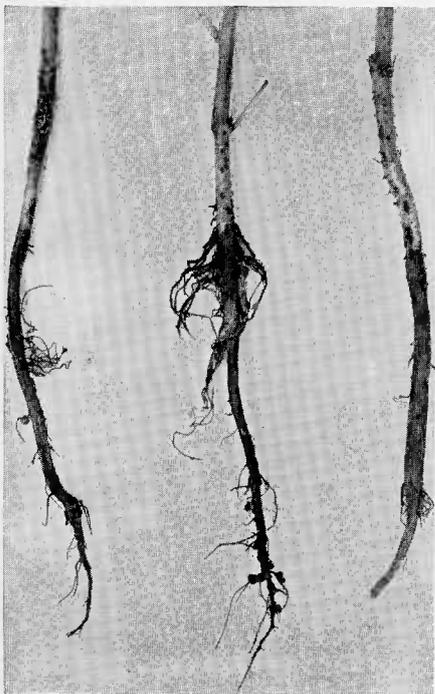


FIGURE 8. — Girdling, near the soil line, of stems of young soybean plants, caused by *Rhizoctonia* fungus.

ected plants wilt and die for lack of water and nutrients.

Dead plants sometimes occur in areas 4 to 10 feet in diameter distributed irregularly over the field. Frequently the dead plants appear in scattered sections of rows distributed over an entire field. The disease is not consistently severe on soybeans, but in wet years it may cause up to 10-percent loss in stand in some North Central States. Seed treatment is of no value in controlling the rot caused by the *Rhizoctonia* fungus, and there are no resistant soybean varieties.

In certain areas of the South, particularly in Louisiana and North Carolina, the *Rhizoctonia* fungi sometimes spot and blight the leaves. The spots are irregular in shape and are buff to dark brown. This type of infection develops best under hot, humid conditions.

Fusarium Root Rot

Fusarium root rot of soybeans occurs in Iowa, Minnesota, and Missouri and occasionally on sandy soils in the Southern States. Several phases of the disease have been described and have been attributed to the different species of *Fusarium*.

The root rot phase is caused by the fungus, *Fusarium orthoceras* Appel & Wr. The fungus is usually confined to roots or the lower portions of stems (fig. 9). If the stem is invaded, it is usually through the pith. The fungus can infect nearly mature pods and is seedborne. Wilting sometimes occurs from severely rotted roots when soil moisture is inadequate. Under such conditions, disease-free plants grow normally but diseased plants wilt and die. This phase of the disease is most frequently observed on seedlings or young plants, and entire fields can be affected.

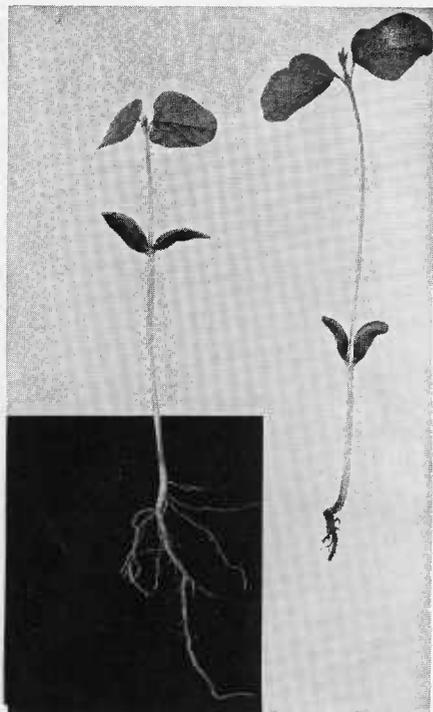


FIGURE 9. — *Fusarium* root rot of soybeans: *Left*, healthy plant; *right*, plant with roots almost completely destroyed.

The true wilt phase of the disease causes wilting of older plants and is much less common than the root rot phase. Wilt of soybeans has never caused such extensive losses as have wilts of cotton, cowpea, and watermelon. Infected soybean plants do not wilt so easily as infected plants of these other crops and may only develop yellow leaves that fall prematurely. When the stem base and taproot of an infected plant are split longitudinally, a brown or black discoloration of the vascular tissues is evident. *Fusarium oxysporum* Schlecht. f. *tracheiphilum* (E. F. Sm.) Snyder & Hans. and *F. udum* Butl. f. *crotalariae* Padwick, the *crotalaria* wilt fungus, have been shown to cause a wilt of soybeans in South Carolina.

Occasionally, inspection of infected plants reveals rotted tap-

roots, and the plants exist only on water and nutrients supplied by a few lateral roots that have developed from the base of the stem. Seedlings infected with *F. orthoceras* and showing signs of wilting or death of lower leaves should not be cultivated until adequate soil moisture is available. When the plants are cultivated, soil should be ridged around the base of the plants. This will promote development of roots from the stem base. These roots are not easily infected by the fungus, and they help the plants to recover rapidly.

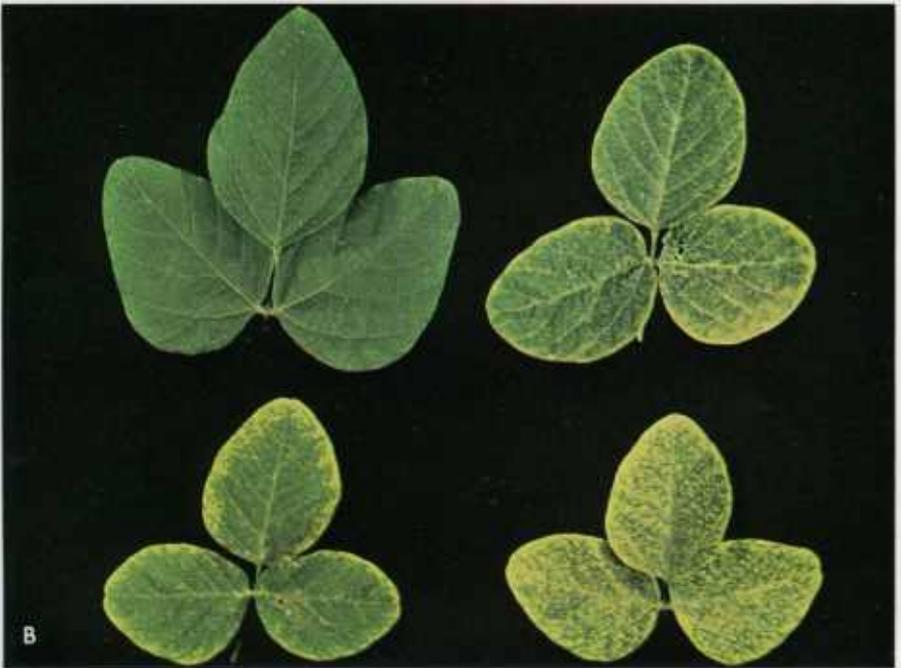
Poor stands resulting from this disease are usually associated with heavy rains, soil compaction, and soil flooding just after planting.

Anthracnose

Anthracnose of soybeans is caused by two species of fungi, each producing similar symptoms. *Glomerella glycines* (Hori) Lehman & Wolf was first reported as the causal agent of anthracnose of soybeans in America. The imperfect fungus *Colletotrichum truncatum* (Schw.) Andrus & W. D. Moore, which causes stem anthracnose of lima bean, is now probably the most common cause of anthracnose of soybeans. Although it is not a major disease of soybeans, anthracnose is found in all major soybean-producing areas of the United States and has been reported from China. Soybean plants in all stages of growth are subject to anthracnose. When infected seeds are planted, many of the germinating seeds are killed before emergence. Dark-brown, sunken cankers are often seen on the cotyledons of young seedlings. The causal fungus may completely destroy one or both cotyledons or grow from them into the tender tissues of the young stems. There it produces numerous, small, shallow, elongated, reddish-brown



A, Bacterial blight spots appear wet in early stages of development and are flat; *B*, raised pustules surrounded by rings of yellow tissue on the lower side of soybean leaves are symptoms that characterize bacterial pustule.



A, *Left*, soybean leaf damaged by wildfire bacteria displays broad, yellow halos around dead areas of leaf; *right*, healthy soybean leaf; B, progressive development of bacterial wilt on leaves; leaf at upper left is healthy.



A, *Rhizobium*-induced chlorosis of soybean plants; B, brown spot lesions on primary leaves of young soybeans.



Split soybean stems: *Left and center*, internal discoloration of brown stem rot; *right*, healthy stem. Scale is metric.



Leaf blight sometimes results from plugging of vessels in stem by brown stem rot fungus.



Stem canker lesion girdling soybean stem.



Soybean seeds with purple stain.



A, Soybean leaflets showing (left to right) severe, moderate, and light symptoms of potassium deficiency; *B*, new leaves of soybean plants with symptoms of iron deficiency.

lesions or large, deep-seated, dark-brown lesions that usually kill the young plant. The causal fungus is capable of growing within stem, leaf, and pod tissues of soybean plants without giving external evidence of its presence until some favorable condition of the plant induces sporulation of the fungus on the surface of the invaded tissue.

On older plants, anthracnose reaches its most destructive stage of development during rainy periods in late summer. Lower branches and shaded leaves are killed by the fungus. Likewise, young pods may be attacked. Indefinite brown areas develop and coalesce to cover the entire surface of the diseased stems and pods, and the causal fungus forms numerous, black fruiting bodies (acervuli) on the diseased areas. As these structures develop, several short, dark spines (setae) emerge from each acervulus, giving a dark, stubble-bearded appearance to the diseased area. Seeds in diseased pods may be shriveled and moldy. On the other hand, infected seeds may exhibit no outward sign of disease.

Both species of fungi survive from one growing season to the next in diseased stems left in the field. Both overwinter on infected seeds and are spread by planting diseased seeds in new localities. Treatment of anthracnose-infected seed with fungicides greatly improves the stand, but it does not eliminate the disease.

Phymatotrichum Root Rot

Phymatotrichum root rot of soybeans is caused by the same fungus, *Phymatotrichum omnivorum* (Shear) Dug. that attacks cotton. It is prevalent in heavy alkaline soils in parts of Texas. The fungus attacks soybeans in these areas, causing the plants to wilt rapidly and die in patches of con-

siderable size. If the dead plants are pulled from the soil, one can observe the decayed bark of the roots. Frequently, brownish woolly strands of fungus growth can be seen on the roots. The fungus may persist in the soil for many years in its resting, or sclerotial, stage.

Charcoal Rot

Charcoal rot, caused by the fungus *Macrophomina phaseoli* (Maub.) Ashby, is a disease of the roots and stem base of soybeans. When the bark is peeled from diseased areas, small, black propagating bodies (sclerotia) of the fungus may be seen (fig. 10, A). These are frequently abundant enough to cause the tissue beneath the bark to appear grayish black, and this color has suggested the name "charcoal rot" for this disease.

The charcoal rot fungus is a weak parasite of soybeans and causes disease only when plant growth is retarded by hot, dry weather, poor soil, or other unfavorable conditions. The fungus is widely distributed in soils in the warmer sections of the United States and attacks many other cultivated plants and weeds, as well as soybeans.

Sclerotial Blight

Sclerotial blight, caused by the fungus *Sclerotium rolfsii* Sacc., like charcoal rot is characterized by a rot at the base of the plant stem, but differs from charcoal rot in that these fungus sclerotia are much larger and rounder than those of the charcoal rot fungus and are brown instead of black. Furthermore, they are produced on a cottony, mycelial growth on the outside of the stem, rather than under the bark (fig. 10, B). Infected plants die prematurely, sometimes before the seeds form.

The disease is found in sandy soils in the South where high summer temperatures occur; the name "southern blight" is sometimes applied to this disease. In some fields plant losses may be as high as 25 to 30 percent, but it is more common to see small, scattered areas of dead plants among the healthy ones.

The sclerotial blight fungus attacks a wide variety of plants, including practically all the summer legumes adapted to the South. Attempts at the Georgia Agricultural Experiment Station to select soybean plants resistant to sclerotial blight have been unsuccessful.

Good control of sclerotial blight of peanuts has been obtained by

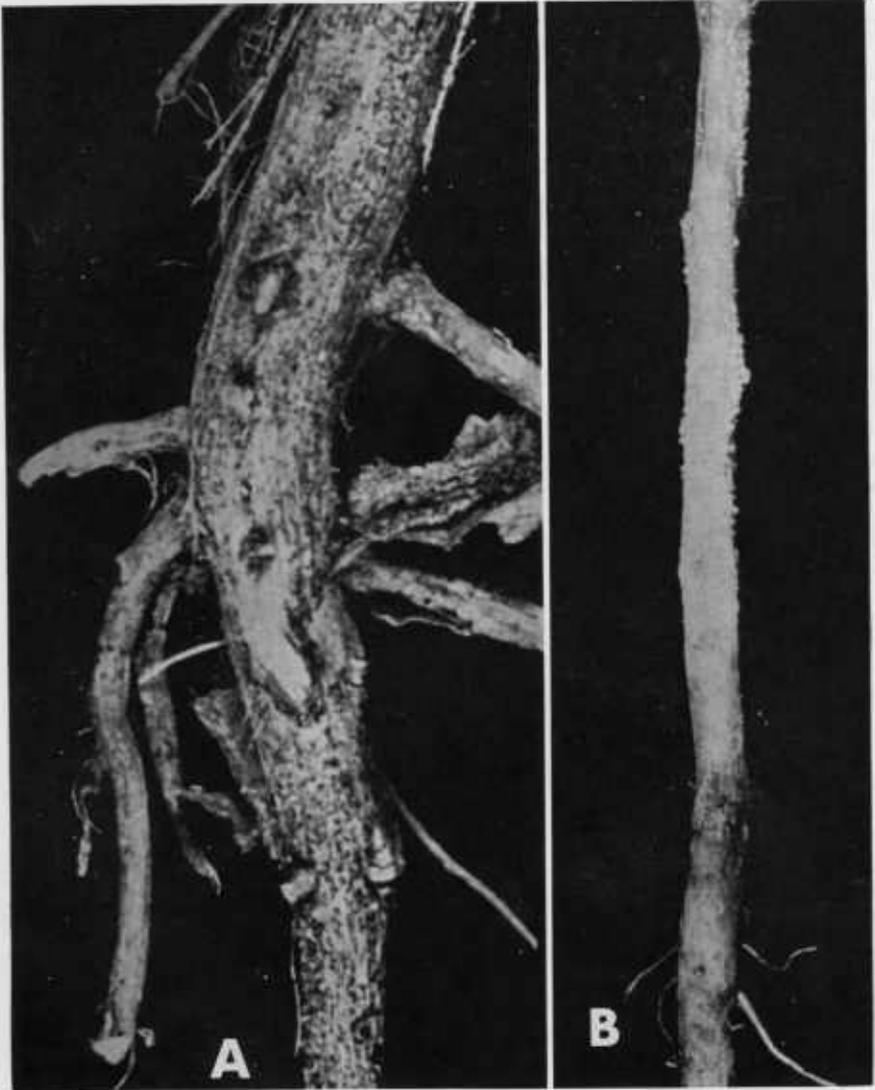


FIGURE 10. — *A*, Soybean stem base and root with exposed small, black sclerotia of the charcoal rot fungus; *B*, soybean stem with a heavy surface growth of the sclerotial blight fungus.

plowing deeply enough to bury plant debris under 4 inches of soil. This disease control practice should also prove valuable in soybean production. Crop rotation with nonsusceptible crops, such as corn or cotton, also has been successful in controlling this disease.

In rare instances in North Carolina this fungus has been observed to cause circular brown or straw-colored spots on the leaves. These spots usually have concentric markings and narrow, dark-colored borders of necrotic tissue. A clump of white mycelium or a small, spherical, brown sclerotium is often present at the center of the lesion. The size of the spot may vary from less than one-fourth to more than one-half inch in diameter. Leaf infections occur when wind and rain splash soil containing the causal fungus onto the leaves.

Stem Rot

Stem rot, caused by the fungus *Sclerotinia sclerotiorum* (Lib.) D. By., begins on soybean stems near the soil level. The fungus first forms a white cottony growth on the stem of the infected plant. Then large, hard, black bodies called sclerotia are formed on or inside the stem (fig. 11, A). The fungus overwinters in the sclerotia. In spring the sclerotia germinate and the fungus causes new infections. Infected plants are killed by the girdling action of the fungus.

The disease has been reported from Illinois, Iowa, Maryland, New Hampshire, and New York, and Ontario, Canada. It appears infrequently and is considered a minor disease, but it has occasionally been locally destructive. It is most frequently observed after prolonged wet periods.

The greatest hazard connected with stem rot is encountered in foreign trade, where no tolerance for sclerotia is allowed. The large

sclerotia are not separated from the seed in combines; consequently, a small center of infection in a field can contaminate a large volume of seed during harvesting operations. At a foreign port of entry, the finding of even a few sclerotia in a shipment of soybeans intended for human consumption can result in the rejection of the entire shipment.

Soybeans contaminated with sclerotia should not be used for seed.

Diseases Affecting Seed

Purple Seed Stain

Purple seed stain was reported on soybeans in the United States for the first time in 1927 when an Indiana Agricultural Experiment Station report called attention to the objectionable discoloration. The disease has since been observed in most States where soybeans are grown.

As far as is known, this disease is caused by the fungus *Cercospora kikuchii* (T. Matsu. & Tomoyasu) Gardner. Investigations in Mississippi, however, have demonstrated that 10 other species of *Cercospora* isolated from other hosts are capable of causing purple discoloration of soybean seed when the fungi are artificially injected into developing pods. Whether these 10 other species of *Cercospora* are capable of causing purple stain of soybean seeds in the field remains to be determined. The causal fungus probably overwinters on diseased leaves and stems as well as in infected seed.

The amount of purple discoloration in seed lots is important from the grading standpoint, and the value of seed may be lowered considerably by excessive amounts of purpling. Weather conditions at the time of flowering and plant maturity apparently have a pronounced influence on the percentage of discolored seeds that

develop, since this varies widely from year to year with a given variety. Under conditions favorable for the disease, 50 percent or more of the seeds of certain varieties may be discolored.

Although the symptoms of purple stain are most conspicuous on the seed, the causal fungus also attacks the leaves, stems, and pods on susceptible varieties. The foliage symptoms become most evident during the latter part of the growing season as the plants approach maturity. Individual lesions are angular, reddish-brown spots, approximately one-sixteenth inch in diameter. They frequently coalesce to produce large areas of dead tissue. The discoloration on the seed varies from pink or light purple to dark purple, and ranges in size from a small spot to the entire area of the seed coat (pl. 7). Cracks often occur in the discolored areas, giving the seed a rough, dull appearance.

When diseased seeds are planted, the fungus grows from the seed coats into the cotyledons and from these into the stem of a small percentage of the seedlings. The fungus produces spores abundantly on the diseased seedlings, and the wind-blown and rain-splashed spores lodge on the leaves of adjacent plants. Leaf spots develop and the fungus produces a second crop of spores that cause infections on other leaves, stems, and pods.

Varietal differences in susceptibility have been observed, and varieties Hill and Lee with moderate resistance have been released. Seed treatment aids in preventing loss of seedlings, but it will not assure freedom from purple stain in the seed crop. Dusting with copper dusts during the growing season has given partial, but inadequate, control of purple seed stain in tests conducted at

the North Carolina Agricultural Experiment Station.

Soybean Smut

Soybean smut has been found only in several locations in Missouri. The fungus *Melanopsichium missouriense* Whitehead & Thirum causes pods and seeds to be transformed into small, dark brownish-black galls resembling pieces of charcoal (fig. 11, B). From one to three galls per thousand seeds have been found in seed lots. The galls contain many minute spores that allow the fungus to overwinter and infect plants the following summer.

Very little information is available on soybean smut. Seed containing galls should not be planted. Removal of galls by hand sorting seed is of little value because many spores sift through the cracked surfaces of galls and contaminate seed.

Pod and Stem Blight

Pod and stem blight, caused by the fungus *Diaporthe phaseolorum* (Cke. & Ell.) Sacc. var. *sojae* (Lehman) Wehm., is chiefly a disease of the pods and stems of plants nearing maturity. The fungus penetrates the pod walls and grows on the seed coats. It is usually not present on seed in sufficient quantity to be observed; but if plants are weakened by other diseases or unfavorable environmental conditions, the fungus can completely cover some seed, causing the seed coats to appear white. Such severely diseased seed is usually weak before invasion of the fungus and does not germinate after infection.

The disease can be identified by the numerous, small, black fruiting bodies called pycnidia that appear on the pods and stems of infected plants. The pycnidia are scattered on the pods, but they are usually arranged in linear

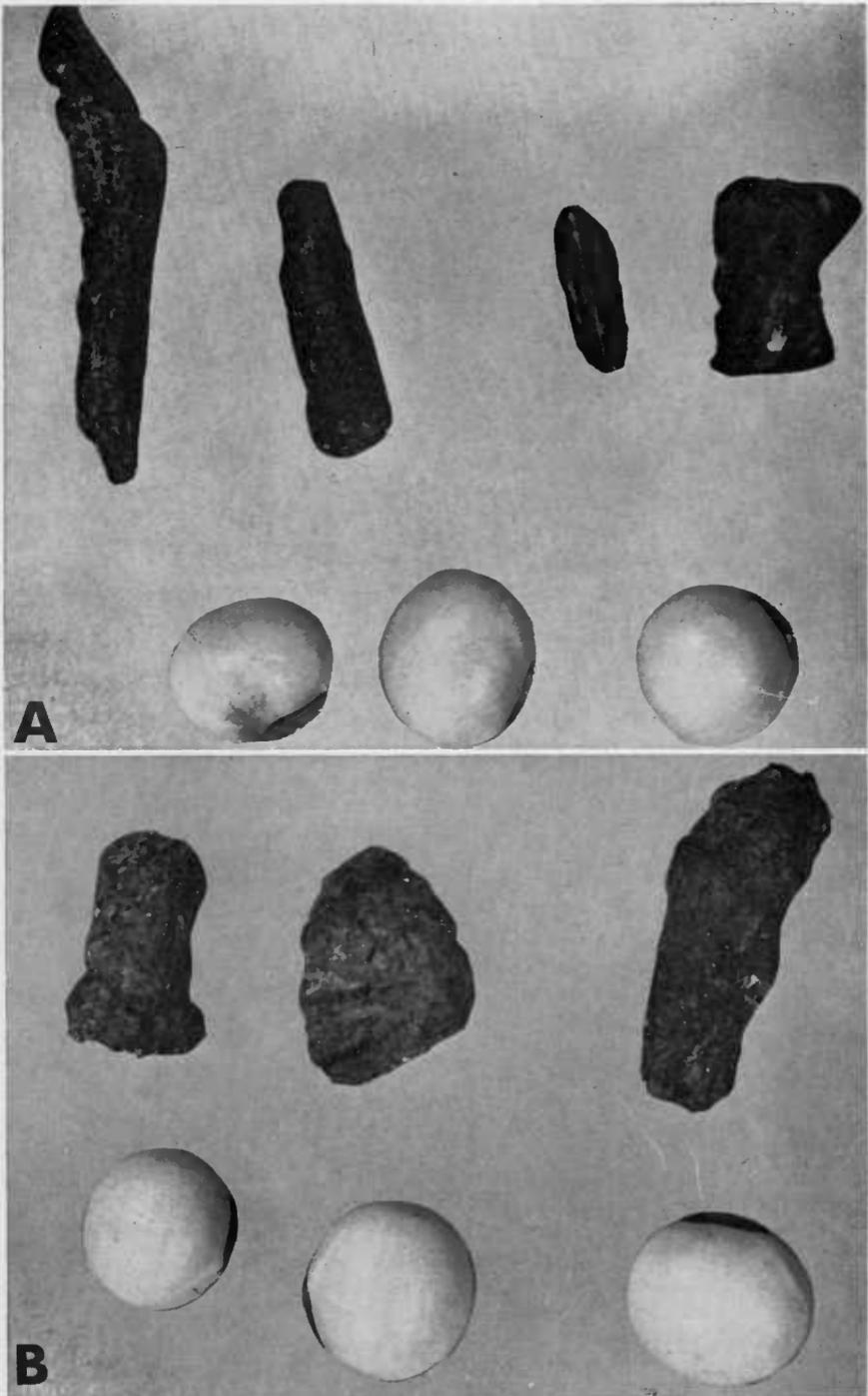


FIGURE 11. — *A*, Black sclerotia (top) produced by stem rot fungus compared to soybeans (bottom); *B*, dark-brown smut galls (top) produced by soybean smut fungus compared to soybeans (bottom).

rows on stems. Pod and stem blight fungus is well distributed over the soybean-growing areas of the United States.

High humidity and rain favor the formation and spread of spores from pycnidia. The disease is seedborne, and the fungus can also overwinter on diseased stems in fields. Because the fungus is widespread on other crop plants, crop rotation is probably of little value. Canadian workers found that seed treatment greatly increased germination rates in seed affected by pod and stem blight, although the treatment did not completely control the disease.

Yeast Spot

Yeast spot is caused by one of the yeast fungi *Nematospora coryli* Pegl. The spores of the

fungus are carried on the mouth parts of the green stink bug and are forced into the developing seeds during the feeding activity of this insect. Seeds infected early may not mature or they may remain small and shriveled. On the developing seeds the infected tissue is slightly depressed and varies from yellowish or light cream to brown. There may be little or a considerable volume of dead tissue extending well into the infected seeds. Externally, pods usually show small, pinpoint, discolored areas. Seed shriveling caused by stink bug injury and yeast spot can frequently be differentiated from shriveling caused by soybean wilt and other diseases by locating the small discolored puncture wounds on seeds.

The disease has been reported only from the South.

VIRUS DISEASES

Viruses are minute, submicroscopic particles that enter plants through leaf wounds or are injected by insects or nematodes feeding on internal tissues. Virus particles multiply within the host plant and produce disease symptoms. Many different types of viruses can infect soybeans; however, only three are found frequently.

Soybean Mosaic

Soybean mosaic occurs to a limited extent in all soybean-producing areas of the United States. Virus-infected plants are stunted and leaves are narrower and deeper green than normal. Leaf margins are turned down and blades are severely ruffled along the edge of the main veins (fig. 12, *A* and *B*); however leaf distortion may disappear in some varieties with the onset of high summer temperatures. Infected plants produce distorted pods and fewer seeds than normal plants.

Varieties differ widely in their range of susceptibility to soybean mosaic. In general, commercial soybean varieties are less susceptible than vegetable varieties, but no immune varieties are known.

Soybean mosaic virus can be transmitted in 100 percent of the seed of very susceptible varieties, but the percentage is much lower in most improved varieties. Diseased plants should be rogued from fields where soybeans are grown for seed production. Seeds from infected plants occasionally show mottling and should never be saved for planting. Several species of aphids spread the virus from plant to plant in the field.

Leaf symptoms resembling soybean mosaic are frequently caused by 2,4-D (fig. 12, *D* and *E*) and related herbicides.

Bud Blight

Bud blight, caused by the tobacco ringspot virus, occurs mainly throughout the Midwes-

tern States and in southern Canada; however, it has been found in most soybean-producing areas. In recent years, most severe outbreaks have occurred in Indiana where the disease was first reported. Many strains of the virus exist and some cause only

severely dwarfed, barren plants. Symptoms of bud blight vary with the stage of development at which plants become infected. When plants are infected before flowering, the stem tip bud turns brown, curves downward markedly, and becomes dry and brittle

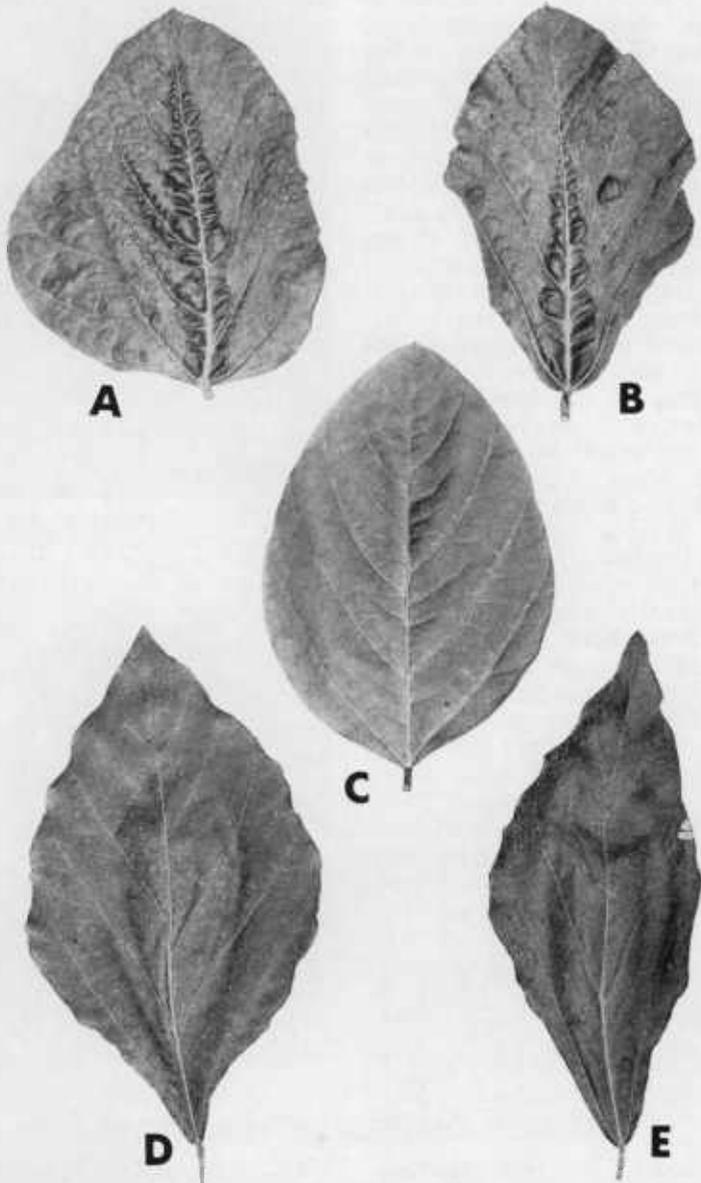


FIGURE 12.— Soybean leaflets showing: A and B. Mosaic symptoms; C, normal leaflet; D and E, injury caused by 2,4-D.

(fig. 13). The youngest leaf often develops a rusty flecking. The plant is dwarfed and produces virtually no seed. Sometimes the inside of the stem below the blighted terminal bud is discolored, most often at the nodes. When infected during flowering, plants produce mainly small undeveloped pods. Infection after flowering results in poorly filled pods that have a conspicuous dark blotching. Many of these pods fall to the ground. Infected plants usually remain green after normal plants have matured, and thus are easily found in the fall.

If plants are infected before flowering, the virus is transmitted to seed; but if plants are infected after flowering, the virus is not transmitted to seed. Bud blight is without question the most severe virus disease of soybeans. Fields have been a complete loss when bud blight infection occurred in the early stage of development of the soybean plants.

The disease usually appears first at the border of a field and progresses inward. This suggests an insect carrier of the virus, but none has been found. There is recent evidence that tobacco ringspot virus is soilborne and that a low percentage of plants may be infected when grown in virus-contaminated soil. Some soybean varieties appear resistant to the disease but additional research is required. There is no effective control for bud blight.

Yellow Mosaic

Yellow mosaic of soybeans is caused by *Phaseolus virus* 2, the same virus that causes yellow mosaic of garden beans. The



FIGURE 13. — Curved stem tip of young soybean plant infected with virus that causes bud blight.

younger leaves of infected plants show a yellow mottling, or sometimes an indefinite yellow band along the major veins. Rusty necrotic spots develop in the yellow areas as the leaves mature. Infected plants are not noticeably stunted.

The virus is not seedborne and does not reduce yields severely. The disease is widely distributed in the Midwest. It is unusual to find more than 1 percent of the plants infected in a field; however, fields with more than 75-percent infection have been observed in Iowa.

DISEASES CAUSED BY NEMATODES

Nematodes are tiny animals, generally eellike, but the adult female of certain kinds are swollen,

being pear or lemon shaped. The larger forms are barely visible without magnification.

Nematodes of soybeans persist from season to season in soil and are distributed by movement of soil from one field to another. The type and severity of symptoms resulting from nematode injury are influenced by many factors, the size of the nematode population at planting time being an important one. If the population is high, severe injury is more likely to occur than if the population is low. The distribution of nematodes throughout a field is almost always variable; hence, plants in some areas of the field may show nematode damage while plants in other areas appear normal.

Root-Knot Nematode

Root knot is caused by nematodes of the genus *Meloidogyne*. All species of this genus known to occur in the United States are parasitic on soybeans. The most common species is probably *M. incognita incognita* (Kofoid & White, 1919) Chitwood, 1949.

The most characteristic symptom of root knot is the root galls. These are roughly spherical or elongate and may vary from slight root swellings to galls as large as 2 inches in diameter. The roots are almost club shaped when infection is severe. Root galls caused by the species *M. hapla* Chitwood, 1949 remain relatively small, and clusters of short roots often emerge just above the galls and partly cover them. Soybean roots severely infected by this species are often densely matted as a result of extensive root growth above the galls.

Symptoms on aboveground parts of affected plants are a variation in color from light green to yellow and a marginal firing of the leaves. All degrees of stunting may occur. Plants with galled roots wilt before normal plants during dry weather and

may die a week or more before the normal date of maturity. Yields of seed are sometimes greatly reduced by root knot. Most varieties of soybean appear to be fairly tolerant of infection by the root-knot nematodes; consequently, the condition of aboveground plant parts is not always a good indication of the extent of disease on the roots. Plants having a liberal supply of soil nutrients and water may show little or no aboveground symptoms, even though roots are heavily galled.

The nematodes survive the winter as eggs, especially in cold areas. In the spring the eggs hatch and larvae enter the root tips. The nematodes migrate through the roots and take permanent positions in cortical tissue adjacent to the vascular cylinder and begin feeding on cells that become special nurse cells. Adjacent cells are stimulated to greatly increased growth. Thus, knotlike swellings, commonly called galls, appear in the roots (fig. 14). Nematode galls cannot be removed without breaking the root and can be distinguished by this test from the beneficial, nitrogen-fixing nodules that are weakly attached to the root and are easily broken away (fig. 15, B).

Female nematodes in a favorable host produce large numbers of eggs from which larvae develop and migrate to new positions in the root, thus producing more or bigger galls. This life cycle may be repeated about every 30 days in roots growing in warm soil, thus rapidly increasing the nematode population and causing malformation of roots of susceptible varieties.

Control of root knot on soybeans is best obtained through the use of resistant varieties. Hill, Hardee, Jackson, and Bragg, varieties adapted for the southern soybean-growing areas, have

fairly good resistance to *M. incognita incognita*. Delmar, adapted for growing in Delaware and Maryland, is also resistant to this species. Resistant varieties are occasionally found to be suscepti-

ble, probably because of the existence of different strains of the nematodes. When resistant varieties adapted for a given location are not available, root knot can be controlled by reducing the nema-



FIGURE 14. — Nematode galls (root knot) on soybean roots.

tode population through use of rotation with immune or highly resistant crops, such as corn (in the case of *M. hapla*) or oats and certain grasses (in the case of other species).

Soybean Cyst Nematode

The soybean cyst nematode, *Heterodera glycines* Ichinohe, 1952, was discovered in the United States in 1954 near Wilmington, N. C., and since then has been found in Virginia and in Mississippi River Delta areas of Arkansas, Illinois, Kentucky, Mississippi, Missouri, and Tennessee. Fields infested with this nematode have been placed under quarantine.

Symptoms of the soybean cyst nematode disease vary, depending on the size of the nematode population, soil type and fertility, and weather conditions. Soybean plants growing in severely infested sandy soil start to turn yellow about 1 month after seedling

emergence, remain severely stunted throughout the growing season, and yield virtually no soybeans. Infested soybean fields may have yellow, stunted plants in roughly circular areas ranging from a few feet to 50 or more feet in diameter; however, in some locations this yellowing symptom is absent. Symptoms on plants growing in infested fields with heavier soil types generally are not so severe as those that develop on plants growing in lighter soils. Soybean roots heavily infected with cyst nematodes are characteristically dark and often lack nitrogen-fixing nodules (fig. 15, *A* and *B*).

Life cycles of the soybean cyst and root-knot nematodes are similar in many respects; however, many eggs of the cyst nematode remain within the swollen lemon-shaped body of the female, which acts as a protective envelope for the eggs. After hatching within the cyst, larvae emerge and seek

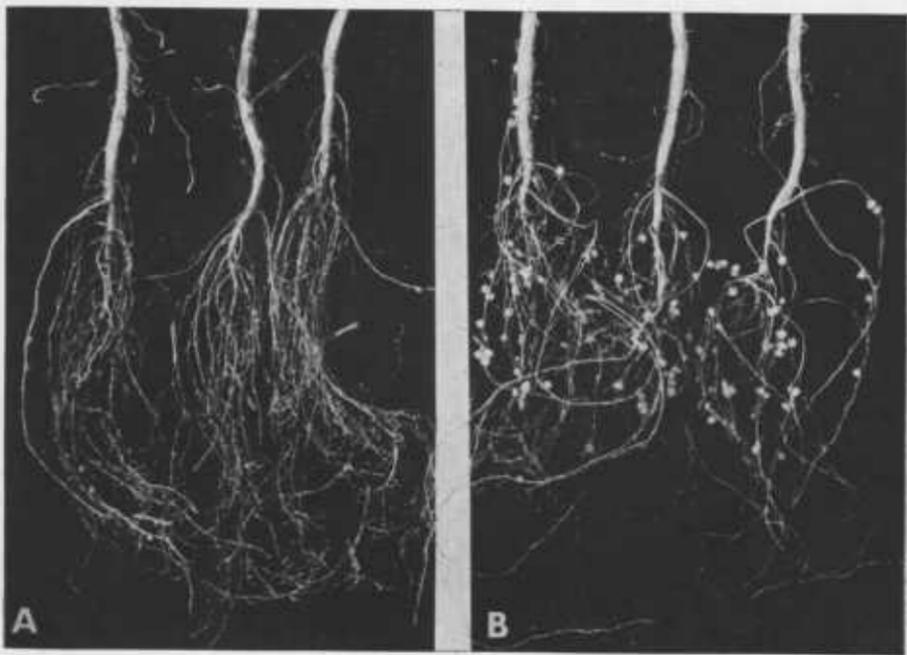


FIGURE 15. — *A*, Soybean cyst nematode infested soybean roots; *B*, healthy roots bearing numerous beneficial nodules.

out soybean roots; after invasion and migration they take up a feeding position. Subsequently the female develops a lemon-shaped body that is attached to the root and can be seen upon close observation (fig. 16). These females develop into cysts. The time required for a complete life cycle is approximately 3 weeks at a soil temperature of 75° F. Soil temperatures above 90° tend to suppress development of the larvae.

All soybean varieties currently grown in the United States are susceptible to the soybean cyst nematode; however, resistant soybean lines have been found, and breeding programs are in progress to transfer resistance to commercially adapted varieties.

Control of the soybean cyst nematode at present (1965) is limited to crop rotation with non-susceptible crops. Soybean, common bean, three kinds of lespedeza (annual, common, and sericea), common and hairy vetch, mung bean, adzuki bean, and white lupine are crops known to be susceptible to the cyst nematode. Hemp sesbania (*Sesbania exal-*

tata (Raf.) Cory) and henbit deadnettle (*Lamium amplexicaule* L.) are weed hosts. In crop rotation experiments for cyst nematode control in North Carolina, 3- to 4-year rotations were necessary to obtain normal soybean yields; in Tennessee, however, normal soybean yields were obtained when soybeans were grown in a 2-year rotation with cotton.

Soil fumigation controls the cyst nematode, but this method of control is not economically feasible at present.

Sting Nematode

The sting nematode, *Belonolaimus longicaudatus* Rau, 1958, is one of the most devastating nematodes that attack soybeans. Soybeans injured by this nematode have failed to grow beyond the seedling stage. The sting nematode is generally limited to sandy soils of the southeastern and southern Coastal Plain.

Aboveground signs of sting nematode damage on soybeans are stunting and dull, light-green foliage. Seedlings often wilt during hot weather and eventually die.

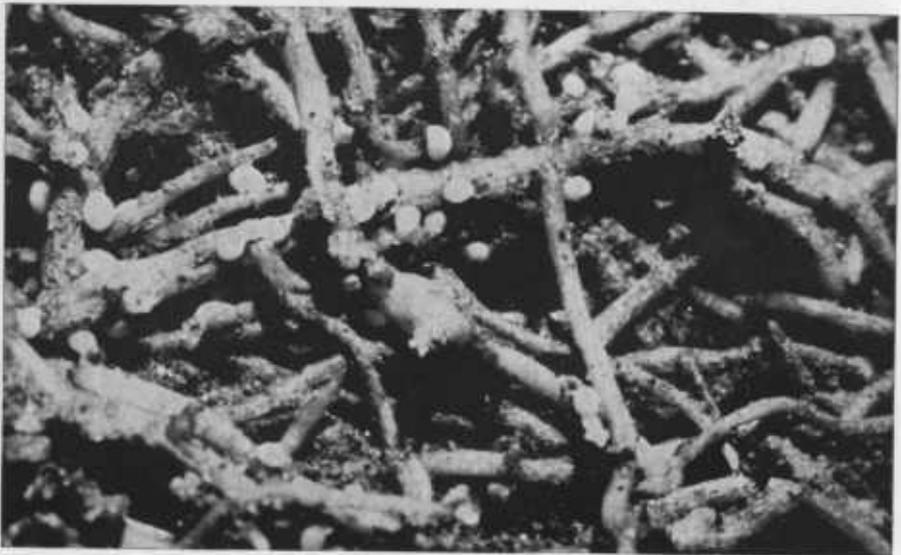


FIGURE 16. — Lemon-shaped encysted female nematodes attached to soybean roots.

The root abnormalities are apparently caused by inhibition of root-tip elongation and result in stubby clusters of coarse, short roots (fig. 17). Frequently a branch root will attain considerable length but will develop few if any side rootlets. Roots of affected plants at first have small, distinct lesions; later, the roots darken. When affected plants are dug, soil tends to cling to the roots and is difficult to remove without washing.

The sting nematode is one of the larger plant-parasitic nematodes and may attain a length of one-eighth inch. For the most part the nematode feeds in the root-tip region and along the sides of young roots without penetrating or becoming attached.

Control of this nematode by crop rotation is difficult because of the large number of plant species that serve as hosts. Tobacco and watermelon have shown good resistance.

Control by soil fumigation with 1,2-dibromo-3-chloropropane is very effective, and population buildup of nematodes surviving fumigation is slow. However, this method of control is not economically feasible at present.

Other Nematodes

In addition to those mentioned in detail in this section, numerous other nematodes parasitize soybean roots. Populations of pin (*Paratylenchus*), spiral (*Helicotylenchus*), stunt (*Tylenchorhynchus*), and root-lesion (*Pratylenchus*) nematodes increased in soybean fields in Illinois; and stubby root (*Trichodorus*), lance (*Hoplolaimus*), and ring (*Criconemoides*) nematodes have been associated with plant injury in the South. Although little is known of the extent of damage caused by these nematodes to soybeans, undoubtedly some reduce yields significantly.



FIGURE 17.— Roots of soybean seedling severely injured by sting nematodes.

Relation of Nematode Injury to Other Diseases

Nematode injury often places plants under a stress and thereby increases susceptibility of the plant to diseases caused by other plant pathogens. Work carried out in greenhouses in Minnesota indicates that damping-off of soybeans caused by *Rhizoctonia solani* is greatly increased by root-knot nematodes, *Meloidogyne javanica javanica* (Traub, 1885) Chitwood, 1949 or *M. hapla*.

In North Carolina susceptibility of soybeans to fusarium wilt was greatly increased when plants grew in soil infested by soybean cyst nematodes and the wilt *Fusarium* species of fungus. Plants growing in plots treated with a nematocide remained free of the wilt, whereas large numbers of plants of the variety Jackson died in plots that received no nematocide application.

Although the relation of parasitic nematodes to other diseases of soybeans has only recently been recognized, research investiga-

tions in the future will probably reveal that the intensity of certain other soybean diseases is increased by nematode injury.

NUTRITIONAL DISEASES

Chlorosis of soybean leaves may be caused by a deficiency of nutrients, as well as by parasitic microorganisms. It is important to recognize these nutritional diseases because they are much more easily corrected than diseases caused by parasites. Potassium, nitrogen, and phosphorus are the elements most frequently deficient in agricultural soils. Application of commercial fertilizer remedies shortages of any of these elements. Acid soils frequently require calcium for good soybean growth. Application of agricultural lime corrects this deficiency. The soil test is an effective tool for determining whether soil acidity, phosphorus, or potassium might be limiting production. Iron, manganese, molybdenum, boron, zinc, and copper are required for soybean growth but only in minute quantities and are called microelements. The microelements are usually present in adequate quantities to permit satisfactory crop production, but soils sometimes lack one or more of these elements and soybeans grown on such soils develop characteristic symptoms.

Potassium Deficiency

Chlorosis and firing of soybean leaves caused by insufficient potassium occur rather frequently. The first indication of this deficiency is an irregular yellow mottling around the edges of the leaflets. The chlorotic areas soon merge to form a continuous yellow border. This is followed by marginal browning that may

spread to include half or more of the area of the leaflet (pl. 8, A). Only the center and base of the leaflet may remain green when deficiency is severe. The dead tissue usually falls out, giving the leaflets a ragged appearance. Old leaves also show symptoms. This distinguishes the disease from iron and manganese deficiency in which the symptoms first occur on the youngest leaflets as they are unfolding. Potash deficiency is most commonly observed on sandy soils or on sandy ridges of fields.

Nitrogen Deficiency

Nitrogen deficiency is indicated by a gradual paling of the green color over the entire leaf blade, with only a slight yellowish tinge. The symptom is most commonly the result of the absence of *Rhizobium japonicum* (Kirch.) Buch., the bacterium that causes root nodulation and that fixes atmospheric nitrogen for plant use. If soils are low in nitrogen and the nodule-forming bacteria are not present, nitrogen deficiency will result. Because of poor bacterial development in highly acid soils, nodules on soybean roots are usually few or entirely absent. Application of lime reduces soil acidity and promotes better nodulation, thus correcting nitrogen deficiency in acid soils low in nitrogen.

Formerly, nitrogen-deficiency symptoms were seen frequently when noninoculated soybean seed was sown. They are rarely seen now because the soybean root-nodule bacteria are present in

most of the soils in the major producing areas. Seed should be inoculated whenever soybeans are grown in fields where they have not been grown previously.

Soybeans parasitized by soybean cyst nematodes or affected by fusarium root rot frequently have very few nodules on their roots. If such plants are grown in soil low in nitrogen, nitrogen-deficiency symptoms will be evident. Nitrogen deficiency should not be confused with *Rhizobium*-induced chlorosis. (See p. 3.)

Iron Deficiency

Iron deficiency is indicated by a general yellowing or chlorosis of the new growth of soybean plants (pl. 8, B). The veins of the affected leaves, however, remain green. In the most severe cases, the leaves show many brown spots of dead tissue that are more numerous near the leaf margin. Ultimately the dead tissue drops out, leaving only the leaf veins. Plant growth is depressed in proportion to the severity of the deficiency. The deficiency is observed most commonly on soils high in lime where it has reduced yields as much as 37 percent.

Manganese Deficiency

Manganese-deficient soybean plants have a light-green to white mottling between leaf veins. The degree of leaf discoloration is proportional to the severity of the deficiency. Symptoms range from pale-green leaves with slight defi-

ciency to white with severe deficiency. The veins remain green until chlorosis nears the white stage, at which time the veins become yellow and the leaves fall from the plant. If moisture is excessive, the leaves frequently are covered with many small brown spots. The deficiency seldom affects entire fields and usually develops in an irregular pattern.

Manganese deficiency occurs in only a few soils. It has been observed most frequently on dark, poorly drained soils limed to near the neutral level in northwestern Indiana, in the old lakebed area of Indiana and Ohio, and in the high lime soils of the Coastal Plain in the Southeastern United States. Manganese deficiency has reduced yields as much as 75 percent.

Molybdenum Deficiency

Soils deficient in molybdenum are rare in the United States. The chief symptom of molybdenum deficiency in soybean plants is a slight depression in growth. Yields increased substantially when molybdenum was applied to the soil in Georgia, Mississippi, and Wisconsin. Yields also increased in Indiana and Missouri after this microelement was applied. Only very small quantities of molybdenum are required to correct deficiencies. Great care should be used in applying molybdenum to soil, because if it is added in excessive amounts, plants may accumulate levels that are toxic to animals.

MISCELLANEOUS CAUSES OF DAMAGE

Plant damage from causes other than disease is frequently confused with symptoms of diseases caused by bacteria, fungi, viruses, nematodes, or nutritional defi-

ciencies. The following kinds of soybean injury are those most frequently confused with disease symptoms.

Herbicide Injury

Indiscriminate use of 2,4-D frequently damages soybeans. Spraying activities on windy days can result in injury to plants several hundred feet away. Severely affected plants develop malformed leaves that are tightly puckered and narrow. Terminal leaves are most severely malformed. Small, round, raised, light-colored areas develop along the stems. In most cases, however, injury is not so severe and leaves merely become elongated with ruffled margins (fig. 12, *D* and *E*). This type of injury is temporary and foliage subsequently developed appears normal.

Soybeans injured by 2,4-D look very much like soybeans infected by soybean mosaic virus (fig. 12, *A* and *B*). The herbicide spray usually affects all soybean plants in the area of the field. In areas affected with soybean mosaic, healthy and diseased plants usually grow interspersed. Many broadleaf weeds in a 2,4-D-affected area show the same type of symptoms as soybeans, whereas with soybean mosaic, weeds are unaffected.

Herbicides, such as atrazine, diuron, and simazine, sometimes remain active in soil and cause yellowing of soybean plants the year after application. Plants begin to show the yellowing soon after emergence. If there is considerable herbicide residue, the plants will also be dwarfed and eventually killed. Soybeans that are yellow but only slightly stunted usually make a slow recovery as the roots reach deeper, less contaminated soil. The amount of residue depends on many factors. Although use of a field treated the previous year will not necessarily result in injury to soybeans, the practice should be avoided if possible.

Arsenic Injury

Soybean leaves are very sensitive to chemicals containing arsenic. This type of damage results in a brown leaf spot with concentric rings. Arsenic injury has become rare with use of improved insecticides in preference to calcium arsenate.

Root Damage and Drought

After any type of root damage to soybean plants, even a slight drought can be serious. In addition to causes already discussed, cultivation injury, excessive fertilizer, and herbicide residue can cause root damage. Under normal conditions the impaired root systems may go unnoticed, but root damage, coupled with water stress, can result in severe drought damage to aerial parts of the plants. At first, leaves become flaccid during the heat of the day and lower leaves become yellow and fall. If soil moisture is not replenished, wilting becomes more severe and the remaining lower leaves turn brown and dry from the margin inward. These leaves eventually die but will not fall. Affected plants are considerably smaller than those with healthy roots in surrounding fields enduring the same drought.

Lightning Injury

Lightning injury to young soybean plants is usually indicated by sudden death of young plants in circular areas as large as 50 feet in diameter. When plants have reached their maximum heights, affected areas are usually much smaller. In an area affected by lightning injury, both weeds and soybean plants are killed. The clearly defined margins of the areas and absence of any signs of a parasite usually enable one to distinguish lightning injury from diseases caused by parasites.

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