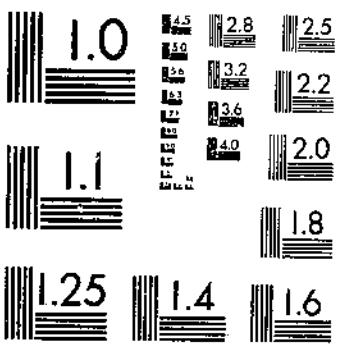
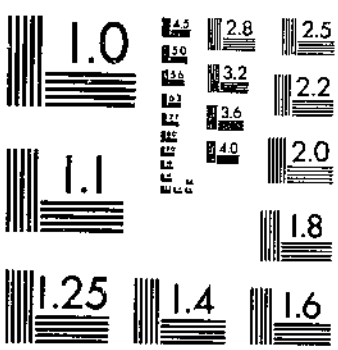
START



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

R630
U53-1

Technical Bulletin No. 1084 • October 1953

1084

DEPOSITORY

REFERENCE
DO NOT LOAN

MAR 1 1954
Los Angeles Public Library

UNITED STATES
DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

Pythium Root Rot of Barley and Wheat[1]

By G. W. Bruehl, *associate pathologist, Field Crops Research Branch, Agricultural Research Service*

Contents

	Page		Page
Introduction	1	Varietal reaction to pythium root rot	18
Symptoms	2	Discussion and summary	22
The causal organism	7	Literature cited	23
Environmental relationships	10		
Field experiments in the root rot nursery	10		
Greenhouse experiments	11		

INTRODUCTION

The root and crown rots have long constituted a major hazard to profitable production of cereal crops in the hard red spring wheat area. Pythium root rot, caused by *Pythium arrhenomanes* Drechs. and related species, contributes substantially to this toll. Barley and wheat in the Great Plains are particularly damaged by these parasites. Vanterpool and coworkers (*31, 32, 33, 34, 35, 37*) [2] described a pythium root rot of wheat and other grasses in the Prairie Provinces of Canada, made an exhaustive study of the species associated with the trouble, and investigated certain major environmental relationships. Vanterpool stressed the importance of host nutrition and achieved practical control mainly through use of phosphatic fertilizers. The occurrence of pythium root rot of barley was studied in Iowa (*13*).

The economic importance of this disease is not yet fully determined. The efforts of Vanterpool in Saskatchewan, Sprague (*26*) in North Dakota and adjoining States, Buchholtz (*2*) in South Dakota, and Ho and coworkers (*13*) in Iowa established the near ubiquity of these pythiaceous parasites in the northern Prairie and Plains soils. The encouragement afforded by the success of control measures used in Canada and the widespread distribution of this disease in the affected areas of the United States combined to stimulate the present investigation.

[1] Submitted for publication May 22, 1953. Cooperative investigations of the Division of Cereal Crops and Diseases and Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, United States Department of Agriculture, and the Plant Pathology Department of the South Dakota Agricultural Experiment Station.

[2] Italic numbers in parentheses refer to Literature Cited, p. 23.

262017—53——1

FIGURE 1.—Alfalfa (left) thrives on the root rot soil where several forage grasses show little growth.

A severe root rot section in south-central South Dakota was selected for control experiments.[3] The condition was tentatively diagnosed as pythium root rot associated with a soil low in organic matter and available nitrogen. Alfalfa and sweetclover grow well on this soil and corn and sorghum are moderately successful, but small grains frequently fail to produce profitable yields (*fig. 1*). Because of its problem soil, tentatively identified as Huggins sandy clay, this section was considered useful as a location from which knowledge for wider application might be obtained. The following logic of Mangelsdorf (*15 p. 228*) seemed pertinent.

> . . . . growth-failure areas are of special interest as subjects for research because they may represent in an exaggerated form the effects of depressing factors which are active in milder degree over large areas and which, in their milder manifestations, may elude analysis.

This section is referred to throughout this bulletin as the root rot nursery.

SYMPTOMS

Pythium root rot of cereals is an insidious disease that is active throughout the life of the plant. It reduces vigor and yield but seldom kills plants outright. It does not cause seedling blight or seed rot in the field except under rare circumstances. The disease is characterized by an increasingly apparent lack of vigor as the plant develops, with a reduction in tillering, stem elongation, green color, and head size. In addition, the heads on diseased plants of many barley varieties are unable to emerge from the boot (fig. 2). Some highly susceptible varieties of barley, such as Plains, Olli, and

[3] Acknowledgment is made to C. J. Franzke, Agronomy Department, South Dakota Agricultural Experiment Station, for suggesting this section, and to John Pospisil, Colome, S. Dak., for his splendid cooperation and for providing land on which to conduct these experiments.

FIGURE 2.—Plains barley grown in sterile sand with nutrient solution (*A*) and inoculated with an isolate of *Pythium arrhenomanes* (*B*). The pythium root rot reduced the height, tillering, head size, and ability to project the head from the boot.

Atsel, tend to die prematurely under severe attack rather than ripen, whereas certain tolerant varieties, such as Spartan, are delayed in maturity. In general, an appreciable delay in maturity is apparent in barley (fig. 3).

Pythium arrhenomanes is a true root-rotting organism, not attacking crown or basal stem tissues under ordinary field conditions. If a

FIGURE 3.—The disease severity in the root rot nursery is indicated by the poor growth of Feebar barley on untreated soil (foreground), as compared with that on chloropicrin-treated soil (background). Maturity, height, and tillering are retarded.

root trouble is indicated and the crowns are not appreciably damaged, the presence of this disease may be suspected. The *Helminthosporium-Fusarium* spp. complex of common root rot attacks basal stem tissues as well as roots. The isolates of *Rhizoctonia solani* Kuehn of the northern Great Plains and the Prairies are primarily crown rotters. These tissue preferences (fig. 4) are an aid in diagnosis. In greenhouse experiments leaves of inoculated wheat showed a dull-gray cast, while leaves of inoculated barley were generally lighter green than those of comparable healthy plants. Longitudinal chlorotic streaks frequently occurred in the leaves of both wheat and barley and were especially noticeable in the barley tillers.

A review of the literature on pythium root rot reveals marked differences in reports of aboveground symptoms of this disease, indicating that such symptoms are too variable for complete diagnosis. These differences may result from environmental effects or from inherent differences in host materials. Direct loss of stand of barley is reported as a serious phase of the disease in Iowa (*13*), but the majority of observations on corn and small grains stress damage at later growth stages (*1, 14, 23, 29, 35*). Leaf symptoms are variable. Vanterpool (*34*) and his associates in Saskatchewan have used the name "browning root rot" for this disease of wheat and other small grains because of a characteristic browning of the lower leaves in early June. The browning symptom is apparently associated with severe root pruning, together with succulent foliage developed under cool moist conditions followed by leaf desiccation brought on by hot dry weather. The browning symptom has not been observed on

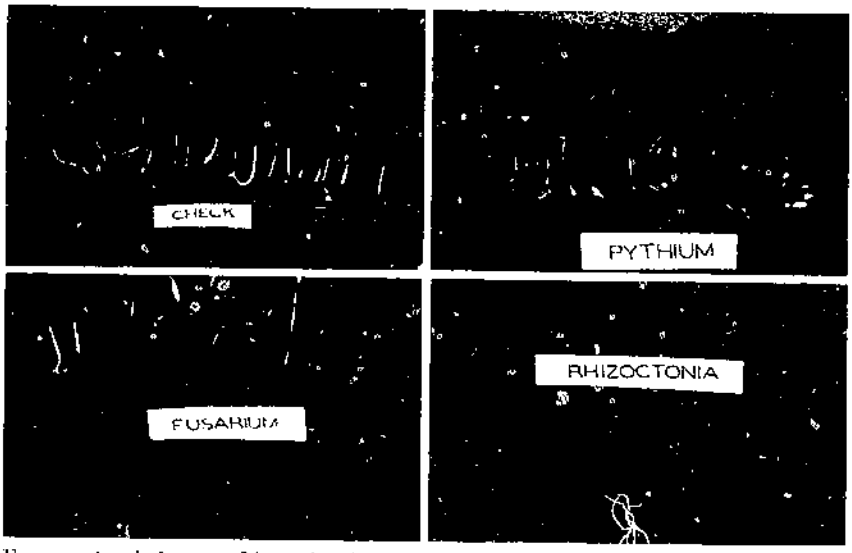


FIGURE 4.—Injury to Marquis wheat seedlings grown in steamed soil inoculated with *Pythium* sp., a *Fusarium* sp., and an isolate of *Rhizoctonia solani*.

range grasses by the writer or by Vanterpool (*34*), and for these grasses the more general name of pythium root rot is preferred. A marked chlorosis of diseased barley was also observed in Iowa (*13*). On both wheat and barley, the shortened culms and general failure to tiller properly were widely observed (*13*, *35*).[1] Delayed maturity is an important effect of this disease in Canada (*35*, *36*). A general lack of vigor may result from various causes other than the disease, including nutrient deficiencies or salt accumulations. Any root decay not associated with an obvious soil defect might be termed root rot.

Observations based on the investigations covered by this bulletin indicate the destruction of rootlets (fig. 5) as the main direct disease loss in barley and wheat. Local necrosis of large roots occurs in rather mild form in this locality and is of interest mainly as an indication of the presence and activity of root-rotting *Pythium* spp. Since the fine rootlets are lost in ordinary excavation, their original abundance in the soil is largely indeterminable. The difficulty of quantitative observation of fine rootlets in soil has led Vanterpool and Truscott (*37*) to stress the lesions on coronal roots (fig. 6).

Wheat appears to develop local necrosis under a wider range of conditions than barley or oats and is a better diagnostic host in the field. Diagnosis in dry soil is difficult because the tissues of healthy roots frequently are collapsed. General collapse of cortical cells and shriveled, dry-appearing roots in moist soil, accompanied by browning of the lower plant axis, suggest the *Helminthosporium–Fusarium* spp. complex of crown and root rot.

The root systems of diseased plants, viewed en masse, vary from nearly clear with only slight yellowing, mainly in the stele, to marked yellow and even brown. Casual examination may indicate that the

[1] GRAEBUS, J. L. STUDIES ON ROOT NECROSIS OF WHEAT CAUSED BY PYTHIUM GRAMINICOLA SUBR. 1913. [Unpublished doctor's thesis. Copy on file Iowa State College Library, Ames, Iowa.]

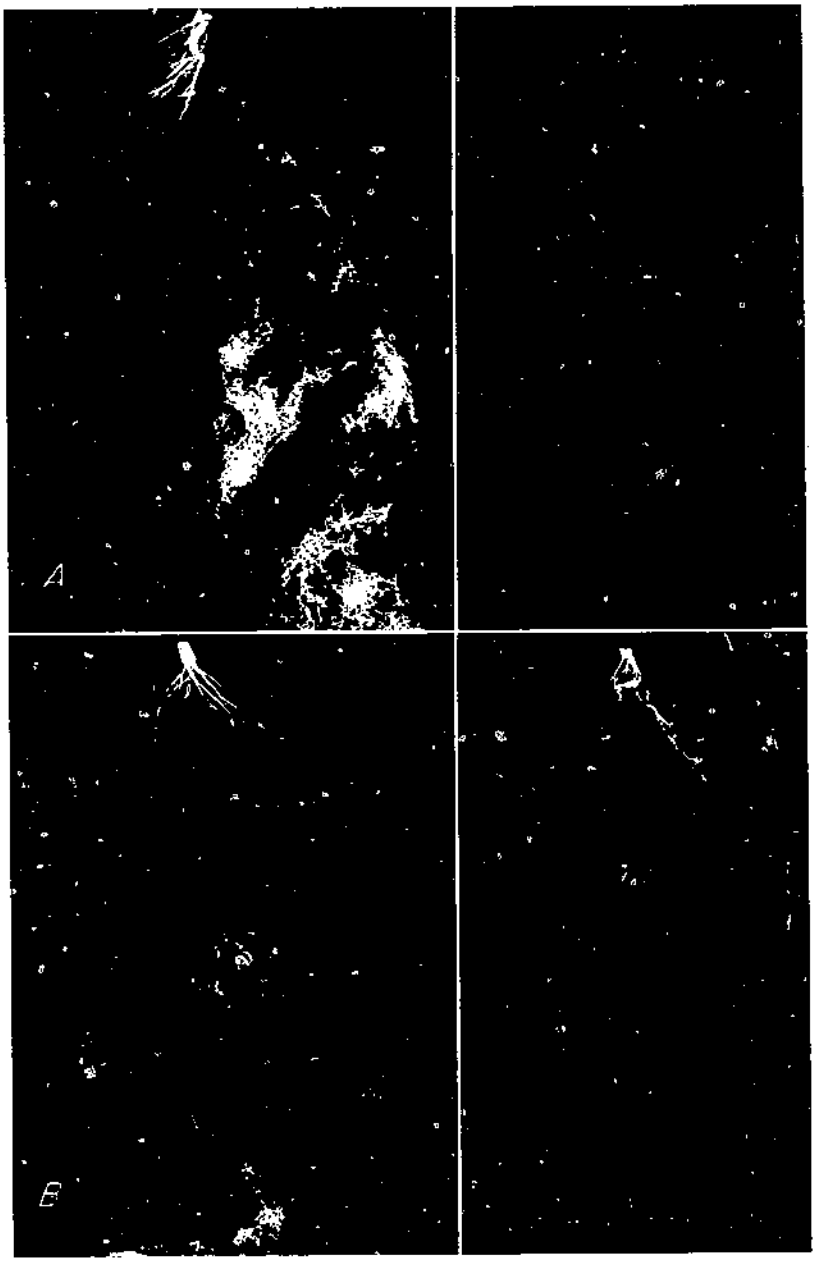


FIGURE 5.—Roots of seedlings of wheat (*A*) and barley (*B*). The diseased seedlings at the right were infected with pythium root rot.

roots are healthy, when a detailed examination reveals local necrotic areas and a general mild discoloration of the stele. Upon clearing of intact rootlets (*28*), oospores may be found sparingly distributed throughout the cortical and stelar tissues of necrotic areas. A general invasion of a mild tissue reaction type with comparatively few

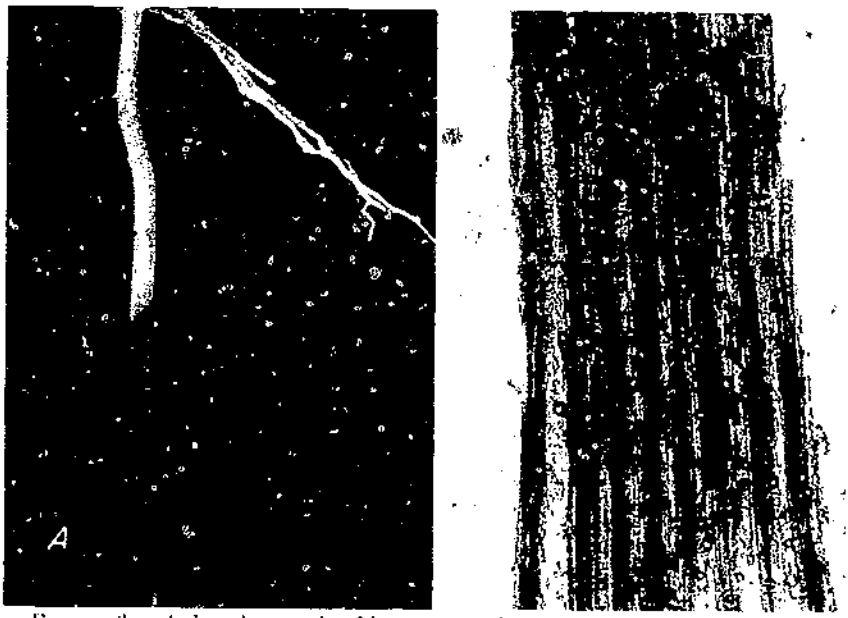


FIGURE 6.—*A*, Local necrosis of large coronal roots caused by pythium root rot (× 5). *B*, Crushed root showing oospores (× 80).

local lesions may largely escape detection in the field. Oospores have been observed consistently in diseased field materials, but their formation has been relatively sparse and sporadic in sand culture (fig. 7). Considerable agreement exists among the descriptions of the effect of pythium root rot on the root system reported by various investigators. The local-lesion type of symptom on wheat and barley has been reported in Canada and Iowa (*13, 32, 35*). Similar symptoms have been reported on corn (*1, 10, 29*) and on sugarcane (*5, 9, 21*), but for these crops the general destruction of fine rootlets usually has been stressed.

THE CAUSAL ORGANISM

Pythium arrhenomanes was isolated consistently from the roots of barley and wheat grown in the root rot nursery soil, and oospores were abundant and universally present. Oogonia formed on Rands and Dopp's medium (*18*)[5] at room temperature were large and typical of the species. Oogonial measurements of 13 isolates gave means of 34.9μ to 37.9μ. Lobulate sporangia occurred in host materials and developed sparingly on 2 percent water agar. Antheridia were crook-necked, numerous (5 to 12, sometimes more, seldom less), and diclinous in origin. An unidentified *Pythium* sp. with spherical sporangia was occasionally isolated from cereal roots grown in this soil, but pathogenicity tests proved it to be nonvirulent. Resting spores of *Olpidium brassicae* (Wor.) Dang. occurred abundantly in roots of both barley and wheat but were not considered of primary importance (*27, 30*). *Fusarium* spp.; *Helminthosporium sativum* Pam., King, & Bakke; and *Rhizoctonia solani* were present but were eliminated from serious consideration on the basis of symptomology and

[5] Humus extract obtained with the aid of Dr. L. O. Fine.

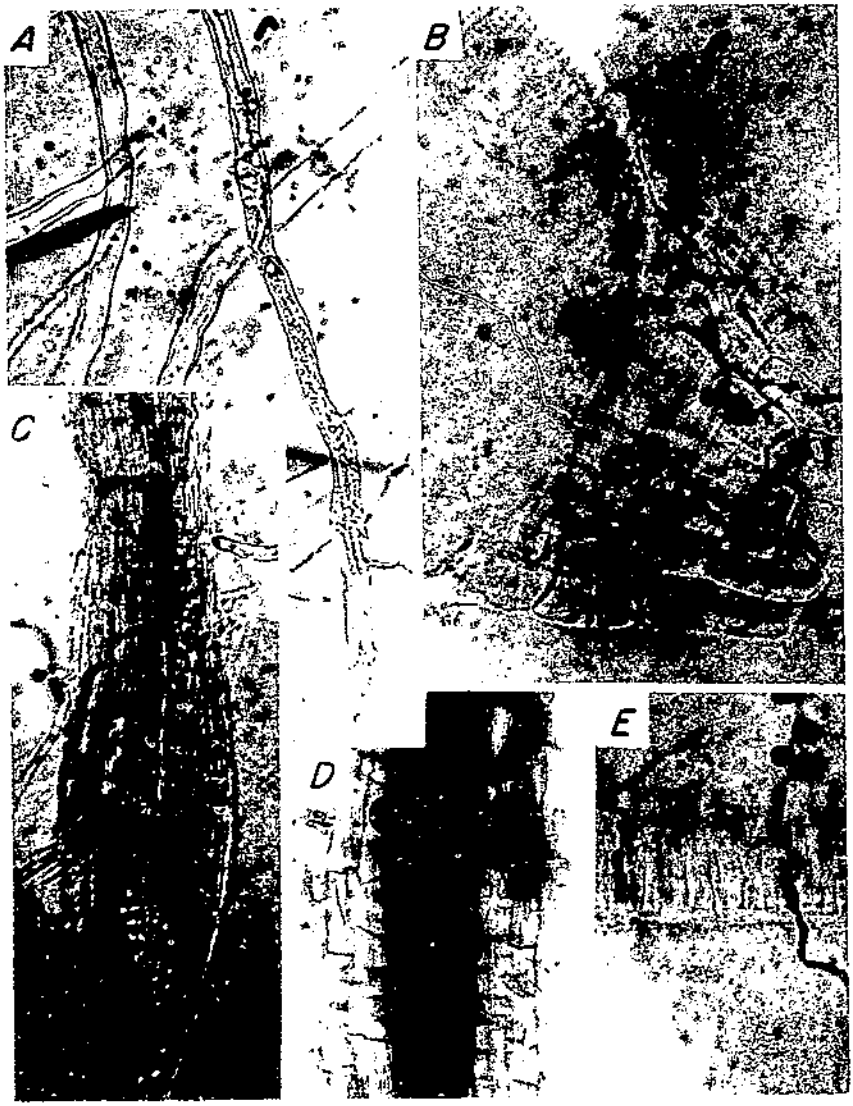


FIGURE 7. Root tissues attacked by *Pythium arrhenomanes*: *A*, Root hair of Mindum durum filled with hyphae (× 181); *B*, root cap of Odessa barley with small sporangium (× 181); *C*, root tip of Mida wheat showing general invasion and collapse behind the tip (× 80); *D*, invasion of Odessa barley far behind the growing point accompanied by little tissue reaction (× 80); *E*, sporangium with exit tube to the "soil" solution, Odessa barley (× 181). *B*, *D*, and *E* stained with acid fuchsine by gentle boiling in lactophenol. Materials from nutrient-sand culture.

limited inoculation trials. Only *P. arrhenomanes* reproduced the field symptoms of this disease closely during the inoculation trials.

Lack of agreement in the nomenclature of *P. arrhenomanes* and allied species makes it difficult to determine the extent and intensity of distribution of this species by consulting the literature. Iowa workers (*13*) consider *P. arrhenomanes* a synonym of *P. graminicolum*

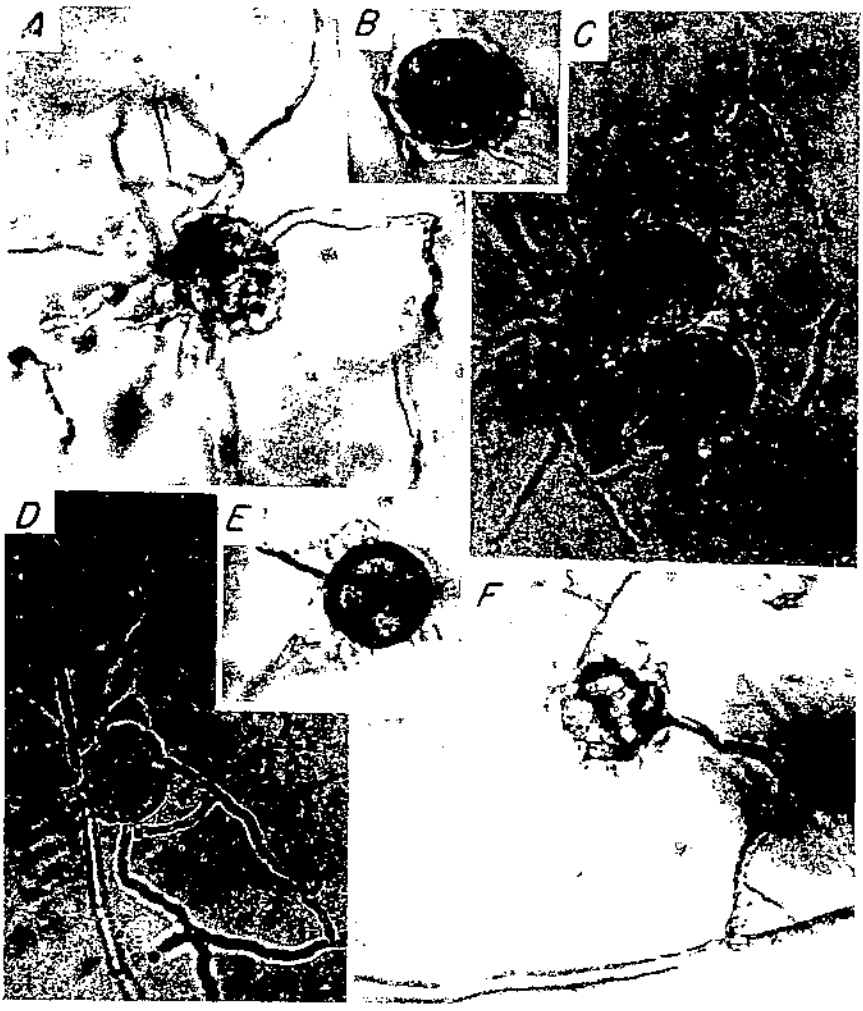


FIGURE 8.—Some morphological features of *Pythium arrhenomanes*. Diffuse origin of antheridia visible in *A*, *C*, *D*, *E*, *F*; large number of antheridia isolated in *A*; *C* branching antheridia in *C*, *D*, *E*; evanescent character of antheridial hyphae in *B*, 3 days past inception of oogonium; and crooknecked character of antheridia in *C*, *E*. The antheridial branches in *D* (nonnutrient agar) have failed to swell and differentiate into true antheridia, whereas those formed on Ranals and Dopp's medium (*A*, *B*, *C*, *E*, *F*) are well-shaped and vigorous. *A*, *B*, *C*, *E*, *F*, ×368; *D*, ×184.

Subramaniam. Sprague (*27*) recently listed *P. arrhenomanes* and *P. ultimum* Vanterpool as synonyms of *P. graminicolum*, although he recognized their differences in morphology. Drechsler (*8*), Rands and Dopp (*19*), Middleton (*17*), Matthews (*16*), and Vanterpool (*31*, *34*) maintain the validity of these species. The author's materials (fig. 8) are clearly isolates of *P. arrhenomanes*, and represent the most common destructive graminicolous *Pythium* sp. of the northern Great Plains (*26*).

ENVIRONMENTAL RELATIONSHIPS

The pathogen *Pythium arrhenomanes* is widespread in the northern Great Plains soils, but severe pythium root rot is local in occurrence and varies in severity from season to season. Variations in environmental conditions appear to be largely responsible for the variable occurrence and severity of this disease. Hawaiian (*5*, *6*) and Canadian (*33*, *34*) workers found low available phosphorus a predisposing factor for pythium root rot. Rands and Dopp (*21*) believed that soil compaction following long cultivation increased root rot, and they investigated the role of organic toxins (*20*) occurring naturally in soils (*24*, *25*) in increasing disease severity. Graham and Greenberg (*12*) found an increase in pythium root rot of wheat with the organic toxin salicylic aldehyde [salicylaldehyde]. Field and greenhouse experiments were conducted to determine the relation of host nutrition and soil toxins to the disease intensity.

Field Experiments in the Root Rot Nursery

Field experiments were conducted in the root rot nursery to determine the extent to which poor growth of barley and wheat could be alleviated by the application of mineral nutrients to the soil. A chemical analysis of the soil suggested that nitrogen carriers might give good responses. The Soils Laboratory of the Agronomy Department, South Dakota Agricultural Experiment Station, reported this soil to be amply supplied with phosphorus and potassium, slightly alkaline, and nonsalty, but low in organic matter and available nitrogen. Successes with phosphatic fertilizers in the control of this pythium root rot in Canada led to their inclusion. In 1948 ammonium phosphate (11–48–0) was applied at seven rates to determine a practical field rate. Small amounts (fig. 9, *A*) gave good returns with barley and wheat. In 1949 (fig. 9, *B*), Odessa barley was treated with ammonium phosphate (11–48–0), treble superphosphate (0–43–0), and ammonium nitrate (33–0–0), each at the rate of 50 pounds of carrier drilled in with the seed. The increases in grain production were 73 percent from ammonium phosphate, 19 percent from treble superphosphate, and 114 percent from ammonium nitrate. Thus, the best responses were from nitrogen.

The behavior of Feebar and Odessa barley in 1949 raised a question as to whether the varieties were affected by nitrogen deficiency, pythium root rot, or both. Ninety pounds of ammonium phosphate (16–20–0) drilled with the seed in 1950 failed to alter varietal standings when sown on April 21 (fig. 9, *C*) or when sown on May 17 on either natural or chloropicrin-treated soil (fig. 9, *D*). The use of phosphorus did not measurably lessen the disease loss, and nitrogen deficiency and root rot were essentially independent in their contribution to reduced grain yields. The yield rankings of the two test barleys were reversed by chloropicrin treatment of the soil (fig. 9, *D*). Allowing for the probable action of the chloropicrin in making more plant food available, root rot seemed to be the chief factor affecting yield.

Field observations have confirmed the value of legumes on this soil, and have indicated that growing them in rotation would increase cereal production in the northern Great Plains, not only by improving the soil itself, but by providing crops that are not hosts to cereal root rots.

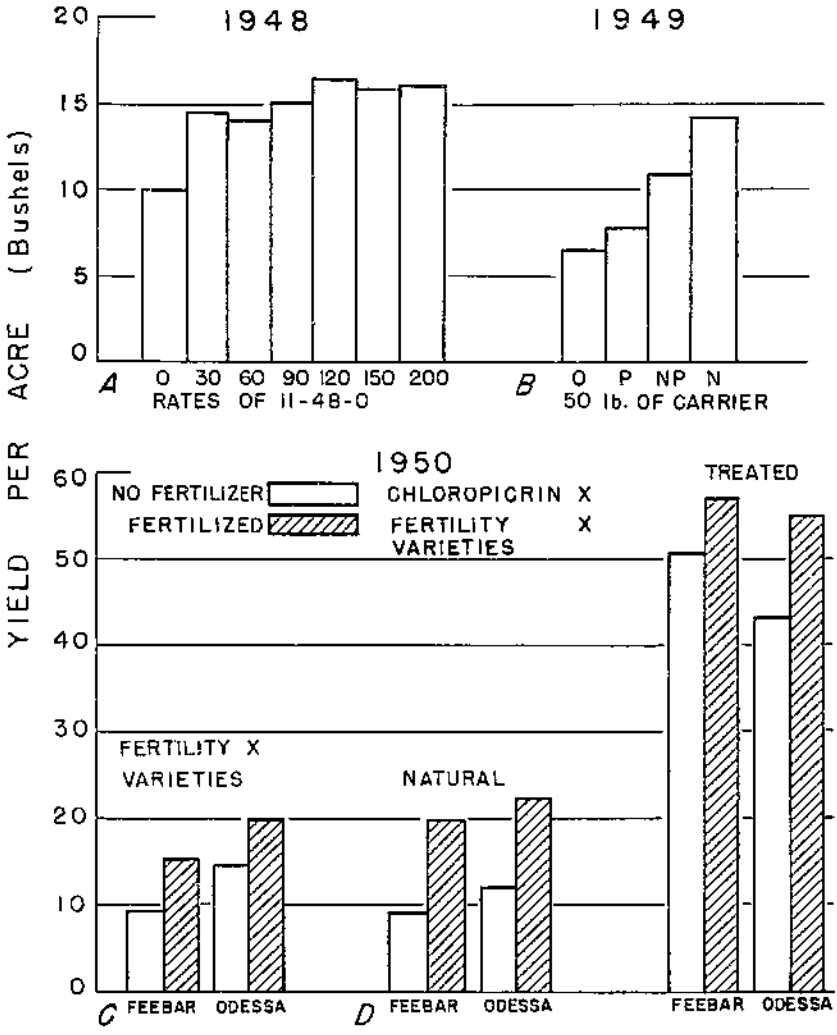


FIGURE 9.—Field experiments on the root rot nursery showed that nitrogen applications gave consistently good returns: *A*, 1948, heavy applications were not necessary for barley and wheat; *B*, 1949, most of the response of barley was from the nitrogen carried by the fertilizer; *C*, 1950, application of ammonium phosphate did not alter barley varietal standings appreciably; *D*, 1950, yield rankings of barley were reversed when grown on chloropicrin-treated soil.

GREENHOUSE EXPERIMENTS

Three greenhouse experiments were conducted with soil from the root rot nursery to further the investigation of the relation of fertilizers to pythium root rot. Weighed amounts per pot of screened soil fresh from the field were used in all tests. Soil steamed for 3 hours at 15 pounds' pressure was used as a disease-free check. A fourth experiment using silica sand, distilled water, nutrient solutions, and a pure culture of *Pythium arrhenomanes* was added for comparison.

EFFECT OF AMMONIUM PHOSPHATE ON WHEAT IN STEAMED AND UNSTEAMED SOIL

Three fertility levels were provided by applying 60 or 120 pounds per acre of 11–48–0 in solution at seed level to the steamed and unsteamed soil, for comparison with the unfertilized check, both steamed and unsteamed. Mindum durum and Mida common wheats were grown, 10 plants per 8-inch pot, with 3 replications. Water was added by estimate to slightly below optimum. Greenhouse temperatures fluctuated about a mean of 70° F. The experiments ran from December 20, 1948, to February 10, 1949. At harvest the plants were divided into 3 parts: Shoots, "crown" or coronal roots, and seminal roots.

Response to fertilizer was greatest on unsteamed, natural soil. Mindum durum showed a marked purplish discoloration near the soil line in unfertilized, unsteamed pots; this discoloration was decreased by fertilizing and eliminated by steaming. Oospores were abundant in the roots from unsteamed soil. Heavy fertilizer applications made the coronal roots noticeably thicker and longer.

Total plant growth (table 1) was increased at all fertility levels by steaming, but the increase was greatest in the unfertilized soil. The response to fertilizer was greatest in unsteamed soil. The seminal root system in steamed soil remained essentially constant but responded markedly to nutrient levels in unsteamed soil. The coronal root system was increased with improved fertility in both steamed and unsteamed soils, and attained a greater size in the unsteamed than in the steamed series. The total root and crown system in steamed soil was constant at all fertility levels, but increased with improved fertility in unsteamed soils. The aboveground parts increased in steamed soil even though the root system remained more or less constant. The increase in shoot growth with improved fertility was greater on unsteamed soil, but a concurrent equal increase in size of the root system kept the shoot/root ratio unchanged. Apparently, the use of fertilizer did not affect the efficiency of the root system in the root rot soil investigated; it merely changed its size. This conclusion was reached also by Vanterpool (*32*).

TABLE 1.—*Effect of nutrient level and soil steaming on the growth of wheat in root rot nursery soil, Dec. 20, 1948, to Feb. 10, 1949*

Plant parts	Dry weight of plant parts at different fertility levels								
	No fertilizer			60 pounds of 11–48–0 per acre			120 pounds of 11–48–0 per acre		
	Unsteamed	Steamed	Ratio: Unsteamed / steamed	Unsteamed	Steamed	Ratio: Unsteamed / steamed	Unsteamed	Steamed	Ratio: Unsteamed / steamed
	Grams	*Grams*	*Percent*	*Grams*	*Grams*	*Percent*	*Grams*	*Grams*	*Percent*
Seminal roots	3. 1	12. 6	0. 25	7. 6	10. 8	0. 71	10. 1	10. 9	0. 93
Coronal roots	. 7	1. 8	. 38	3. 1	3. 0	1. 03	5. 4	3. 5	1. 54
Total roots	3. 8	14. 4	. 26	10. 7	13. 9	. 77	15. 5	14. 4	1. 08
Stems and leaves	3. 2	10. 0	. 32	8. 4	14. 7	. 57	13. 4	16. 9	. 79
Total plants	7. 1	24. 4	. 29	19. 2	28. 5	. 67	28. 9	31. 2	. 93

EFFECT OF NITROGEN LEVEL AND SOIL TOXINS ON THE GROWTH OF BARLEY IN ROOT ROT NURSERY SOIL

The physical condition of the soil at this nursery suggested that it might react similarly to that of the river bottom lands observed by Rands and Dopp (*20*). These workers reasoned that some adverse products of organic decomposition might accumulate to influence the severity of pythium root rot.

In the fall of 1949 Odessa barley was grown in pots, with 6 plants per pot and 3 replications. All pots received only tapwater the first week. Then 2 concentrations of ammonium nitrate (33–0–0) were added in solution equivalent to applications of 50 and 100 pounds of carrier per acre. Two concentrations of the toxin, salicylaldehyde from bisulfite compound [6] (50 and 100 p. p. m., respectively), were added to the water at each watering. The check series received only tapwater throughout.

The plants free of root rot (steamed-soil series) were greener and more vigorous than those in the unsteamed soil. Nitrogen greatly increased the growth of barley on this soil, both steamed and unsteamed, without appreciably affecting the disease (table 2). The heavy toxin application (100 p. p. m.) prevented tillering in steamed soil. No tillers formed in the unsteamed soil until nitrogen was added. Biologic activity did not destroy the toxin until the barley had been damaged. Toxin applications increased the disease loss from about 50 percent in the check to about 75 percent in the toxin series.

TABLE 2.—*Effect of ammonium nitrate and salicylaldehyde on the growth of barley in steamed and unsteamed root rot nursery soil, 1949*

Soil treatment	Tillers per plant		Total dry weights		
	Unsteamed	Steamed	Unsteamed	Steamed	Ratio: Unsteamed / steamed
	Number	*Number*	*Grams*	*Grams*	*Percent*
Toxin (100 p. p. m.)	0	0	0. 7	3. 4	0. 21
Toxin (50 p. p. m.)	0	. 7	1. 0	4. 1	. 24
Check	0	. 7	3. 1	6. 4	. 48
33–0–0 (50 lbs. per acre)	. 5	2. 3	5. 0	9. 2	. 55
33–0–0 (100 lbs. per acre)	1. 0	3. 3	4. 4	10. 3	. 43

RELATIVE VALUE OF DIFFERENT SOURCES OF NITROGEN ON THE ROOT ROT NURSERY SOIL

The consistent response to nitrogen led to an exploration of the relative merits of several nitrogen carriers. Pure chemicals were used to minimize possible minor-element effects. One treatment consisted of phosphorus alone, another of nitrogen and phosphorus

[6] Eastman Kodak Chemical 225 (diluted in absolute alcohol 1/20 before adding to water).

combined. One organic form of nitrogen (ground alfalfa hay) was included.

The chemicals were added in solution, and the ground alfalfa hay was mixed throughout the soil mass. The soils were kept moist for 1 week to establish biological activity and then seeded with Odessa barley on February 14, 1950. For each treatment, 3 plants per pot were grown in 3 pots of unsteamed and 2 of steamed soil at each rate of application. The rates of applications were equivalent to 50, 100, or 200 pounds of nutrient element (nitrogen or phosphorus) per acre. The plants were harvested on March 21, March 28, and April 6, and dry weights of top growth were recorded.

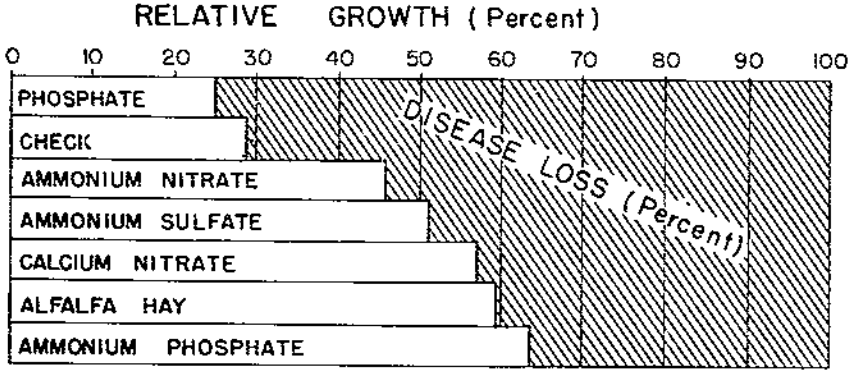


FIGURE 10.—Effect of fertilizers applied to unsteamed root rot nursery soil on the growth and disease loss of Odessa barley.

Soil steaming, as before, greatly improved the growth of the plants, as did all sources of nitrogen in both unsteamed and steamed soil. These treatments increased tillering and vegetative growth. Soil steaming hastened maturity. The effects of various nitrogen carriers differed significantly on unsteamed soil (fig. 10) but were equal on steamed soil. Response to nitrogen carriers was greater on unsteamed than on steamed soil; this may indicate that a decreased disease loss results from better host nutrition (fig. 11). Ammonium phosphate (fig. 11) was superior to phosphorus alone in its effects on unsteamed soil, both in dry weight of plants and in type of plant development. The heavy rates of nitrogen alone favored a vegetative development; while the heavy rates of ammonium phosphate encouraged more normal development, and growth on the unsteamed soil almost equaled the growth obtained on the steamed check.

This greenhouse test further substantiated other field and greenhouse observations, showing that this particular pythium root rot soil was low in available nitrogen but relatively well supplied with phosphorus. The establishment of this relation contrasts markedly with conclusions from experiments with cereal and sugarcane in Canada, Iowa,[7] Louisiana, and Hawaii. Phosphorus alone had little effect on unsteamed soil, whereas nitrogen combined with phosphorus gave the best results (fig. 10). Furthermore, nitrogen was used most effectively in combination with phosphorus, as in the 1949

[7] See footnote 4, p. 5.

field results. The data indicate that fertilization decreases the loss through disease, as the disease loss was 71 percent in the check series as compared with 31 percent in the ammonium phosphate series, when results of treatments in unsteamed and steamed soils were compared.

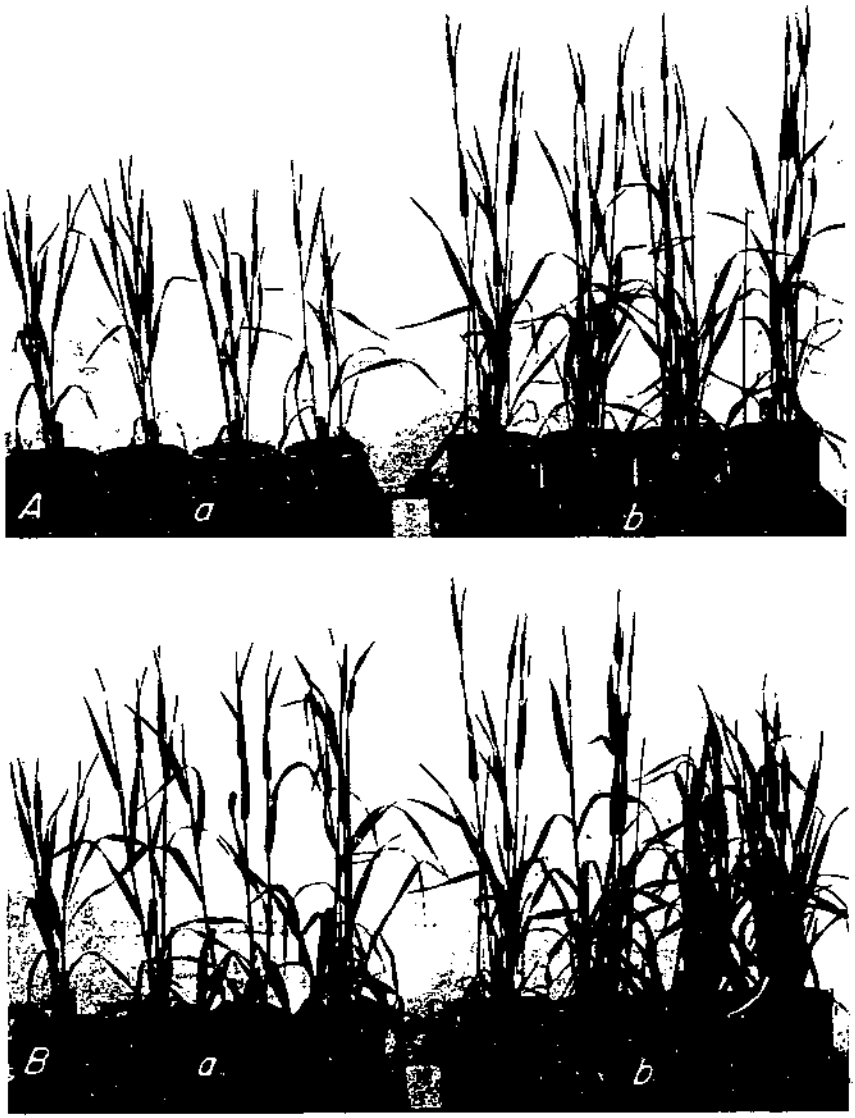


FIGURE 11.— Barley grown on root rot nursery soil: *A*, Phosphorus, *B*, ammonium phosphate; *a*, unsteamed soil, *b*, steamed soil. The rates of application for each element were 0, 50, 100, and 200 pounds per acre, from left to right in each series.

PURE-CULTURE, NUTRIENT-SOLUTION EXPERIMENT TO DETERMINE THE ACTION OF *Pythium arrhenomanes*

An attempt was made to evaluate experimentally the observational evidence on the role of *Pythium arrhenomanes* in the etiology of this disease. Results with inoculated soil were erratic, and those with naturally infested soil cannot be considered conclusive. A sand-culture (*1, 10, 20*) technic was employed.

High-quality silica sand in 8-inch standard pots, distilled water, and modifications of Hoagland's solutions (*11*) formed the physical basis of the experiment. Balanced and low-phosphorus solutions were used unaltered. A minor-element solution was added to the nutrient solution at the rate of 1 ml. per liter. Solutions 1 and 2 were balanced, and solutions 3 and 4 were low in phosphorus. Solutions 2 and 4 received 25 and 12.5 p. p. m. of salicylaldehyde, respectively. Nutrients were added twice weekly, and water was added on other days as needed. The greenhouse temperature was kept near 70° F. Lights were used to attain a 15-hour day.

One petri dish culture of a root rot nursery isolate of *P. arrhenomanes*, 1 week old at room temperature on Rands and Dopp's medium, was added to each pot. Cultures steamed 20 minutes at 10 pounds of pressure were used in the checks. The inoculum was mixed in the lower third of the sand, a thick layer of clean sand was added, then germinated seeds were added and covered with clean sand. This separation of seedlings and inoculum was designed to prevent the seedling-blight phase of this disease. Plains and Montcalm barleys, respectively susceptible and resistant, were sown. The experiment ran from February 5 to May 9, 1951, for Plains barley and to May 15 for Montcalm. There were 4 replications with 3 plants per pot.

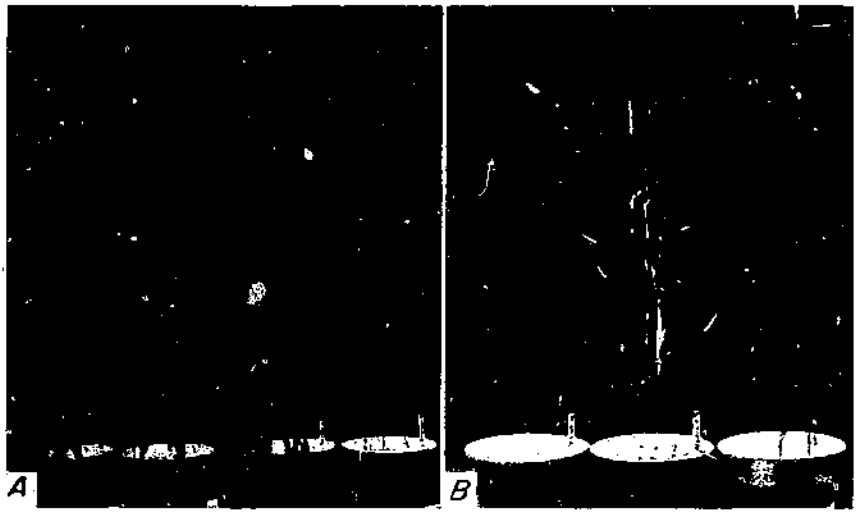


FIGURE 12.—*A*, Plains and Montcalm barleys (check left, inoculated right in each pair). *B*, Plains (left) and Montcalm (center) inoculated with *Pythium arrhenomanes*. The right-hand pot contains 1 plant of Plains (very short) and 2 of Montcalm, in sand inoculated with barley roots from root rot nursery soil.

Nutrients were first added on February 12. The solutions were found to be acid (pH 4.5 to 5.0) and were adjusted with NaOH to pH 5.9 to 6.5 on March 2 and maintained at that level. Aboveground plant parts were removed 1 inch above the sand level and dried. Roots were washed from the sand, examined, dried at 50° C., and weighed. Since the dried roots contained traces of sand, they were macerated, placed in water, and removed by flotation. The sand residue was dried and weighed and the weight subtracted from the gross root weight.

Diseased seedlings were smaller and had slightly narrower leaves when 2 weeks old than did the healthy plants. Both varieties were less vigorous in the inoculated series for all solutions. Tillering was reduced approximately 50 percent. Tillers of the diseased plants tended to develop sporadically and were irregular in length. The leaves of tillers frequently developed longitudinal chlorotic streaks, while those of the main culms were normal green. Elongation of the peduncles was reduced, and the heads of many diseased plants of the Plains variety failed to emerge from the boot (fig. 12). As diseased plants approached maturity, particularly those of Montcalm in solution 2, they tended to retain their chlorophyll while the healthy plants ripened. The maximum delayed maturity observed (Montcalm, solution 2) was estimated at about 2 weeks. Straw length was reduced 35 percent in Plains and 15 percent in Montcalm. All plants survived to maturity. The diseased plants were similar, whether inoculated with *P. arrhenomanes* or with roots from the root rot nursery soil (fig. 12, *B*).

Montcalm surpassed Plains in the capacity of its roots (fig. 13) to withstand the disease (significant beyond the 1-percent level) and also to grow in the poorer solutions (significant beyond the 5-percent level). However, the root growth of Montcalm was reduced about 50 percent by the disease.

The agreement of symptoms and varietal relationships, occurring both in the field and greenhouse materials, tends to identify *P. arrhenomanes* as the pathogen largely responsible for the disease in the root rot nursery.

Low phosphorus, in relation to nitrogen, has been reported as a predisposing factor for the disease and this relationship was confirmed in this experiment. As a result of the disease, the dry weights of shoots were reduced, for Montcalm, 22 percent in balanced and 43 percent in low-phosphorus solutions; and for Plains, 44 percent in balanced and 65 percent in low-phosphorus solutions. Ample phosphorus reduced the disease loss but did not eliminate it, especially in susceptible varieties.

A soil toxin, employed first by Rands and Dopp (*20*), increased disease losses in 3 out of 4 cases when used in these tests.

VARIETAL REACTION TO PYTHIUM ROOT ROT

Varietal resistance to pythium root rot has long been used as a practical control measure in sugarcane (*3*). In 1928 (*4*) the Lahaina variety of cane was used as an indicator for locating root rot soils in the Hawaiian Islands. Hawaiian workers found that more fertilizer was required to produce good crops of susceptible than of resistant

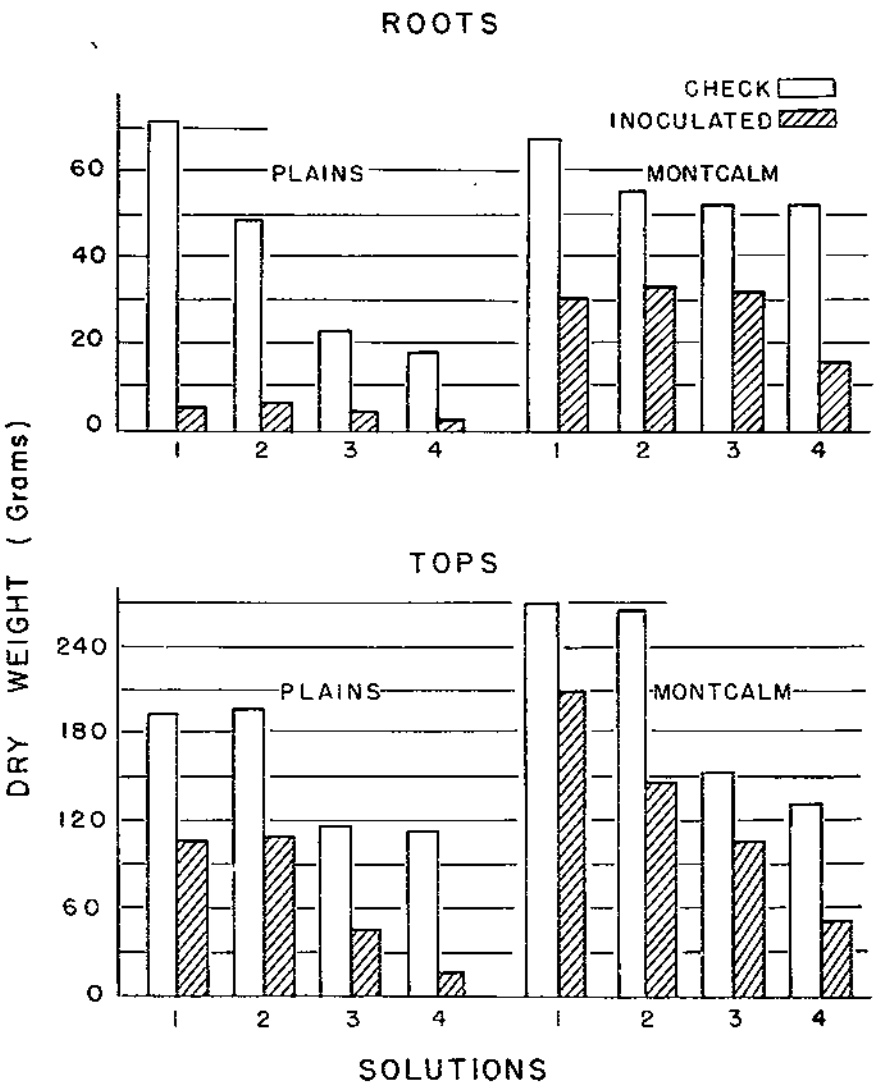


FIGURE 13.—Weight of roots and tops of Plains and Montcalm barleys grown in sand-culture solutions uninoculated and inoculated with *Pythium arrhenomanes*. Solution 1, balanced; 2, balanced plus salicylaldehyde; 3, low-phosphorus; 4, low-phosphorus plus salicylaldehyde.

canes (*6*), and that resistance can be broken down by adverse soil conditions (*5*). Rands and Dopp (*21*) advocated the use of resistant varieties of sugarcane in Louisiana as a practical control measure. Differences in corn also were found (*10, 14*).

Varietal relationships among the small grains, particularly in the adult stages, were not so well demonstrated. Vanterpool (*32*) found differences in wheat varieties. Thatcher and Apex thrived better

than Marquis in adjacent fields. Counts of lesions on coronal roots of six varieties grown in 6-inch pots filled with naturally infested soil confirmed the field observations. Thatcher, Apex, and Pentad were more tolerant than Marquis, Renown, and Reward. Iowa workers (*13*) tested barley varieties for reaction to a pure culture of *Pythium graminicolum*, for which they recorded germination and early growth of roots and tops. A good correlation between this test and field performance on heavily infested soil was reported. Trebi, Peatland, and Velvet were inferior in test results while Minsturdi was best. Grafius [8] tested wheat seedlings and found Solid Straw Tuscan, Surpresa, Thatcher, and Premier to be superior to Ceres, Rival, Marquis, Kubanka, or Hope.

It was apparent from the first that barley varieties differed in their ability to produce on the root rot soil. In 3 successive seasons, 2 adapted varieties, Plains and Feebar, were found inferior in yield to Odessa and Trebi (table 3). Feebar outyielded Odessa on chloropicrin-treated soil, and apparently the yield performance in the root rot nursery resulted from differences in tolerance to pythium root rot.

TABLE 3.—*Relative yields of grain produced in the root rot nursery by 4 barley varieties, 1948–50*

[Expressed as percent of the highest yield of the 4 varieties each season]

Varieties	Relative yield in:			
	1948	1949	1950	Mean
	Percent	*Percent*	*Percent*	*Percent*
Odessa	92	100	100	97. 3
Trebi	100	92	94	95. 0
Plains	74	87	40	67. 0
Feebar	56	45	60	53. 3

Similar experiments were attempted on wheat varieties also, but the results were inconclusive because of interference by aphids and leaf and stem rusts.

In 1950, 2 seedings were made, 1 with 4 replicates of 3 rows each, and 1 with 4 replicates of single rows, each row being 7 feet long. The first test was called the variety trial; the second, the entry trial (table 4). Very little resistance to disease was evident in these tests, because the yields ranged from 3 to 16 bushels per acre. Odessa yielded 43 bushels and Feebar yielded 50 bushels per acre without fertilizer on chloropicrin-treated soil; these 2 varieties yielded 12 and 7 bushels per acre, respectively, on the untreated, unfertilized nursery soil. The treated soil was seeded somewhat later. The practical significance of root rot is very evident: Feebar outyielded Odessa when the disease was eliminated but yielded less than Odessa when the disease was present.

[8] See footnote 4.

TABLE 4.—*Yield of barley varieties on root rot nursery soil, 1950*

Variety trial			Entry trial					
Variety	C. I.[1] No.	Yield, per acre	Variety	C. I.[1] No.	Yield, per acre	Variety	C. I.[1] No.	Yield, per acre
		Bushels			*Bushels*			*Bushels*
Manchuria	2947	13. 2	Montcalm	7149	16. 4	Lion	923	10. 6
Odessa	182	12. 4	Luth	972	14. 9	Ezond	6265	10. 5
Velvet [2]	4252	12. 2	Velvet	4252	14. 5	Spartan	5027	10. 0
Trebi	936	11. 6	Hietpas 5	7124	13. 4	Minn. II–41–2	7560	9. 8
Ped. 38	5105	11. 6	Abyssinian	1243	13. 1	Club Mariout	261	9. 7
Peatland	5267	10. 2	Harlan	7008	12. 2	Unnamed [4]	4757	9. 4
Compana	5438	9. 6	Minsturdi	1556	11. 9	Moore	7251	9. 4
Club Mariout [2]	261	9. 6	Quinn	1024	11. 5	Chilean D	1433	9. 2
Elses		8. 8	Vantage	7324	11. 0	Gartons	7016	8. 4
Feebar	7260	7. 4	Bolivia	1257	10. 8	Valentine	7242	6. 9
Swanneck		6. 8	Velvon 11	7088	10. 7	Vaughn	1367	4. 8
Dryland	5673	5. 7	Morocco	6311	10. 7	Plains	7250	4. 8
Plains [2]	7250	4. 9	Unnamed [3]	4975	10. 6	Estate	3410	3. 2

[1] C. I. refers to accession number of the Division of Cereal Crops and Diseases.
[2] Variety occurs in entry trial also.
[3] From Morocco.
[4] From Manchuria.

The inheritance of tolerance to this disease is not established. Feebar and Plains are both of hybrid origin. Examination of the pedigrees of certain varieties, such as Vaughn, Dryland, and Plains, has shown that when the progenies selected are earlier maturing than the parents, a loss in yield resulted. The earliest varieties tested performed poorly. Late or moderately late varieties in general performed well. There were too many exceptions to permit a definite association of lateness with tolerance. Gartons, Valentine, and Moore yielded poorly for their maturity class. In view of the agronomic value of earliness, a thorough investigation of these relationships would be of practical significance.

As this test was conducted under severe root rot conditions, it is reasonable to assume that varieties that are above the bottom third in susceptibility may perform satisfactorily under a less severe disease attack. The most susceptible varieties might be safely recommended only on soils known to be relatively free of this disease.

DISCUSSION AND SUMMARY

The general destruction of fine rootlets of barley and wheat by *Pythium arrhenomanes*, rather than the local lesions on larger roots, was the chief symptom in South Dakota in a section of severe endemic pythium root rot. This resulted in general lack of vigor, as well as in discoloration of leaves, short straw, lack of tillering, delayed maturity, and poor spike exsertion.

Experiments on the soil in this section are reported. The most noticeable characteristics of this soil are its low level of available nitrogen and organic matter. Field and greenhouse experiments demonstrated that nitrogen applied to this soil in reasonable amounts did not increase the disease loss. Field data indicated a straight fertility response to the application of nitrogen, while greenhouse data gave evidence also of a reduction in disease loss. Previous observations of the benefits of legumes on this soil indicated that their use in crop rotation would increase crop production and serve to reduce the level of inoculum present in the soil.

Organic compounds inimical to plant growth have been demonstrated to influence root rot severity. Louisiana workers (*7*) have shown the influence of *Actinomycetes* on the level of *Pythium* inocula in the soil. Organic toxins may exert a double influence on this disease directly by increasing host susceptibility and indirectly (*22*) by suppressing organisms harmful to the pathogen. The effect of salicylaldehyde and vanillin, two compounds not known to be present in the South Dakota soils, was to increase the severity of the disease in limited experiments.

A low order of varietal tolerance or resistance has been demonstrated in barley. Even these small differences may be helpful under severe attacks. Late barleys in general yielded well, but lateness did not guarantee tolerance or resistance. The edaphic factor in varietal performance was found to be sufficiently great to suggest the advisability of wide testing of barleys in relation to various soil conditions.

LITERATURE CITED

(1) BRANSTETTER, B. B.
1927. CORN ROOT ROT STUDIES. Mo. Agr. Expt. Sta. Res. Bul. 113, 80 pp., illus.

(2) BUCHHOLTZ, W. F.
1949. A COMPARISON OF GROSS PATHOGENIC EFFECTS OF PYTHIUM GRAMINICOLA, PYTHIUM DEBARYANUM, AND HELMINTHOSPORIUM SATIVUM ON SEEDLINGS OF CRESTED WHEATGRASS. Phytopathology 39: 102–116, illus.

(3) CARPENTER, C. W.
1919. PRELIMINARY REPORT ON ROOT ROT IN HAWAII (LAHAINA CANE DETERIORATION, PINEAPPLE WILT, TARO ROT, RICE ROOT ROT, BANANA ROOT ROT.). Hawaii Agr. Expt. Sta. Press Bul. 54, 8 pp., illus.

(4) ———
1928. NOTES ON PYTHIUM ROOT ROT OF SUGAR CANE. Hawaii. Planters' Rec. 32: 107–117.

(5) ———
1934. PREDISPOSING FACTORS IN PYTHIUM ROOT ROT. VII. Hawaii. Planters' Rec. 38: 279–338, illus.

(6) COOKE, D. A.
1933. THE RELATION OF PYTHIUM TO GROWTH FAILURE ON PHOSPHATE FIXING SOILS. Assoc. Hawaii. Sugar Technol. Rpts. 12: 169–178, illus.

(7) COOPER, W. E., and CHILTON, S. J. P.
1950. STUDIES ON ANTIBIOTIC SOIL ORGANISMS. I. ACTINOMYCETES ANTIBIOTIC TO PYTHIUM ARRHENOMANES IN SUGAR-CANE SOILS OF LOUISIANA. Phytopathology 40: 544–552, illus.

(8) DRECHSLER, C.
1936. PYTHIUM GRAMINICOLUM AND P. ARRHENOMANES. Phytopathology 26: 676–684, illus.

(9) EDGERTON, C. W., TIMS, E. C., and MILLS, P. J.
1929. RELATION OF SPECIES OF PYTHIUM TO THE ROOT ROT DISEASE OF SUGAR CANE. Phytopathology 19: 549–564, illus.

(10) ELLIOTT, C.
1942. RELATIVE SUSCEPTIBILITY TO PYTHIUM ROOT ROT OF TWELVE DENT CORN INBREDS. Jour. Agr. Res. 64: 711–723, illus.

(11) GALLEGLY, M. E., JR., and WALKER, J. C.
1949. PLANT NUTRITION IN RELATION TO DISEASE DEVELOPMENT. V. BACTERIAL WILT OF TOMATO. Amer. Jour. Bot. 36: 613–623, illus.

(12) GRAHAM, V. E., and GREENBERG, L.
1939. THE EFFECT OF SALICYLIC ALDEHYDE ON THE INFECTION OF WHEAT BY PYTHIUM ARRHENOMANES DRECHSLER, AND THE DESTRUCTION OF THE ALDEHYDE BY ACTINOMYCES ERYTHROPOLIS AND PENICILLIUM SP. Canad. Jour. Res., Sect. C, 17: 52–56, illus.

(13) HO, WEN-CHUN, MEREDITH, C. H., and MELHUS, I. E.
1941. PYTHIUM GRAMINICOLA SUBR. ON BARLEY. Iowa Res. Bul. 287, pp. [288]–314, illus.

(14) JOHANN, H., HOLBERT, J. R., and DICKSON, J. G.
1928. A PYTHIUM SEEDLING BLIGHT AND ROOT ROT OF DENT CORN. Jour. Agr. Res. 37: 443–464, illus.

(15) MANGELSDORF, A. J.
1935. GROWTH-FAILURE PROBLEMS. Hawaii. Planters' Rec. 39: 222–229

(16) MATTHEWS, V. D.
1931. STUDIES ON THE GENUS PYTHIUM 136 pp., illus. Chapel Hill, N. C.

(17) MIDDLETON, J. T.
1943. THE TAXONOMY, HOST RANGE AND GEOGRAPHIC DISTRIBUTION OF THE GENUS PYTHIUM. Torrey Bot. Club Mem. v. 20, No. 1, 171 pp., illus.

(18) RANDS, R. D., and DOPP, E.
1933. HUMUS EXTRACT AGAR FAVORABLE FOR OOSPORE PRODUCTION IN PYTHIUM. Phytopathology 23: 745.

(19) ——— and DOPP, E.
1934. VARIABILITY IN PYTHIUM ARRHENOMANES IN RELATION TO ROOT ROT OF SUGARCANE AND CORN. Jour. Agr. Res. 49: 189–221, illus

(20) RANDS, R. D., and DOPP, E.
1938. INFLUENCE OF CERTAIN HARMFUL SOIL CONSTITUENTS ON SEVERITY OF PYTHIUM ROOT ROT OF SUGARCANE. Jour. Agr. Res. 56: 53–67, illus.
(21) ——— and DOPP, E.
1938. PYTHIUM ROOT ROT OF SUGARCANE. U. S. Dept. Agr. Tech. Bul. 666, 96 pp., illus.
(22) ROBBINS, W. J.
1918. THE DESTRUCTION OF VANILLIN IN THE SOIL BY THE ACTION OF SOIL BACTERIA. Ala. Agr. Expt. Sta. Bul. 204, pp. [125]–131.
(23) ROLDAN, E. F.
1932. PYTHIUM ROOT-ROT DISEASE OF CORN IN THE PHILIPPINE ISLANDS. Philippine Agr. 21: 165–176, illus.
(24) SCHREINER, O., and SKINNER, J. J.
1914. HARMFUL EFFECTS OF ALDEHYDES IN SOILS. U. S. Dept. Agr. Dept. Bul. 108, 26 pp., illus.
(25) SHOREY, E. C.
1913. SOME ORGANIC SOIL CONSTITUENTS. U. S. Dept. Agr., Bur. Soils Bul. 88, 41 pp., illus.
(26) SPRAGUE, R.
1944. ROOTROTS OF CEREALS AND GRASSES IN NORTH DAKOTA. N. Dak. Agr. Expt. Sta. Bul. 332, 35 pp., illus.
(27) ———
1950. DISEASES OF CEREALS AND GRASSES IN NORTH AMERICA (FUNGI, EXCEPT SMUTS AND RUSTS). 538 pp., illus. New York.
(28) TRUSCOTT, J. H. L.
1934. FUNGOUS ROOTROTS OF THE STRAWBERRY. Canad. Jour. Res. 11: [1]–17, illus.
(29) VALLEAU, W. D., KARRAKER, P. E., and JOHNSON, E. M.
1926. CORN ROOTROT—A SOIL-BORNE DISEASE. Jour. Agr. Res. 33: 453–476, illus.
(30) VANTERPOOL, T. C.
1930. ASTEROCYSTIS RADICIS IN THE ROOTS OF CEREALS IN SASKATCHEWAN. Phytopathology 20: 677–680, illus.
(31) ———
1938. SOME SPECIES OF PYTHIUM PARASITIC ON WHEAT IN CANADA AND ENGLAND. Ann. Appl. Biol. 25: 528–543, illus.
(32) ———
1940. PRESENT KNOWLEDGE OF BROWNING ROOT ROT OF WHEAT WITH SPECIAL REFERENCE TO ITS CONTROL. Sci. Agr. 20: 735–749, illus.
(33) ———
1940. STUDIES ON BROWNING ROOT ROT OF CEREALS. VI. FURTHER CONTRIBUTIONS ON THE EFFECTS OF VARIOUS SOIL AMENDMENTS ON THE INCIDENCE OF THE DISEASE IN WHEAT. Canad. Jour. Res., Sect. C. 18: 240–257, illus.
(34) ———
1942. PYTHIUM ROOT ROT OF GRASSES. Sci. Agr. 22: 674–687, illus.
(35) ——— and LEDINGHAM, G. A.
1930. STUDIES ON "BROWNING" ROOT ROT OF CEREALS. I. THE ASSOCIATION OF LAGENA RADICOLA N. GEN., N. SP., WITH ROOT INJURY OF WHEAT. Canad. Jour. Res. 2: [171]–194, illus.
(36) ——— and SIMMONDS, P. M.
1938. THE RELATION OF BROWNING ROOT ROT TO STEM RUST IN CAUSING INJURIES TO WHEAT. Sci. Agr. 19: 81–82.
(37) ——— and TRUSCOTT, J. H. L.
1932. STUDIES ON BROWNING ROOT ROT OF CEREALS. II. SOME PARASITIC SPECIES OF PYTHIUM AND THEIR RELATION TO THE DISEASE. Canad. Jour. Res. 6: 68–93, illus.

U. S. GOVERNMENT PRINTING OFFICE: 1954

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 15 cents

END