An Investigation of

ASPARAGUS RUST IN ILLINOIS

Its Causal Agent and Its Control

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Bulletin 559 · UNIVERSITY OF ILLINOIS
AGRICULTURAL EXPERIMENT STATION

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Urbana, Illinois August, 1952

Publications in the Bulletin series report the results of investigations made or sponsored by the Experiment Station

An Investigation of
ASPARAGUS RUST IN ILLINOIS
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By Robert P. Kahn, H. W. Anderson, Paul R. Hepler, and M. B. Linn[a]

SEVERE OUTBREAKS of asparagus rust have appeared in Illinois during the past fifteen years in spite of the fact that the Washington varieties, grown extensively in this state, are the same as those which still appear to be commercially rust-resistant in many other asparagus-growing centers in the United States. In Illinois it is not uncommon to find large acreages of these plantings with a 100-percent infection of rust.

Previous investigators have been hampered by the lack of satisfactory methods of greenhouse and field inoculation. They depended on natural outbreaks for evaluating treatments and selections. More progress could evidently have been made if better techniques had been available.

The object of the present investigation was to develop satisfactory field and greenhouse methods of inoculation and to apply these methods to a study of the pathogen and to the control of the disease under Illinois conditions.

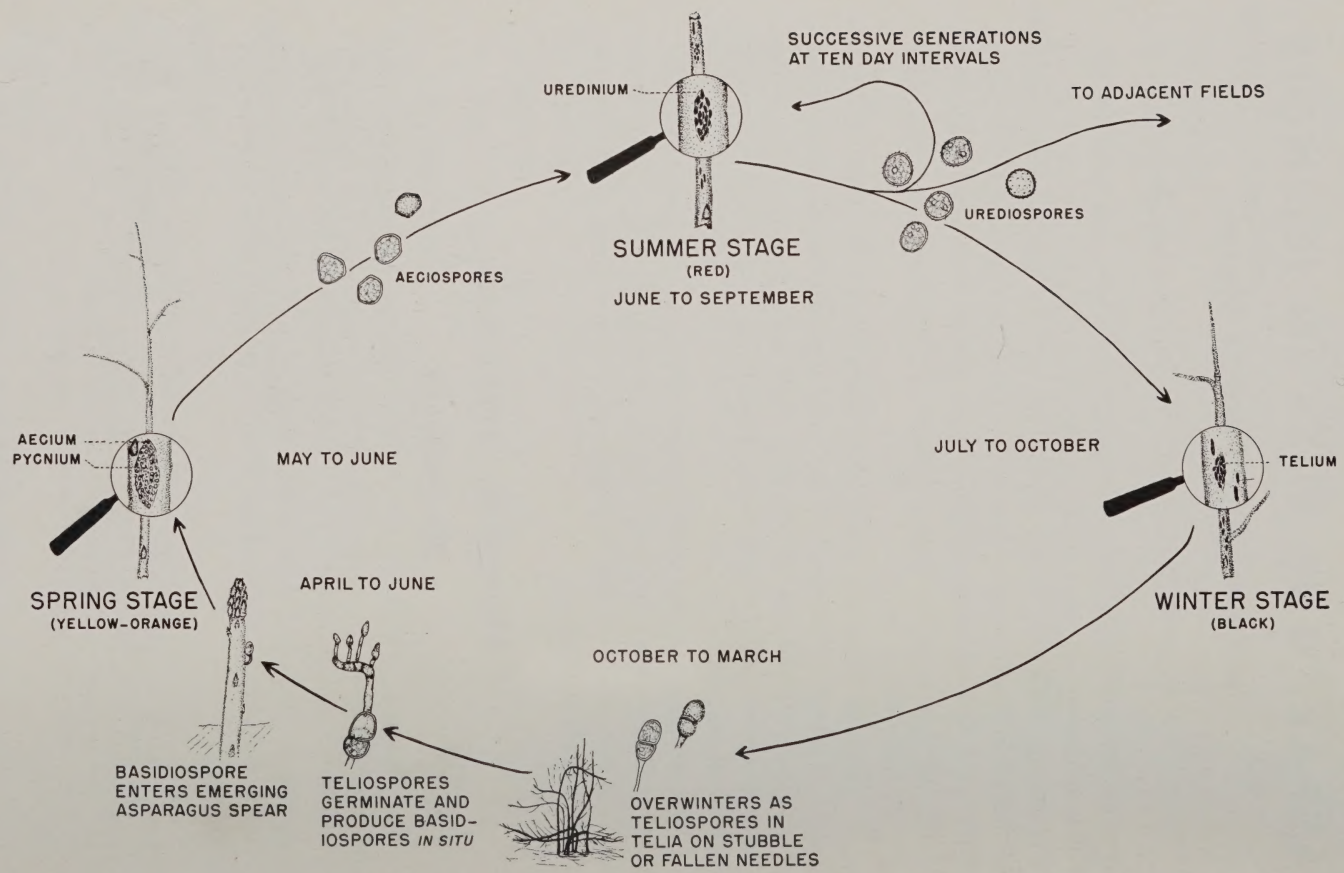
REVIEW OF LITERATURE

The Pathogen

Puccinia asparagi D. C., the causal fungus of asparagus rust, was described in 1805 by deCandolle, whose description has been cited by other investigators.[16, 42*] This fungus belongs in the family Pucciniaceae of the order Uredinales. Arthur[3] lists *Dicaeoma asparagi* Ktze. as a synonym, and on page 25 of his manual[4] gives the following description:

[a] Robert P. Kahn, formerly Assistant in Horticulture; H. W. Anderson, Professor of Plant Pathology; Paul R. Hepler, Assistant in Horticulture; and M. B. Linn, Professor of Plant Pathology. The authors gratefully acknowledge the assistance of Ralph Castenson, Rochelle Asparagus Company, Rochelle, Ill., in the fungicide experiments. This study was supported in part by funds authorized by the Research and Marketing Act of 1946.

* Superior figures refer to literature citations on pages 54 to 56.



Life cycle of *Puccinia asparagi* D. C. on its host, *Asparagus officinalis* L. (Fig. 1)

"Pycnia caulicolous. Aecia caulicolous, in groups or scattered, cupulate; aeciospores globoid, 13-21 by 17-26 μ; wall nearly colorless, 1 μ thick, finely verrucose. Uredia caulicolous, cinnamon-brown; urediospores globoid or ellipsoid, 18-25 by 22-30 μ; wall golden-yellow, 1.5-2 μ thick, echinulate, the pores usually 4, equatorial. Telia caulicolous, chocolate-brown; teliospores oblong or ellipsoid, 18-25 by 30-48 μ, rounded at both ends, slightly constricted at septum; wall chestnut-brown, 2-3 μ thick at sides, 4-8 μ above; pedicel somewhat colored, one-half to twice length of spore. Mesospores often numerous, 19-23 by 29-35 μ."

The following outline of the life cycle of this fungus is based on descriptions found in the works of Heald,[21] Norton,[35] Smith,[45] and Stone and Smith.[48]

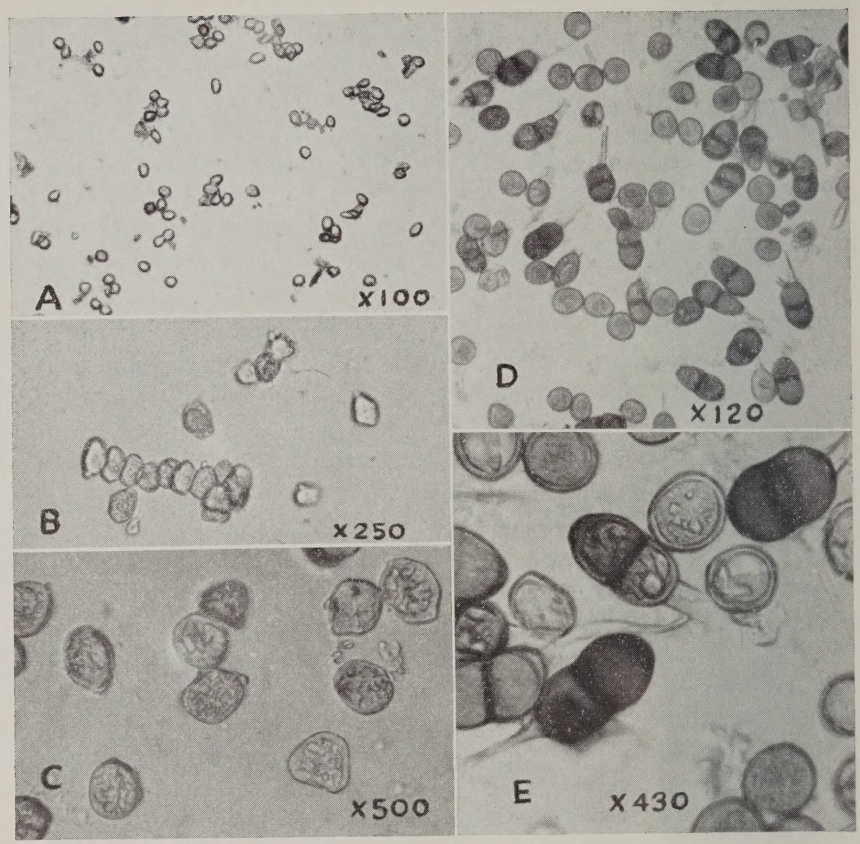
Puccinia asparagi D. C. is an autoecious macrocyclic rust of the Eu-type which produces all of its spore forms in the normal sequence of pycnia, aecia, uredinia, and telia during the course of one year (Figs. 1 to 4).

The pycnia are minute, spherical, ostiolate, sub-epidermal fruiting structures lined with erect hyphae which produce oval one-celled pycniospores. These pycnia arise from the intercellular sub-epidermal mycelium produced by basidiospores discharged from the promycelia of germinating teliospores.

The aecia are cylindrical or tubular fruiting structures which form in concentric rings around the pycnia. They are erumpent when mature and may protrude as much as 2 millimeters beyond the host epidermis. Aeciospore mother cells within the aecium give rise to catenate, many-sided, one-celled, yellow-orange aeciospores which are disseminated by wind or splashing rain. Germinating aeciospores penetrate susceptible tissue by means of appressoria and the resultant mycelium gives rise to the uredinial stage.

Uredinia are fruiting structures which consist of a cushion or layer of one-celled echinulate urediospores formed on pedicel cells beneath the host epidermis. This epidermal layer is ruptured by the pressure of the maturing spores, which are thus exposed to the air currents. Germinating urediospores usually enter the susceptible plant through the stomates. The resultant mycelium may give rise either to other uredinia or to telia, depending on the environmental conditions. During the summer, successive crops of urediospores may be formed each 10 to 14 days.

Telia are collections of hyphae that bear two-celled brown teliospores beneath the host epidermis. Telia may form either in a uredinial sorus or as a result of urediospore germination. Mixtures of urediospores and teliospores are frequently found in the same sorus during late summer and early fall. As teliospores in telia, the fungus



Three spore forms of *Puccinia asparagi*. A, B, C are aeciospores; D and E are urediospores (one-celled) and teliospores (two-celled). (Fig. 2)

overwinters on the frost-killed asparagus stubble and on asparagus needles on the ground. A perennial mycelium has not been reported.

After a period of dormancy each cell of a teliospore is capable of germinating to produce a septate promycelium upon which four sporidia or basidiospores are borne. These are discharged into the air currents, and if they germinate on susceptible emerging spears, the resultant mycelium gives rise to pycnia.

Susceptible Plants

A survey of the literature reveals that only plants of the genera *Asparagus* and *Allium* (onion) are susceptible to *Puccinia asparagi*. The following species have been reported as susceptible: *Asparagus*

asparagoides Wight (*A. medeoloides*),[42] *A. brouseopetii* Jacq.,[42] *A. caspius* Hoh.,[16] *A. maritimus* Poll.,[16] *A. officinalis* L.,[16] *A. plumosus* Baker,[42] *A. verticillatus* L.,[16, 39] *Allium cepa* L. var. *bulbellifera* Bailey.[13, 42, 54]

Three other species of *Asparagus* and *Allium* have been recorded as susceptible to rust fungi. *Asparagus lucidus* Lindl. has been reported as susceptible to *Puccinia asparagi-lucidi* in China,[12] *Asparagus falcatus* L. to *Puccinia phyllocladis* in Africa,[16] and *Allium cepa* L. to *Puccinia porri* in various places.[4]

Only *Asparagus scandens* Thumb and *A. plumosus* Regel have been reported as resistant.[16]

Significance of "varieties" in Asparagus officinalis. The validity of the use of the term "variety" when applied to collections of asparagus plants is open to question because of the absence of distinct morphological characters upon which to base varietal differences.

Hexamer[22] characterized several varieties on the basis of some indistinct morphological characters. For example, Barr's Mammoth was described as "largest, very productive, early"; Elmira, as "delicate green color of stems, tender, succulent"; while Eclipse was listed as "large, light green." Only one variety, Columbian Mammoth White, had a distinct morphological characteristic to distinguish it from all others: "tips much smaller than portion of stalk just below."

Basing his opinion on observations of varietal tests, Norton[35] stated on page 16:

"A lot of seedlings would show nearly all the variations found in the whole trial field. . . . To judge from the observations made on the varietal lots at Concord there are at present no pure strains of asparagus, the difference between the various lots being on a percentage basis."

Bailey[5] stated on page 410:

"The varietal differences in the asparagus plant do not appear to be very pronounced except in the color of the young shoots, and most of the variations seem to be due to differences in culture and environment rather than to those characteristic of the variety."

Since the term "variety" is so thoroughly entrenched in the literature concerning asparagus, it will be used in this bulletin, with the reservation, however, that the term "strain" may be more appropriate.

The Disease

Asparagus rust is a disease of the aerial portions of the asparagus plant that so decreases the amount of carbohydrates and other nutrients available for root storage that the yield and vigor of the

plant are reduced during the following year. After a few years of severe infection the plant may be so weakened that it dies.

History and distribution

This rust has been known in Europe since 1805, as evidenced by the writings of deCandolle, Saccardo, Schroster, Frank, Tubeuf, Leach, and Sajo (reported by Halsted[16]), but it never was destructive.

In the United States the disease was first reported[a] by Halsted in 1896, as he mentioned on page 1 of a later publication.[16] He determined by correspondence in 1896 that the disease was confined to "the New England States, Long Island, New Jersey, and Delaware."

Between 1896 and 1902 the rust spread to every important asparagus-growing region in the United States and Canada.[45] After its initial appearance in the northeastern states in 1896, it spread in 1897 to the southeastern states, especially South Carolina, but was still absent from the interior and western portions of the country. The following year (1898) found rust as far west as Michigan; and in 1899 it was reported in Illinois, Ohio, Kansas, and Canada. The Dakotas, Texas, and Nebraska experienced outbreaks in 1900. In 1901 and 1902 severe outbreaks were reported from asparagus-growing centers in California.

The distribution of the disease in Illinois in 1940, 1941, and 1942 was determined by Fulton,[13] who observed that 1940 and 1941 were severe rust years, especially in northern and eastern Illinois, while infection in 1942 was comparatively light.

The distribution of the disease in Illinois in 1944 was reported by Tidd,[52] who surveyed 1,000 acres of asparagus in Cook, Kankakee, Kendall, Iroquois, LaSalle, Ogle, and Vermilion counties and reported infection varying from a trace to 100 percent per field.[b]

Economic importance

A survey of the literature reveals no experimental evidence to indicate the relation between severity of infection and reduction in yield the following season. Reports in terms of percent of infection or relative degree of infection are numerous, but these fail to indicate the loss in pounds per acre; information convertible to dollars and

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[a] Some investigators[16, 48] cite an 1880 *Catalogue of the Pacific Coast Fungi* by Harkness and Moore, which is reported to include the causal fungus of asparagus rust. Since no specimen was preserved, however, the report is subject to question.

[b] Based on Tidd's figures, the over-all infection appeared to be between 75 and 95 percent although it was not specifically so indicated in the report.

cents is therefore not available. A summary of these types of reports appearing in the *Plant Disease Reporter* is presented in Table 1.

The severity of the disease during the first few epidemics was depicted by Smith,[45] who stated on page 19:

"After the first few years of the epidemic, most of the older beds in the Atlantic States were entirely destroyed, the canning industry was practically abandoned, prices became about double what they had previously been, new varieties came into use, and an entire readjustment of the asparagus industry took place."

Table 1. — Severity or Presence[a] of Asparagus Rust in Six States in Selected Years

(Compiled from Plant Disease Reporter, 1933-1943)

Year of report	Illinois	Massachusetts	Maryland	New Jersey	Connecticut	New York
1933	.....	.....	1.5%	1.5%	1.5%	1.5%
1934	.....	2%	1.5%	Reported	.....	.....
1935	.....	3%	1.5%	.....	Not serious	Not serious
1936	.....	4%	Usual	Severe	.....	Absent
1937	Reported	.....	Reported	Slight	Reported	.....
1938	Reported	4%	2.5%	2.5% in some sections	.....	.....
1940	Severe	Normal	.....	Severe in one county	.....	.....
1943	None	Severe	Absent	Absent in summer, reported in fall	Absent	Low

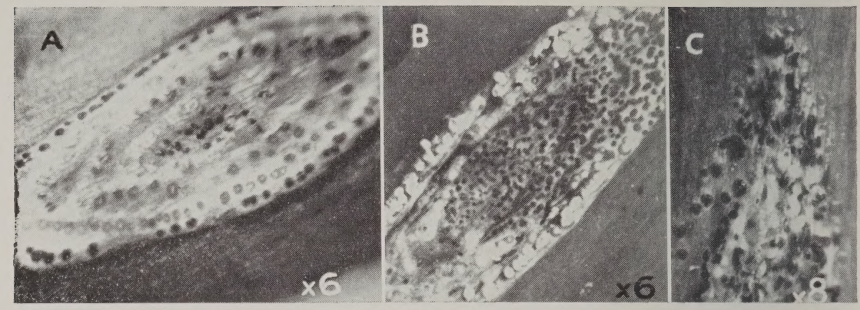
[a] Percentages indicate estimated reduction in asparagus yield for the year after the report, based on the severity of infection during the report year. Blanks indicate that no report appeared for that state in the year specified.

Symptoms

Rust symptoms[21, 35, 45, 48] do not appear on the asparagus spears which are cut for market or canning, but are confined to the green tops produced after the end of the cutting season. The symptoms may be discussed in three stages: (1) the spring or cluster-cup stage, (2) the summer or red-rust stage, (3) the overwintering or black-rust stage (Figs. 3 and 4).

The spring stage first appears in May in Illinois as light-green oval patches usually on the main stalk, but occasionally on the lateral branches and on the true leaves (bracts). These oval spots enlarge to about ½ to ¾ inch and become bright orange because of the presence of pycnia surrounded by concentric rings of aecia. At maturity the aecia protrude through the epidermis of the plant. These pycnial-aecial clusters are usually far less abundant than the subsequent uredinia and telia.

The summer stage is characterized by the red color of the sori, which may be found on all aerial portions of the plant except the flowers and fruit. These uredinial sori may form in three ways: (1) as



Picnial and aecial sori. A shows concentric rings of immature aecia surrounding a center of subepidermal pycnia; B, concentric rings of aecia, those in outer ring mature; C, pycnidia of *Darluca filum* in association with aecia of *Puccinia asparagi.* (Fig. 3)

concentric rings of uredinia around the initial point of infection; (2) as single oval sori from ⅛ to 1 inch long; or (3) as large irregular patches formed by the coalescence of several sori. At maturity the sori rupture the host epidermis, which covers the developing fungus, and expose the rust-colored spores.

The winter stage is similar in appearance to the summer stage except that the sori are black. Either stage may produce premature needle-fall and a brown discoloration of the infected tissue.

Epidemiology

The role of atmospheric and soil moisture in determining the severity of the infection of asparagus by the rust fungus was given close attention by early investigators.

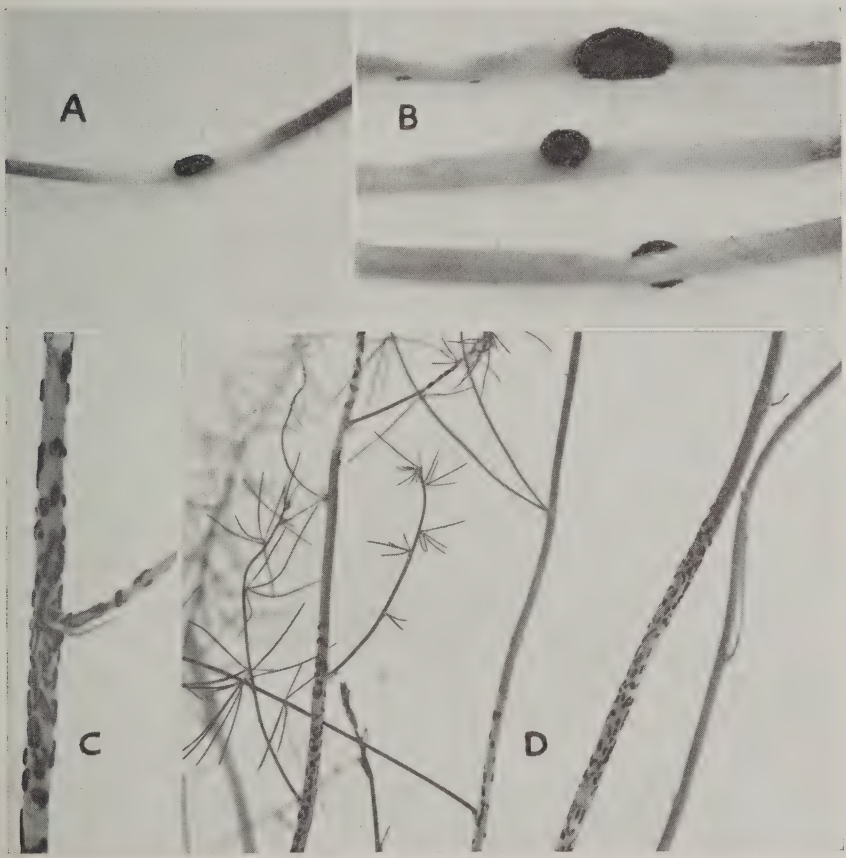
Atmospheric moisture in relation to the severity of rust refers to the moisture necessary for spore germination. Dew is the principal source of this moisture.[38, 43, 44, 48, 49] Smith[45] stated on page 52 that "the amount of rust varies directly and exactly with the amount of dew, and . . . so long as there is little or no dew there can be no rust." He observed that in California, especially in the region of the Sacramento Valley, where prevailing winds are from the west, rows planted in a north-south direction rust sooner on their sheltered east sides than rows planted in an east-west direction parallel to the direction of the prevailing winds. Norton[35] concurs in this prevailing wind-dew theory for conditions in Massachusetts, as do Ogilvie and Hickman[37] for Bristol, England, and Halsted[17] for New Jersey.

Soil moisture in relation to asparagus rust refers to the moisture in the soil as it influences the vigor of the asparagus. Smith[44] and other

investigators[8, 34, 36, 37, 39] stated that the moisture conditions in the soil which tend to increase the vigor of the plant tend simultaneously to decrease the severity of the disease; or, in effect, that dry soils favor the disease. On the other hand, Bremer[7] concluded that in Germany no relation exists between the severity of outbreaks and the prevailing weather conditions.

Control

Fungicides. The losses from rust in years of severe infection gave impetus to the search for effective fungicides. Investigations in the eastern states and in Germany centered around the application of



Uredinial and telial sori. A and B show uredinia on cladophyls; C, concentric rings of uredinia and telia arising from one focus of infection; D, uredinia and telia on 10-week-old seedlings, artificial inoculation. (Fig. 4)

copper in various forms; investigations in California stressed the use of sulfur; while, those in Illinois involved dinitro-o-cresol.

The principal copper-containing fungicide used by investigators in the eastern states and in Germany was bordeaux mixture. Bordeaux was recommended by Arthur,[3] Jahnel,[24] Bollow,[6] and Halsted.[33] The latter obtained 16.9 percent less infection on treated plots than on untreated plots. Halsted[16] also compared the effects of "soda bordeaux," "potash bordeaux," and "hydrated bordeaux" and found that the average infection on all treated plots was 55 percent compared with 74.9 percent for the untreated plots. Bordeaux mixture was compared with K_2S, $KMnO_4$, and saccharate of lime by Stone and Smith,[48] who found that K_2S gave the best control. However, none of these compounds gave satisfactory control because they did not adhere enough. To correct this defect, Sirrine[43] added 2 gallons of a mixture containing resin, potash lye, fish oil, and water to 48 gallons of bordeaux mixture. Bordeaux-resin mixture was also recommended by Chester.[9, 10] Bordeaux mixtures were considered unsatisfactory by Waldron[53] and Stone.[47]

Other copper compounds tested were Paris green,[45, 49] copper sulfate, copper acetate, copper carbonate,[45] and copper oxychloride.[19] These compounds either failed to control the disease or the results were too erratic to warrant further consideration. Hassebrauk[20] doubted the toxicity of copper sprays but suggested that they be employed "within reasonable limits" on young fields until more effective compounds could be developed.

Experiments in California reported by Smith[45, 46] showed that sulfur applied as a dust or spray would reduce the severity of the disease. According to Smith, sulfur was a more efficient fungicide than copper because the mat of fern produced by many stems from a single crown was subject to a fumigatory action by sulfur but it could not be permeated by copper. He recommended that 100 pounds of flowers of sulfur per acre be applied as a dust two or three times during the season. Jones and Robbins[26] reduced this recommendation to 25 to 30 pounds per acre.

Experiments in Illinois by Anderson, Thornberry, and Fulton[2] were conducted to determine the efficiency of dinitro-o-cresol (Elgetol) in reducing the severity of the disease. These investigators found that a reduction in aecia may be obtained by applying this compound, at concentrations of ½ to 2 percent and at rates of 400 to 800[a] gallons

[a] Two percent at a rate of 800 gallons per acre is equal to 50 pounds of technical dinitro-o-cresol.

per acre, as an eradicant spray on asparagus stubble and ground that contain the overwintering teliospores. This rate of application is not practical for the average asparagus grower to use, but was recommended for use on young seedbeds which are not to be cut in the spring.

Fungous parasites of the rust fungus. The presence of the hyperparasites of rusts, *Darluca filum* Cast. and *Tubercularia persecina* Ditt., in the aecial, uredinial, and telial pustules of *Puccinia asparagi* has been observed and reported by many workers.[15, 25] Reports conflict as to the role of these parasites in reducing the severity of the disease. Halsted[16] questioned the advisability of using fungicides if *D. filum* is killed in the process. Smith[45] presented drawings showing urediospores being invaded by this parasite. Fulton[13] suggested that this parasite may have been responsible for the reduction in the severity of rust in Illinois during 1942. Keener[28] reported the existence of physiologic races of *D. filum* but did not use *P. asparagi* as a host.

Cultural practices. Early workers in Europe and the United States stressed cultural practices as a means of controlling asparagus rust. Burning the stubble was recommended by many investigators.[1, 3, 6, 16, 37, 38, 43, 47, 48, 50] Others[29, 40, 45] questioned the efficacy of this treatment. The eradication of volunteer asparagus was also recommended,[3, 26, 31, 38, 46] as was the destruction of aecia "by hand."[3, 27] Based on the assumption that an increase in vigor of asparagus plants would bring about a reduction in the severity of rust, irrigation[3, 44, 45] and fertilizer[8] in the form of nitrate of soda at 100 to 200 pounds per acre were recommended. In Iowa, however, fertilizers were reported as ineffective in preventing the disease.[38]

Resistant varieties. The preliminary work[45] on spraying and varietal tests brought out the fact that certain European varieties were more rust-resistant than American varieties. Argenteuil, the most rust-resistant European variety grown in the United States, and Palmetto, the most resistant American variety, appear to be the same plant. All other American varieties were apparently descended from Conover's Colossal and were susceptible.

Halsted and Kelsey[18] ascertained the susceptibility of eight varieties. The percent of infection for three years is listed below:

	1901	1902	1903
	perct.	*perct.*	*perct.*
Palmetto and Argenteuil	Trace	Trace	Trace
Mammoth and Elmira	20	25	10
Columbian, Colossal, Brunswick, and Crossbred	50	75	10

The apparent resistance shown by Palmetto and Argenteuil at the turn of the century disappeared, as is evidenced by the severe outbreaks of rust which appeared in later plantings of these varieties.

In order to find a new source of resistance, a selection program was undertaken by Norton[35] for the Massachusetts Asparagus Growers Association. As a result of selections from the European varieties Reading Giant and Argenteuil, he found one male and two female plants whose progeny showed rust resistance. Greenhouse infection by artificial inoculation was not achieved, but fortunately from a plant breeder's point of view, severe outbreaks of rust appeared in the experimental plots during the years in which selections were made. In fact infections were so severe that Norton was able to select only one plant in 600 as superior to the others. Occasionally aecia were more numerous on lines which showed resistance to uredinial infection. Norton concluded that heterozygote asparagus plants are intermediate in rust-resistance. No inbreeding was attempted in this program inasmuch as the asparagus plants are dioecious.

The nature of the resistance of asparagus to the rust fungus has received some consideration, but no definite conclusions have been drawn. Halsted[17] believed that the less susceptible varieties were those with thicker cuticle. In an attempt to increase the thickness of the cuticle layer, he applied gelatine, creolin, glue, lime, milk, and soap to the different groups of stems. However, he was of the opinion that his experiments were on too small a scale to warrant any conclusions. Norton[35] states in his summary that "rust resistance in asparagus seems to be based on structural differences." This hypothesis seems to stem from his observations that resistant plants appear to have smaller stomates and that mature, hardened stems show less rust during epidemics.

Inoculation studies

Four references which discuss attempts at artificial inoculation of *Puccinia asparagi* on *A. officinalis* may be found in the literature. Sheldon[42] reported successful inoculations in which urediospores were applied to wet plants, but he failed to specify any details as to the method of inoculation, percent of infection, severity of infection, or varieties employed.

Ogilvie and others[36] inoculated emerging spears by suspending over them stems bearing telia. Norton[35] was unable to produce greenhouse infection and therefore depended on natural infections.

Clinton and McCormick[11] inoculated detached cladophyls and

Table 2. — Record of *Puccinia asparagi* Spore Collections

No.	Stage[a]	Date received	Collector	Variety	Locality of collection
1	I	6/14/49	Kahn	Washington	Rossville, Ill.
2	II	7/6/49	Kahn	Washington	Rossville, Ill.
3	II	7/11/49	Semeniuk	Paradise	Ames, Iowa
4	II	7/20/49	deZeeuw	Seneca Washington	East Lansing, Mich.
5	II	8/1/49	Haenseler	Washington	Bridgeton, N.J.
6	II	8/2/49	Walker	.....	Ripon, Wis.
7	III	8/3/49	Semeniuk	Paradise	Ames, Iowa
8	II	8/14/49	Kahn	Washington	Rossville, Ill.
9	II	8/19/49	Kahn	Washington	Rochelle, Ill.
10	III	8/29/49	Kahn	Washington	Rossville, Ill.
11	III	10/27/49	Kahn	Washington	Rossville, Ill.
12	III	10/28/49	Nagel	.....	Brookings, S. Dak.
13	III	11/4/49	Hepler	Washington	Rochelle, Ill.
14	III	11/9/49	Haenseler	Washington	New Port, N.J.
15	III	11/9/49	Haenseler	Martha Washington	New Port, N.J.
16	III	1/3/50	Semeniuk	Paradise	Ames, Iowa
17	III	2/1/50	Kahn	Washington	Rossville, Ill.
18	III	2/1/50	Kahn	Washington	Rossville, Ill.
19	III	2/10/50	deZeeuw	.....	East Lansing, Mich.
20	III	3/3/50	Kahn	Washington	Rochelle, Ill.
21	III	4/20/50	Kahn	Washington	Rochelle, Ill.
22	III	5/1/50	Kahn	Washington	Rochelle, Ill.
24	III	4/28/50	Kahn	Washington	Rossville, Ill.
25	O & I	6/12/50	Kahn	Washington	Rochelle, Ill.
26	II	7/8/50	Kahn	Washington	Rochelle, Ill.
27	II	7/24/50	Kahn	Washington	Rochelle, Ill.
28	II	7/22/50	Boyd	Mary Washington	Hampshire City, Mass.
29	III	7/22/50	Boyd	Mary Washington	Hampshire City, Mass.
30	II, III	8/4/50	Kahn	Washington	Rochelle, Ill.
31	II, III	8/22/50	Kahn	Washington	Rossville, Ill.
32	III	8/24/50	Kahn	Washington	Rochelle, Ill.
33	III	8/31/50	Christenson	Wild asparagus	Ft. Snelling, Minn.
34	III	9/12/50	Kahn	Washington	Urbana, Ill.
35	III	9/14/50	Kahn	Washington	Urbana, Ill.
36	II, III	9/16/50	Kahn	Washington	Urbana, Ill.
37	III	9/20/50	Nagel	Washington	Brookings, S. Dak.
38	III	9/26/50	Kahn	4-5 × 3-9	St. Paul, Minn.
39	III	9/27/50	Kahn	Washington	Rochelle, Ill.
40	III	9/29/50	deZeeuw	Washington	Hartford, Mich.
41	III	9/29/50	deZeeuw	Paradise	Paw Paw, Mich.
42	III	9/29/50	deZeeuw	Washington	Paw Paw, Mich.
43	III	10/6/50	Floate	Washington	Berrien County, Mich.
44	III	10/6/50	Floate	Washington	Paw Paw, Mich.
45	III	10/6/50	Floate	Washington	Allegon County, Mich.
46	III	10/6/50	Floate	Washington	Berrien County, Mich.
47	III	10/6/50	Floate	Washington	Allegon County, Mich.
48	III	10/9/50	Haenseler	Washington	Dutch Neck, N.J.
49	III	10/9/50	Haenseler	California 500	Bridgeton, N.J.
50	III	10/9/50	Haenseler	Washington	Bridgeton, N.J.
51	III	10/9/50	Haenseler	Paradise	Bridgeton, N.J.
52	III	10/15/50	Haenseler	Washington	Mullica Hill, N.J.
53	III	10/15/50	Haenseler	Washington	Shirley, N.J.
54	III	10/15/50	Haenseler	Washington	Mullica Hill, N.J.
55	III	10/17/50	Kahn	Washington	Rochelle, Ill.
56	III	10/24/50	Kahn	Washington	Urbana, Ill.
57	III	10/30/50	Kahn	Washington	Urbana, Ill.
58	III	11/1/50	Kahn	Washington	Urbana, Ill.
59	III	11/4/50	Semeniuk	.....	Ames, Iowa
60	III	11/6/50	Christenson	.....	St. Paul, Minn.
61	III	11/9/50	Kahn	Washington	Urbana, Ill.
62	III	11/14/50	Boyd	Washington	Massachusetts
63	III	12/6/50	Boewe	.....	Genoa, Ill.
64	III	1/11/51	Castenson	Washington	Rochelle, Ill.
65	III	1/24/51	Kahn	Washington	Urbana, Ill.
66	III	2/10/51	Kahn	Washington	Urbana, Ill.
67	III	3/1/51	Kahn	Washington	Urbana, Ill.
68	III	4/25/51	Kahn	Washington	Rochelle, Ill.
69	III	5/3/51	Castenson	Washington	Rochelle, Ill.
70	III	5/28/51	Kahn	Washington	Rochelle, Ill.

[a] O = pycnia, I = aecia, II = uredinia, III = telia.

branches of *A. officinalis* with urediospores and used petri dishes as moist chambers. These investigators were unable to infect asparagus tissue so treated, although nine species of *Puccinia* out of the nineteen which were tested produced infection on other susceptible plants.

RESEARCH ON DISEASE AND PATHOGEN UNDER ILLINOIS CONDITIONS

Rust Spore Collections and Asparagus Seed Accessions

Collections of the spores of *Puccinia asparagi* as well as of the seeds of *Asparagus officinalis* were made over a two-year period (1949-1951). The pertinent data on these collections are included in Tables 2 and 3. The accession numbers given these collections are used for identification and reference in the rest of this bulletin.

Table 3.— Record of *Asparagus officinalis* Seed Accessions

Accession No.	Variety	Stock No. if any	Source of seed
23	Mary Washington	13 B	Vaughan Seed Company, Chicago, Ill.
24	Palmetto	....	T. W. Wood and Sons, Richmond, Va
25	Paradise	14 B	Vaughan Seed Company, Chicago, Ill.
26	Palmetto	....	T. W. Wood and Sons, Richmond, Va.
27-29	Individual plant selections from "V35"	....	Disease-free open-pollinated female plants from Hort. Exp. Sta., Vineland Station, Ontario, Canada
37	Conover's Colossal	....	Hurst & Sons Ltd., Houndsditch, London, England
38	Carter's Mammoth Emperor	....	Carter's Seed Co., Raynes Park, London, England
39	Early Argenteuil	....	Vilmorin-Andrieux, Paris, France
40	Late Argenteuil	....	Vilmorin-Andrieux, Paris, France
41	Snowhead	....	Vilmorin-Andrieux, Paris, France
42	Mary Washington	637/55	Northrup, King & Co., Minneapolis, Minn.
43	Mary Washington	....	George Pedrick, Pedricktown, N.J.
44	Mary Washington	10981	Ferry-Morse Seed Co., Detroit, Mich.
45	Mary Washington	70248	Ferry-Morse Seed Co., Detroit, Mich.
46	Mary Washington	7090	L. L. Olds Seed Co., Madison, Wis.
47	Mary Washington	....	Corneli Seed Company, St. Louis, Mo.
48	Mary Washington	2052	Herbst Brothers, New York City
49	California 500	....	D. V. Burrell, Rocky Ford, Colo.
50	Mary Washington	....	D. V. Burrell, Rocky Ford, Colo.
51	Mary Washington	449	W. Atlee Burpee, Philadelphia, Pa.
52	Washington	....	T. W. Wood and Sons, Richmond, Va.
53	Washington	....	Robert Buist & Company, Philadelphia, Pa.
54	Mary Washington	....	H. S. Huber, Pedricktown, N.J.
55	Mary Washington	1401	Barteldes Seed Company, Denver, Colo.
56	Washington	....	Ritter Seed Company, Bridgeton, N.J.
57	Washington bulk selection	....	Plants twice selected for rust resistance at Reg. Veg. Breeding Lab., Charleston, S.C.
58	Washington bulk selection	....	Seven strains of plants from Reg. Veg. Breeding Lab., Charleston, S.C.
59	California 500	39039	F. H. Woodruff & Sons, Milford, Conn.
60	Mary Washington	7-230-3	F. H. Woodruff & Sons, Milford, Conn.
61	4-5 × 3-9	....	L. M. Currence, Minn. Agr. Exp. Sta., St. Paul
62	KBF (Kidner's "pedigree")	....	L. M. Currence, Minn. Agr. Exp. Sta., St. Paul
63	Viking	....	Hort. Exp. Sta., Vineland Station, Ontario, Canada
64	Washington	00962	Aggeler-Musser Seed Co., Los Angeles, Calif.
65	Paradise	00963	Aggeler-Musser Seed Co., Los Angeles, Calif.

Dormancy of Teliospores

Physical and chemical agents have been used to stimulate spore germination and to break or shorten the dormancy of teliospores. Alternation of wet, dry, hot, and cold conditions and benzaldehyde have broken the dormancy of the teliospores of *Puccinia graminis tritici*;[34] and carbohydrates, nitrogen sources, furfuraldehyde, organic acids, mineral acids, and wetting agents have been effective in stimulating spore germination in other fungi.[14, 30, 32, 51]

Experiments were set up to determine the effect of these and other physical and chemical agents on the dormancy of teliospores of *Puccinia asparagi*. In germination tests, dormancy was considered broken artificially when promycelia were produced by treated spores earlier than by untreated spores collected periodically from the field. Unless otherwise indicated, the tests were made in triplicate with spores in drops of sterile distilled water on glass slides in moist chambers and on 2-percent water-agar in stacks of Syracuse watch glasses. Observations were made at the end of 24 and 72 hours.

The controls in these tests were teliospores collected from the field at Rossville and Rochelle during the 1949-50 season and at Urbana and Rochelle during the 1950-51 season (Table 4).

For the most part, collections of teliospores made before April did not germinate, whereas those made after April did germinate (see Table 4). Dormancy therefore appears to be an essential factor in teliospore germination.

Table 4. — Observations on the Breaking of Dormancy of Teliospores Overwintering Under Field Conditions in Illinois

Locality and overwintering season	Number of collections	Inclusive dates of observation	Dormancy broken[a]
Rossville, 1949-50	3	8/29 to 1/10	−
	2	2/1 to 4/28	+
Rochelle, 1949-50	2	2/5 to 3/3	−
	2	4/20 to 5/1	+
Urbana, 1950-51	15	9/2 to 4/2	−
	8	4/10 to 7/5	+
	2	7/15 to 7/25	−
Rochelle, 1950-51	2	10/17 to 3/11	−
	2	4/25 to 5/3	+

[a] (+) = Dormancy broken. (−) = Dormancy not broken.

Physical stimuli

The physical conditions employed to break teliospore dormancy consisted of (1) alternate freezing and thawing, (2) gradual drying, (3) alternate wetting and drying, and (4) storage at various constant temperatures and humidities.

In the alternate freezing and thawing experiments conducted in 1949, two methods were employed. In one method, teliospores were stored in sealed 23 x 65 mm. glass vials at successive temperatures of −10° F. for 2 to 6 hours, 35° for 24 hours, and then at room temperature for 48 hours. This cycle of temperatures was repeated twelve times. Germination tests were made at the end of each room-temperature period. Samples stored continuously at each temperature were also included in the germination tests. In the second method, portions of stems bearing telia were (1) soaked in water for one hour and then placed in sealed 500-cc. Erlenmeyer flasks, (2) not soaked but placed in sealed flasks, (3) not soaked but placed in sealed flasks containing 5 cc. of water, or (4) not soaked but placed in unstoppered flasks. Three flasks of each of these treatments were stored at −10° and 24° F. for 8 to 24 hours followed by 68° F. for 24 hours. Germination tests were made at the end of each thaw during a 30-day period. None of these freezing-thawing treatments stimulated the germination of teliospores.

In alternate freezing and thawing experiments conducted in 1950, portions of stems bearing telia were wrapped in moist cheesecloth and stored in sealed 23 x 100 mm. glass vials for 12 hours at either −25°, −10°, 24°, or 35° followed by 24 to 36 hours at 68° F. This cycle of temperatures was repeated fifteen times. Germination tests were made at the end of each thaw period on these samples as well as on samples stored continuously at each temperature. None of the treatments broke the dormancy of the teliospores.

The effect of the gradual drying out of teliospores on their dormancy was investigated with sulfuric acid and calcium chloride as desiccants. Stems bearing telia from Collection 35 were placed in each of two desiccators on September 9, 1950. Sulfuric acid (specific gravity 1.84, 96.3 percent) was placed in one desiccator and then both were sealed. Telia from Collection 57 were placed in each of four desiccators on November 11, 1950. Calcium chloride, technical grade, was placed in two of the desiccators and all four were sealed. Two of the desiccators, one with calcium chloride and one without, were placed at 38° F., while the other two were stored at 68° F. At intervals of 6 to 14 hours, telia were removed and the teliospores tested for germination. None of these treatments broke the dormancy of the teliospores.

The effect of alternate wetting and drying on the dormancy of teliospores was investigated during the 1949-50 season using Collections 10, 11, 12, and 13, and during the 1950-51 season using Collections 35, 39, 41, 55, and 56. These teliospores were placed in drops of sterile

distilled water and examined for promycelia after 24 and 72 hours. The water was allowed to evaporate and the slides with their spores were stored at 68° to 72° F. for 3 to 5 days. Then the spores were covered with sterile distilled water and re-examined for promycelia at the end of 24 and 72 hours. This wet-dry cycle was repeated ten times, but none of the treatments broke the dormancy of teliospores.

The effect of constant temperatures and constant humidities on the dormancy of teliospores was investigated in 1950 and 1951. In 1950 teliospores, or portions of stems bearing telia, were stored in 23 x 65 mm. sealed glass vials at 24°, 35°, 50°, and 60° F. and at room temperature and outdoors. In 1951 telia were stored in 23 x 100 mm. glass vials at temperatures of −25°, −10°, 24°, 35°, 50°, 68°, and 86° F. and outdoors. The temperatures above 35° were held constant in chambers equipped with 150-watt light bulbs or heat elements, or both, and a coiled metal-strip thermostat with a sensitivity of about 3 degrees; the temperatures below 24° were held constant in cold-storage rooms. Constant relative humidities of 20, 35, 56, 75, and 95

Table 5. — Breaking of Dormancy by Teliospores Collected During 1950-51 Season and Stored at Various Temperatures and Humidities

Collection No. and locality	Temperatures (°F.)			Temperatures with 56 percent humidity				Relative humidities at constant temperature of 68° F.					Outdoors (humidity and temperature not controlled)
	−25°	−10°	24°	35°	50°	68°	86°	20	35	56	75	95	
29 Massachusetts	−	−	−	−	−	−	−	−	−	−	−	−	−
30 Rochelle, Ill.	−	−	−	+	−	−	−	−	−	−	+	−	−
31 Rossville, Ill.	−	−	−	+	+	−	−	−	−	+	+	−	+
33 Rochelle, Ill.	−	−	−	+	+	+	−	−	−	−	−	−	−
35 Urbana, Ill.	−	−	−	+	−	−	−	−	−	−	−	−	−
36 Urbana, Ill.	−	−	+	−	−	+	−	−	−	+	−	−	+
38 Minnesota	−	−	−	−	−	−	−	−	−	−	−	−	−
39 Rochelle, Ill.	−	−	−	+	+	+	−	−	−	+	+	−	−
47 Michigan	−	−	−	−	−	−	−	−	−	−	−	−	−
48 New Jersey	−	−	−	−	−	−	−	−	−	−	−	−	−

(+) = Dormancy broken. (−) = Dormancy not broken.

percent were maintained for each temperature between 35° and 86° by placing in each vial saturated inorganic salt solutions[a] separated from the asparagus stems by a false bottom of perforated cork. Teliospore Collection 17, which had broken its dormancy under field conditions at Rossville, was included in all treatments to determine whether

[a] The saturated salt solutions that were used and their relative humidities at 68° F. in sealed containers were: $KC_2H_3O_2$, 20 percent; $MgCl_2 \cdot 6H_2O$, 33 percent; $Ca(NO_3)_2 \cdot 4H_2O$, 55 percent; $NaNO_3$, 75 percent; KNO_3, 95 percent.[23] The difference in the relative humidities averaging 2 percent was caused by the difference in the moisture-holding capacity of the atmosphere at 38°, 50°, 68°, and 86° F.

Table 6. — Breaking of Dormancy by Teliospores Collected During 1949-50 Season and Stored at Various Temperatures, Humidity Not Controlled

Collection No. and locality	Temperatures at which dormancy was broken					
	24° F	35° F	50° F	60° F	Room temperature	Outdoors
10 Rossville, Ill.	+	+	+	−	−	+
11 Rossville, Ill.	−	+	−	−	+	+
12 South Dakota	−	+	−	−	−	−
13 Rochelle, Ill.	−	+	−	−	+	+
16 Iowa	−	−	−	−	−	−
17 Rossville, Ill.[a]	+	+	+	+	+	+
19 Michigan	−	−	−	−	−	−

(+) = Dormancy broken. (−) = Dormancy not broken.

[a] This collection had broken its dormancy under field conditions. However, it received the same treatments as other collections in order to ascertain whether these treatments inhibited promycelium production once dormancy was broken. The collection continued to germinate at all storage temperatures.

the treatments had any adverse effect on germination once dormancy was broken (Tables 5 and 6).

It was found that most of the collections of teliospores in storage and teliospores that overwintered in the field broke their dormancy at about the same time. The authors do not consider the breaking of dormancy by the teliospores in storage to have been artificially caused, but wish to point out that these spores germinated after a period of dormancy without ever having been subjected to cold temperatures.

Chemical agents

Chemical agents in the form of organic acids, mineral acids, wetting agents, aldehydes, and other compounds and extracts were used in tests to determine their effect on the dormancy of teliospores of *P. asparagi* from Collections 35 and 39. These compounds or extracts were used in ten-fold dilutions between 1/100 and 1/100,000,000. The treatments for testing germination were as follows: (1) spores placed in drops of the test chemical on glass slides in moist chambers; (2) spores placed in 3 cc. of the test chemical in stacks of Syracuse watch glasses: (3) telia soaked for 1 hour in the test chemical, rinsed in distilled water, placed in test-tube moist chambers for 24 hours, and spores then removed and examined under the microscope for promycelia; (4) same as 3 above but telia soaked for 4 hours; (5) same as 3 but telia soaked for 24 hours; (6) telia soaked in the test chemical for 1 hour, rinsed in distilled water, and teliospores placed in drop of distilled water on glass slides in moist chambers for 24 hours; and (7) same as 6 but telia soaked for 4 hours.

The compounds and extracts that were used in these tests are

listed below, followed by numbers that refer to the treatments described in the preceding paragraph: acetic, nitric, hydrochloric, and sulfuric acid, and sodium hydroxide (1, 6); citric acid, furfuraldehyde, salicylaldehyde, and benzaldehyde (1 to 7); frozen orange juice (1, 2, 3); asparagus stubble extract, asparagus tissue extract, canned asparagus extract, and soil extract (1, 2); soap, Kleermor detergent, Dreft, paraffin oil, and Emerson's broth (1, 3); sucrose, malt extract, maltose, peptone, and yeast extract (1, 6); tap water, distilled water, redistilled water, and charcoal distilled water (1). None of the test compounds and extracts under the conditions employed stimulated dormant teliospores to produce promycelia.

Urediospore Germination

A preliminary experiment was set up to ascertain whether urediospores collected from one sorus would show any significant variation in percent of germination from those collected on adjacent sori or from sori on other stalks. Five stalks bearing uredinia were therefore selected at random from a field at Rossville on August 14, 1949 and on August 29, 1949. The urediospores from each of ten successive sori on each stalk were placed in separate drops of sterile distilled water on glass slides in a moist chamber. At the end of 24 hours the percentage of germination was determined from four counts of 100 spores each (Table 7). The results indicate that in order to obtain uniform germination, urediospores from numerous sori in a given collection should be thoroughly mixed.

Six methods of urediospore storage at six temperatures were compared in three replications in order to determine the most satisfactory

Table 7. — Variability in Germination of Urediospores Obtained From Adjacent Sori on the Same Stalk

Sorus No.	Percent germination in collection of August 14, 1949					Percent germination in collection of August 29, 1949				
	Stalk 1	Stalk 2	Stalk 3	Stalk 4	Stalk 5	Stalk 1	Stalk 2	Stalk 3	Stalk 4	Stalk 5
1	80	0	83	91	82	90	89	25	67	90
2	60	38	29	76	80	81	91	86	9	70
3	33	82	78	21	25	79	7	83	80	91
4	76	74	29	62	90	64	43	9	46	85
5	80	43	71	91	76	19	70	36	16	75
6	28	5	72	89	91	83	7	39	87	92
7	88	80	28	96	89	24	96	52	83	86
8	65	80	76	88	10	86	0	9	91	93
9	91	91	83	78	83	70	84	62	38	72
10	88	20	11	92	84	86	88	48	57	80
Average	69	51	56	78	71	68	57	45	57	83

Table 8. — Number of Weeks After Collection During Which Urediospores Remained Viable When Stored at Six Different Temperatures and Under Six Methods of Storage[a]

(Each figure is the average of three replications)

Temperatures	Number of weeks urediospores remained viable under six methods of storage						Average
	1	2	3	4	5	6	
	weeks	*weeks*	*weeks*	*weeks*	*weeks*	*weeks*	*weeks*
−10° F.	3	3	4	1	2	1	2
24° F.	9	10	6	3	4	3	6
38° F.	20	30	28	17	20	26	23
50° F.	18	23	17	12	16	18	17
60° F.	13	19	14	11	13	16	14
Room temperature	12	17	12	8	12	13	12
Average	12	17	13	8	11	13	..

[a] Methods of storage: (1) urediospores sealed in 23 x 65 mm. glass vials; (2) uredinia sealed in 23 x 65 mm. glass vials; (3) uredinia, stems wrapped in kraft paper; (4) uredinia, stems unwrapped; (5) uredinia, stems in paper bags; (6) uredinia, stems in glass milk bottles.

method for prolonging the viability of urediospores to be used in germination and inoculation experiments. The temperatures used were −10°, 24°, 38°, 50°, and 60° F. and room temperature. The 50° and 60° temperatures were maintained in constant-temperature chambers while the −10°, 24°, and 38° temperatures were maintained in cold-storage rooms. Germination tests were made periodically with spores in drops of distilled water on glass slides in moist chambers.

The results (Table 8) indicate that sealing uredinia in vials is the best method of storage regardless of the temperature and that 38° is the best temperature regardless of the method.

The effect of temperature on the germination of urediospores of three collections was determined by means of germination tests on spores in drops of distilled water on glass slides in moist chambers at 35°, 50°, 60°, 68°, and 86° F. At the end of 24 hours, two counts of 200 spores were made in each of 3 replications.

The results (Table 9) indicate that urediospore germination takes place at the higher temperatures that correspond to temperature conditions during the asparagus-growing season.

The effect on the germination of dry urediospores, of the atmospheric humidity immediately surrounding them, was investigated in September, 1950, with Collections 35 and 38. Constant humidities were maintained by placing the appropriate saturated inorganic salt solutions[a] in sealed van Tieghem cells at 68° ± 2° F. At the end of 24

[a] $KC_2H_3O_2$, 20 percent; $MgCl_2 \cdot 6H_2O$, 35 percent; KNO_2, 45 percent; $NaNO_2$, 66 percent; $K_2Cr_2O_7$, 88 percent; K_2HPO_4, 92 percent; $Na_2HPO_4 \cdot 12H_2O$, 95 percent; $PbNO_3$, 98 percent; distilled water, 100 percent.[23]

Table 9. — Germination of Urediospores in Distilled Water at Various Temperatures

(Each figure is the average of six counts of 200 spores each)

Collection No. and locality	Percent germination at temperatures indicated				
	35° F.	50° F.	60° F.	68° F.	86° F.
26 Rochelle, Ill.	11	67	75	77	70
31 Rossville, Ill.	6	76	80	76	80
36 Urbana, Ill.	21	58	69	81	68

hours one count was made of 200 spores in each of four van Tieghem cells for each collection at each relative humidity. As a control, one count was also made of 200 urediospores in each of six drops of distilled water on glass slides in moist chambers.

The results indicated that free moisture is necessary for urediospore germination since 79 percent of the urediospores did germinate in the distilled water control while no germination by dry urediospores was observed.

The effect of the hydrogen ion concentrations on germination was investigated with urediospores collected at Urbana. Buffered systems were obtained when .01 M solutions of two adjacent salts in the series H_3PO_4, KH_2PO_4, K_2HPO_4 and K_3PO_4 were mixed. This system was selected because the ions in the concentrations used are not fungitoxic. Half a milliliter of a urediospore suspension containing 250,000 urediospores per milliliter (as determined by a haemacytometer) was added to 3 ml. of each buffered system. Three drops of the buffered urediospore suspension were placed on each of two glass slides in a moist

Table 10. — Urediospore Germination[a] After 24 Hours in Systems Buffered Between pH 2.5 and 11.1

(Each figure is the average of six counts of 200 urediospores each)

Ratio of buffer system components[b]				pH	Percent germination		
H_3PO_4	KH_2PO_4	K_2HPO_4	K_3PO_4		Average	Minimum	Maximum
4	1	..	..	2.5	0	0	0
1	9	..	..	3.5	1	0	1
1	45	..	..	4.8	28	20	36
..	9	1	..	6.3	76	65	80
..	1	1	..	6.9	75	68	82
..	1	9	..	7.7	78	65	86
..	1	19	..	8.5	48	41	55
..	..	4	1	9.8	3	1	6
..	..	1	1	10.8	0	0	0
..	..	1	4	11.1	0	0	0

[a] Distilled-water controls showed an average germination of 80 percent.
[b] Approximately 0.01 M.

chamber for 24 hours. One count was made of 200 spores in each of the six drops.

The data in Table 10 show that urediospores germinate in buffers between pH 3.5 and 9.8, but that most of these germinated between pH 6.3 and 7.7, which corresponds with the probable pH's of field germination.

Inoculation Techniques

Aeciospores

Aeciospores were used as a source of inoculum in two replicates each consisting of 20 Palmetto and 40 California 500 seedlings. These spores, collected from the field in Urbana on May 9, 1951, were either mixed with talc and dusted on the plants or suspended in distilled water and sprayed on the plants. Plants thus inoculated were incubated for 36 hours in a moist chamber into which distilled water was atomized intermittently.

At the end of 21 days, infection in the Palmetto plants averaged 56 percent, with an average of 2.3 uredinial sori per infected plant; while the infection in the California 500 plants amounted to 33 percent, with an average of 3.1 uredinial sori per plant. However, inasmuch as the aeciospores in storage failed to germinate after three weeks and aecial production in the field ceased after the second week in June, aeciospore inoculation experiments were discontinued.

Urediospores

Urediospores were used as a source of inoculum in tests conducted during the summers of 1949, 1950, and 1951. Negative results were obtained in 1949 probably because free moisture was not maintained on the plants during the inoculation period. In 1950 and 1951, Glass-o-net moist chambers (see Fig. 5) were used. Each chamber contained two DeVilbiss No. 15 atomizers through which distilled water was forced at 10 pounds pressure, creating artificial dews.

The methods of inoculation which were tried on various species and varieties of *Asparagus* were: (1) urediospores mixed with talc and dusted,[a] (2) urediospores suspended[b] in (a) distilled water, (b) 5-percent sucrose solution, (c) 0.2-percent Dreft solution, or (d) warm 0.1-percent water-agar solution, and sprayed; (3) urediospores injected

[a] The urediospore-talc mixture was prepared as follows: Urediospores and the tissue covering and underlying uredinial sori were scraped from heavily infected asparagus stems with a scalpel. About three grams of this mixture were rotated in a 1000-cc. Erlenmeyer flask with 100 grams of quartz sand in order to remove urediospores adhering to this suscept tissue. Five hundred grams of talc were mixed with quartz sand-urediospore-suscept tissue mixture.

[b] Two grams of the urediospore-suscept tissue mixture were mixed with 400 cc. of spraying solution and filtered through four layers of cheesecloth.

Artificial dew on asparagus seedlings (*upper picture*) created by atomizing distilled water in moist chambers. The Glass-o-net moist chambers used in the greenhouse inoculation tests are shown in lower picture. (Fig. 5)

into stems by means of a Yale B-D Lok 24-gauge hypodermic needle; (4) urediospores applied to wet plants with a camel's hair brush; (5) urediospores suspended in distilled water in glass vials into which the ends of lateral branches were immersed for 24 hours (Table 11).

Since dusting with the spore-talc mixture or spraying distilled-water spore suspensions appeared to be the most satisfactory and practical methods of inoculation, further greenhouse experiments were initiated to investigate some of the other factors which influence the

Table 11. — Percentage of Infection Obtained With Various Methods of Inoculation With Urediospores on Several Species and Varieties of *Asparagus* and *Allium*

Materials	Experiment No.	Variety of species	Number of plants treated	Number of plants infected	Percent of plants infected
Inoculation by dusting					
Talc	1	Palmetto	49	40	82
	2	Palmetto	25	25	100
	2	Paradise	22	18	82
	2	California 499	50	49	98
	5	Palmetto	10	9	90
	5	Paradise	10	8	80
	5	*A. sprengeri*	5	0	0
	5	*A. plumosus*	5	0	0
	5	*Allium cepa*	5	0	0
Inoculation by spraying					
Distilled water	3	Palmetto	25	25	100
	3	California 499	25	24	96
	3	California 500	25	24	96
	4	Paradise	14	13	93
	4	Washington	15	13	87
	6	Palmetto	15	15	100
	6	*A. sprengeri*	5	0	0
	6	*A. plumosus*	5	0	0
	6	*Allium cepa*	5	0	0
	7	Palmetto	15	14	94
	7	Washington	45	40	88
	8	Palmetto	33	24	73
	8	Paradise	22	16	64
	8	Washington	17	15	88
5 percent sucrose	4	Palmetto	20	6	30
	4	Paradise	20	9	45
0.2 percent Dreft	4	Palmetto	10	6	60
	4	Paradise	10	7	70
	4	Washington	10	7	70
0.1 percent water-agar	4	Paradise	20	2	10
	4	California 500	20	5	25
Other methods					
Hypodermic injection	5	Washington	10	1	10
	6	Washington	12	1	8
Camel's hair brush	5	Palmetto	10	8	80
	6	Washington	10	8	80
Stem tips in vials of spore suspension	5	Palmetto	6	1	16
	6	Washington	8	0	0

Table 12. — Percent of Infection Obtained With Two Methods of Urediospore Inoculation: Spraying and Dusting

(Each treatment consisted of 40 plants)

Moisture condition in moist chamber	Method of inoculation	California varieties	Number of plants infected	Percent of plants infected
Water atomized	Spraying	499	19	48
	Spraying	500	16	40
	Dusting	499	25	63
	Dusting	500	33	83
Water not atomized	Spraying	499	1	3
	Spraying	500	0	0
	Dusting	499	1	3
	Dusting	500	1	3

amount and the severity of infection in the greenhouse. In 1950 these two methods of inoculation were compared as to their effect on two varieties of asparagus in one replication. All the plants were placed under moist chambers, but only half of them were subjected to atomized water (Tables 12 and 13). In 1951 these same methods of inoculation were compared on two varieties of asparagus in three replications (Table 14). Each replication was divided into four groups containing the same number of plants of each variety. One group was inoculated and left uncovered. The other three groups were inoculated and placed in separate Glass-o-net moist chambers. Distilled water was atomized continuously under one chamber, intermittently under the second, and not at all under the third.

Table 13. — Results in Table 12 Summarized According to Comparative Treatments

Treatment	Percent of infected plants	Treatment	Percent of infected plants
Spores sprayed	37.5	Water atomized	97.0
Spores dusted	62.5	Water not atomized	3.0
Spores sprayed, water atomized	97.0	Variety, California 499	47.0
Spores sprayed, water not atomized	3.0	Variety, California 500	53.0
Spores dusted, water atomized	96.6		
Spores dusted, water not atomized	3.4		

Table 14. — Severity of Infection as Influenced by Two Methods of Urediospore Inoculation and by Three Moisture Conditions Within Inoculation Chambers

(Three replications of 10 plants each in each test)

Variety	Moisture condition in inoculation chamber	Percent of plants infected	Average number of sori per infected plant
Inoculation by dusting			
Conover's Colossal	Continuous atomizing	100	42
	Intermittent atomizing	100	43
	No atomizing	3	1
	Uncovered	0	0
California 500	Continuous atomizing	100	23
	Intermittent atomizing	97	21
	No atomizing	0	0
	Uncovered	0	0
Inoculation by spraying			
Conover's Colossal	Continuous atomizing	97	16
	Intermittent atomizing	100	10
	No atomizing	0	0
	Uncovered	0	0
California 500	Continuous atomizing	97	7
	Intermittent atomizing	97	4
	No atomizing	0	0
	Uncovered	0	0

Table 15. — Severity of Infection as Influenced by Age of Plant and Three Different Methods of Inoculation[a]

Variety	Age of plants		Percent of plants infected			Average number of sori per infected plant		
	Stems	Roots	Method 1	Method 2	Method 3	Method 1	Method 2	Method 3
Mammoth Emperor....	1 wk.	6 mo.	90	100	100	7	12	15
	4 wk.	6 mo.	100	100	90	6	14	14
	8 wk.	8 wk.	100	100	100	21	31	38
	9 wk.	6 mo.	90	90	100	10	18	17
California 500.....	2 wk.	2 wk.	60	70	70	2	2	4
	8 wk.	8 wk.	100	100	100	12	21	26
	3 mo.	6 mo.	90	100	100	8	10	13
	6 mo.	6 mo.	80	90	90	12	12	15
Conover's Colossal.....	2 wk.	2 wk.	80	80	80	1	2	2
	8 wk.	8 wk.	100	100	100	15	25	36
	9 wk.	6 mo.	80	90	90	25	31	42
Washington.....	4 wk.	4 wk.	80	80	80	4	8	9
	8 wk.	8 wk.	80	90	90	18	24	32
	4 wk.	1 yr.	70	80	90	4	8	8
	4 wk.	2 yr.	50	80	80	3	7	10
	12 wk.	2 yr.	50	70	70	3	6	6

[a] In Method 1, urediospore suspension was sprayed on plants. In Method 2, urediospore-talc mixture was dusted on dry plants. In Method 3, urediospore-talc mixture was dusted on wet plants. For further particulars see page 24 of text.

Table 16. — Severity of Infection as Influenced by Method of Inoculation and Length of Time Plants Were Held in Moist Chamber After Inoculation

Method of inoculation and date	Hours in moist chamber	Number of plants in each replication	Percent of plants infected	Average number of sori per infected plant[a]
Palmetto				
Dusted 7/12/50.....	15	15	73	....
	24	17	81	....
	40	17	71	....
Sprayed 7/10/50.....	15	15	66	....
	24	15	79	....
	40	15	79	....
Conover's Colossal (two replications)				
Dusted 7/2/51.....	15	30	80	7.6
	24	30	100	11.5
	40	30	97	11.8
Sprayed 7/2/51.....	15	30	76	8.8
	24	30	87	10.0
	40	30	87	11.2
Carter's Mammoth Emperor (two replications)				
Dusted 7/4/51.....	15	20	85	12.4
	24	20	100	15.6
	40	20	95	14.8
Sprayed 7/4/51.....	15	20	75	10.1
	24	20	95	12.9
	40	20	95	13.4

[a] Blanks indicate that observations were not made.

Two other experiments were conducted. In one the relationship between severity of infection and the age of the plants when inoculated were studied. In the other an attempt was made to correlate the degree of infection with the length of time the plants were held in the moist chamber after inoculation (Tables 15 and 16).

Teliospores

Teliospores which had broken their dormancy under field conditions were collected at Urbana and Rochelle and used as inoculum in both greenhouse and field inoculation tests.

Greenhouse inoculations were made on Washington, Palmetto, California 499, California 500, and Paradise varieties. Three methods were employed: (1) stubble containing overwintered telia was presoaked for 1 hour in tap water and suspended above emerging spears in a moist chamber for 48 hours; (2) presoaked stubble was placed on the soil around emerging spears in a moist chamber; and (3) teliospores were sprayed on the surface of wet ground around emerging spears in a moist chamber. The percentage of sporidial infection varied from none to 70 percent. Since temperatures within the moist chamber in the greenhouse rose above 70° F. on certain days in March, April, and May, 1951, it was felt that high temperatures were primarily responsible for the low infection rates in some instances. However, the results were just as erratic when indoor moist chambers held at 50° F. were used.

Two methods of field inoculation were applied to two-year-old Washington plants at Urbana. In one method four treatments were used to test the efficiency of inverted flower pots as field moist chambers: (1) stubble bearing overwinter telia was presoaked in tap water for 2 hours and placed around emerging spears and under 6-inch flower pots (the ground under these pots was thoroughly soaked in order to prolong the drying out of the telia); (2) the presoaked telia were not covered by flower pots; (3) the telia were not presoaked but were covered by pots on soaked ground; (4) the telia were neither presoaked nor covered with pots. The flower pots and inoculum were removed at the end of 40 hours. Each treatment consisted of 10 plants replicated three times and randomized in a field which contained no overwintering inoculum. The results are reported in Table 17.

In the second method, stubble containing overwintered telia was placed on the ground so that it would come in contact with emerging asparagus spears. Moist chambers were not employed. It was necessary to anchor this stubble to the ground with stakes and string in order to

Table 17. — Infection Resulting From Field Inoculations With Teliospores as the Inoculum and Inverted Flower Pots as Moist Chambers, Urbana, Illinois, May 23, 1950

(Ten plants in each replication)

Treatment[a] and replication	Total number of plants showing infection at various dates						
	5/27	5/29	5/31	6/1	6/2	6/6	6/12
Telia presoaked							
Moist chambers							
1	0	1	7	8	9	9	9
2	0	2	6	8	8	10	10
3	0	0	4	5	6	8	8
No moist chambers							
1	0	0	0	1	1	1	1
2	0	0	0	0	0	0	1
3	0	0	0	0	0	0	0
Telia not presoaked							
Moist chambers							
1	0	0	0	0	0	0	0
2	0	0	0	0	1	1	1
3	0	0	0	0	0	0	0
No moist chambers							
1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0

[a] Inoculum and moist chambers removed after 40 hours.

prevent it from being blown away. The inoculum was left in place for 10 days. The results are given in Table 18.

The significance of the data in Tables 17 and 18 is discussed in the discussion section, pages 48-49.

Table 18. — Infection Resulting From Field Inoculations With Teliospores, Urbana, Illinois, May 25, 1950, Without Moist Chambers[a]

(Twenty plants in each replication)

Treatment and replication	Total number of plants showing infection at various dates[b]					
	6/12	6/14	6/18	6/22	6/26	6/30
Inoculated						
1	1	6	11	11	13	13
2	0	0	3	6	9	9
3	2	8	10	14	16	16
4	0	5	8	8	12	12
Control, no inoculation						
1	0	0	0	1[c]	1	1
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0

[a] Overwintered stubble anchored in rows of emerging spears for 10 days. Inoculation dependent on weather conditions.

[b] No infection appeared between June 2 and 10.

[c] One plant infected in check plots; apparently basidiospores were wind-disseminated from inoculum in treated plots.

Fungicides

Protectant fungicides

Protectant fungicides were evaluated in experimental plots located at Urbana and on farms of the Rochelle Asparagus Company, Rochelle, Illinois. At Urbana seven dusts were applied with a Root hand duster to 1/200-acre plots at intervals of 2 to 4 days. At Rochelle seven fungicides were applied as dusts or sprays with ground equipment in 1/20-acre plots at 7- to 10-day intervals, while three were applied as dusts from airplanes on a commercial basis.

Tests at Rochelle. The seven protectant fungicides applied with ground equipment at Rochelle were used at the following rates: (1) 12 percent Fermate dust at 40 pounds per acre, which is equivalent to 3.5 pounds of ferbam (ferric dimethyl dithiocarbamate) per acre; (2) Fermate spray, 4 pounds in 200 gallons of spray per acre, equivalent to 3.0 pounds of ferbam per acre; (3) a mixture of 10 percent Fermate dust and 34 percent Kolodust at 40 pounds per acre, equivalent to 3.0 pounds of ferbam and 13 pounds of sulfur per acre; (4) 12 percent Parzate dust at 40 pounds per acre, equivalent to 3.1 pounds of zineb (zinc ethylene bisdithiocarbamate) per acre; (5) Puratized Agricultural spray, 1:400, at 200 gallons per acre, equivalent to 3 ounces of phenyl mercury triethanol ammonium lactate per acre; (6) Fermate and Kolospray spray, 3 pounds of Fermate and 4 pounds of Kolospray in 200 gallons of spray per acre, equivalent to 2.2 pounds of ferbam and 3.5 pounds of sulfur per acre; and (7) Kolospray, 6 pounds in 200 gallons of spray per acre, equivalent to 5.2 pounds of sulfur per acre. Armour sticker was employed in each treatment at the rate of 3 pounds per 100 pounds of dust or 1 pound in 100 gallons of spray.

These seven fungicides and an untreated check were arranged in a randomized block design in three replications. Each plot was 20 by 100 feet (4 rows of 67 plants each), comprising 1/20 acre and consisting of three-year-old plants of the Washington variety.

Dusts were applied with a Root rotary hand duster, Model C-3B; sprays were applied with the power take-off of a Massey-Harris tractor. The tractor carried a 55-gallon tank and operated at 80 pounds pressure through one nozzle.

Five applications were made between July 7 and August 15, 1950. The growing season started during the last week in May, but the plants did not reach the needle stage until the end of June since they were cut for 10 days. Consequently the first application could not be made until the first week in July. Dusts were applied between 5:30 and 7:00 a.m. in order to take advantage of the dew and the general absence of wind.

Table 19. — Percent of Stems Infected and Severity of Infection After Plots Were Treated With Ground Equipment at Rochelle, Illinois, July 7-August 15, 1950

(One-twentieth acre in each plot)

Treatment at 7- to 10-day intervals[a]	Percent of stems infected[b]	Average severity of infection on infected stems[c]
Fermate dust	61	3.5
Fermate spray	75	2.4
Fermate-sulfur dust	75	2.8
Parzate dust	73	3.0
Puratized Agricultural spray	83	3.4
Fermate-sulfur spray	76	2.7
Sulfur spray	72	2.8
Check, no treatment	84	3.6

[a] See page 31 for concentrations of active ingredients.
[b] Each figure represents an average of three replications of approximately 1,500 stems each, produced by the 240-260 plants in each plot.
[c] For explanation of classes of severity, see Fig. 6 on opposite page.

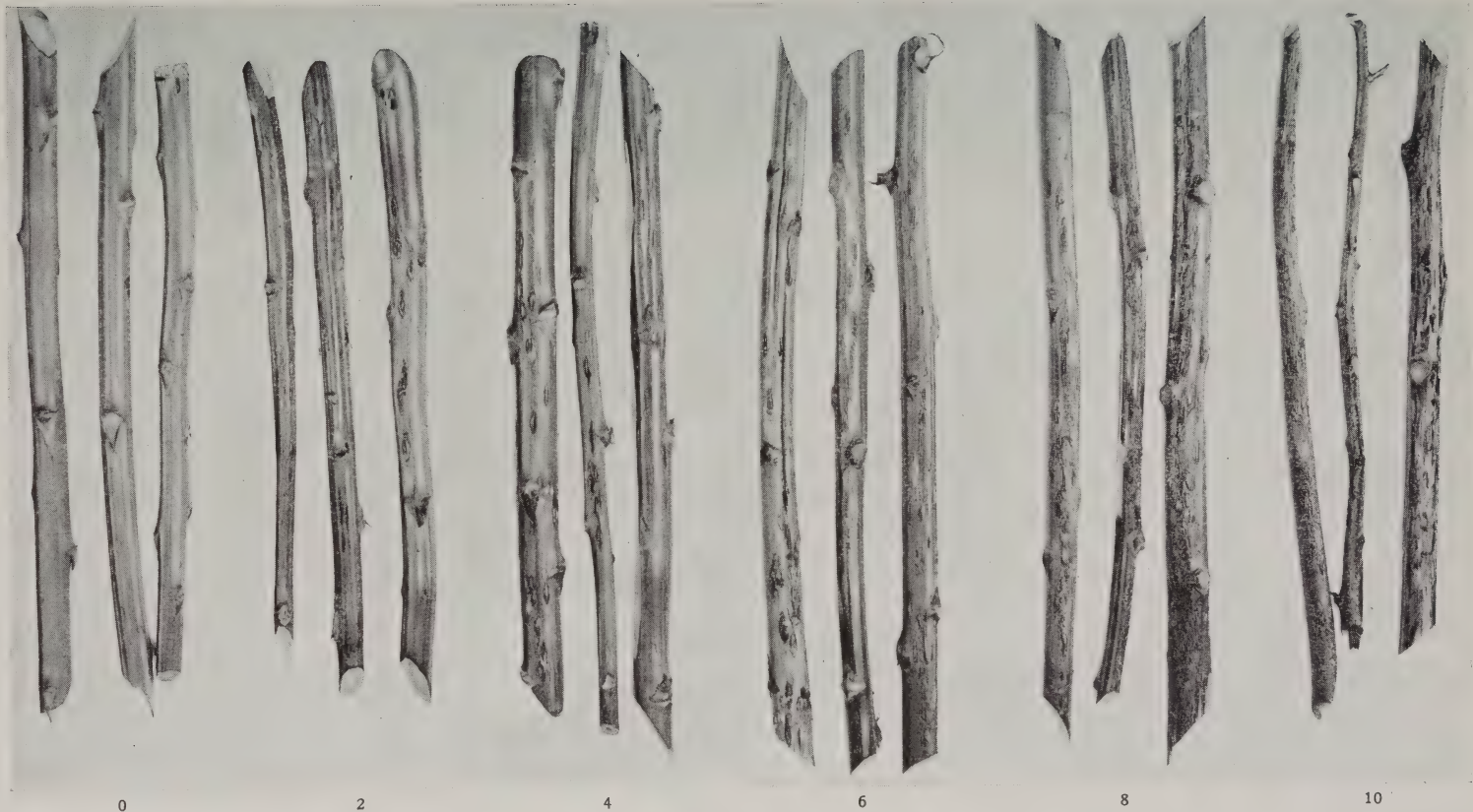
Fourteen days after the last treatment and with a scale ranging from 0 to 10 (0 representing no infection), the fungicides were evaluated by estimating the severity of uredinial and telial infection in two of the four treated rows. The estimates are shown in Table 19; representatives of Classes 0, 2, 4, 6, 8, and 10 are shown in Fig. 6.

The three fungicides which were applied at Rochelle on a commercial basis by airplane dusting were ferbam (10 percent Fermate), zineb (10 percent Parzate), and sulfur (93 percent active ingredient). These dusts were applied in the early morning or late evening when the wind velocity was less than 2 m.p.h. Swaths were parallel to the direction of the rows. The percent of stems showing infection and the average severity of infection on these stems were determined two weeks after the last application (Table 20).

Table 20. — Percent of Stems Infected and Severity of Infection After Airplane Dusting With Three Fungicides on a Commercial Basis at Rochelle, Illinois, June 15-July 7, 1950[a]

Treatment	Rate of application per acre	Number of applications	Number of acres treated	Percent of stems[b] showing infection	Average severity of infection on infected stems[c]
	lb.				
10 percent Fermate	30	3	5	65	5.0[d]
Sulfur	36	1	145	72	4.5[e]
10 percent Fermate	30	2			
10 percent Parzate	30	2	5	85	6.1[d]
Check, no treatment	..	..	5	83	6.0[d]

[a] Dusts applied under supervision of Rochelle Asparagus Company.
[b] P'ants averaged six stems.
[c] For explanation of classes of severity, see Fig. 6 on opposite page.
[d] Determined from four counts of 200 plants each.
[e] Determined from twenty counts of 200 plants each.



Numerical values assigned to different degrees (severity) of rust infection. (Fig. 6)

The results of all ten fungicide tests at Rochelle (Tables 19 and 20) were negative: the fungicides did not control the disease when applied at 7- to 10-day intervals. The lack of control may be attributed to the fact that the asparagus plant sends up new spears and elongates older ones throughout the growing season, so that during the 10-day interval between applications, much of the asparagus tissue is not protected by a deposit of fungicide. Small plots were therefore set up at Urbana and treatments applied more frequently.

Tests at Urbana. Treatments at Urbana were made 2 to 4 days apart. The seven fungicide dusts applied were: (1) 12 percent Fermate (76 percent ferbam, ferric dimethyl dithiocarbamate); (2) 7 percent Crag 658 (32 percent copper-zinc-chromate); (3) Kolodust (87 percent sulfur); (4) 12 percent Dithane Z-78 (65 percent zineb, zinc ethylene bisdithiocarbamate); (5) 10 percent Fermate and 70 percent Kolodust mixture; (6) Tennessee Tribasic Copper Sulfate (98 percent basic copper sulfate); and (7) 10 percent Dithane Z-78 and 70 percent Kolodust mixture. Armour sticker was used in all dusts at a rate of 3 pounds to 100 pounds of dust.

These seven fungicides and an untreated check were arranged in a randomized block design of five replications. Each plot was 5 by 42 feet (one row of 20 plants), comprising 1/200 acre and consisting of three-year-old plants of the Washington variety.

Dusts were applied with a Root rotary hand duster, Model C-3B, in sixteen applications between June 15 and August 20, 1951. The rates of application were: 30 pounds per acre for the first five applications, 45 pounds per acre for the next five applications, and 65 pounds per acre for the last six.

Results were evaluated two weeks after the last treatment by estimating the severity of uredinial and telial infection in each plot. The five replications of the untreated plots showed an average infection of 45 percent of the plants, with an infection index of 2; while the average infection on all treated plots was 48 percent, also with an infection index of 2.[a] Thus the average was almost the same for the treated as for the untreated plots; and under no treatment did the infection vary significantly from the average for all treatments. It is therefore concluded that none of the treatments reduced the severity of rust infection.

[a] An infection index of 2 represents a light infection (Fig. 8). Apparently conditions at Urbana were not conducive to the establishment of rust in spite of a 10-percent aerial infection established by artificial inoculation.

Eradicant sprays

That the number of aecial sori may be reduced following application, during the dormant season, of dinitro-o-cresol to the asparagus stubble bearing overwintering teliospores was indicated by the investigations of Anderson, Thornberry, and Fulton.[2] The most effective treatment of these investigators required 400 to 800 gallons of water per acre. Since it is difficult for the average grower to supply these gallonages, experiments were set up to determine whether reduced gallonages and increased concentrations of the eradicant fungicide would effectively reduce the number of aecia.

Experimental plots were set up at Rochelle, Illinois, in a field of two-year-old Washington plants. The plots were 50 by 112 feet (10 rows of 75 plants each) comprising $\frac{1}{8}$ acre. The sprayer was a Bean sprayer which produced 300 pounds pressure through 16 nozzles with flat cone trajectories adjusted to cover 25 feet, or five rows of asparagus plants. The eradicant was Elgetol, consisting of 34 percent dinitro-o-cresol. Overwintering inoculum was abundant since the field had shown 100-percent infection the previous growing season. Applications were made during October, 1950, and the field was disked in May, 1951.

The treatments were evaluated by determining the number of stalks bearing aecia and the severity of the infection on these stalks (Table 21). Since the entire field in which the plots were located was to be cut for more than 10 days, one row near the center of the ten treated rows in each plot was left uncut so that aecial infection could take place. Index-of-infection readings were made in this uncut row 30 days after the beginning of the growing season. The significance of the results obtained is discussed on page 50.

Table 21. — Percent of Stems Showing Aecial Infection in Eradicant Spray Plots at Rochelle, Illinois, 1949-50 Dormant Season

Treatment			Percent of stems showing amount of infection indicated			
Elgetol	Rate of application per acre	Technical dinitro-o-cresol	1 to 5 aecia	6 to 10 aecia	Over 10 aecia	Total
perct.	*gal.*	*lb.*	*perct.*	*perct.*	*perct.*	*perct.*
1	100	3.3	3	5	18	26
2	100	6.5	2	2	21	25
2	200	13.0	1	4	18	23
8	100	26.0	3	2	17	22
8	200	52.0	2	3	17	22
2	800	52.0	2	4	8	14
None	...	....	3	3	23	29
None	...	....	2	3	22	27

Epidemiology (Epiphytology)

The epidemic aspects of asparagus rust were investigated from two points of view: the general spread of the disease over large areas, and the local spread on individual plants. The factors considered were: (1) volunteer asparagus as a source of primary infection; (2) the effect of "snapping" spears on primary infection; (3) the effect of asparagus planting programs on primary and secondary infection; (4) the dissemination of aeciospores and urediospores by wind, rain, and insects; (5) the role of *Darluca filum* in reducing the severity of the infection; and (6) the importance of dews in rust epidemics.

Volunteer asparagus and primary infection. Near commercial fields in Ogle county and along Route 47 in Kane and Grundy counties volunteer asparagus was observed for signs of the rust fungus in 1949 and 1950. One hundred twenty plants were examined along Route 47 in 1949 and 150 plants in 1950. Only one aecial sorus and no uredinial or telial sori were observed in spite of the fact that both years were severe rust years in northern Illinois. The volunteer asparagus around growers' fields and county roads in Ogle county showed 20 percent uredinial infection in 1949 and 10 percent in 1950. However, since no aecial pustules were observed, wild asparagus was probably not a factor in the primary infection during these years. Nevertheless, if telia are formed on these wild plants, the plants become potential sources of primary infection during the following spring, especially in areas where there are no uncut fields. Destruction of volunteer asparagus[3, 26, 31, 38, 46] is therefore warranted as a precaution.

Effect of "snapping." The effect of "snapping"[a] on primary infection was observed in the field at Rossville, Illinois, and in greenhouse inoculation experiments at Urbana. Field observations indicated that if approximately 8 inches or more of the stalk remains attached to the crown after the spear is snapped, adventitious growth usually appears. On the other hand, when the stub is less than 6 inches long, it invariably dries up within a week.

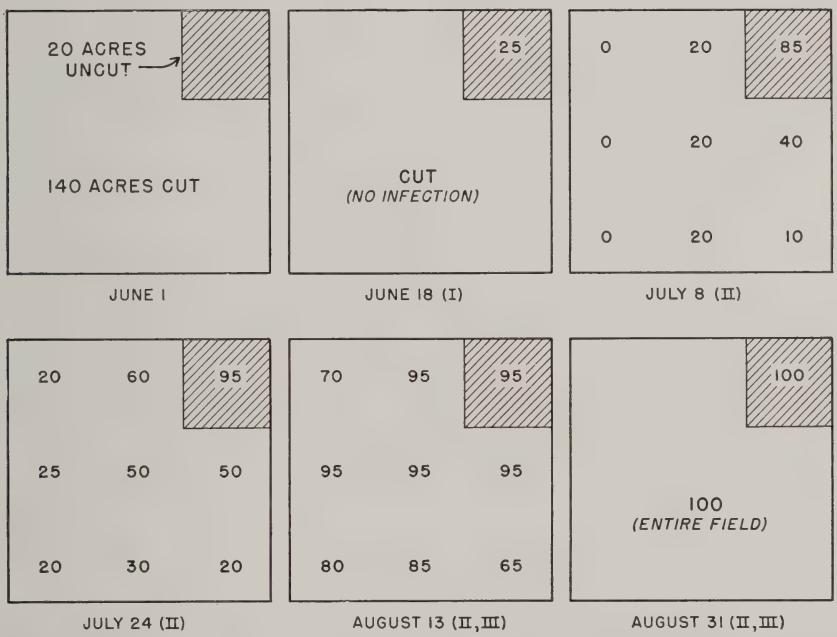
Since there was no aecial infection in the field in which these observations were made (although overwintering inoculum was present), it was necessary to depend on artificial greenhouse inoculation[b]

[a] Spears are either snapped or cut when harvested. If the spear is cut, the worker uses an asparagus knife and severs the spears at or below the ground line and then trims off some of the tough basal portion of the spear before placing it in his basket. If a spear is snapped, the worker breaks off the spear by hand, leaving the tough basal portion attached to the crown.

[b] The inoculation technique employed was the overhead suspension of presoaked overwinter telia as described on page 28.

to ascertain whether this adventitious growth was susceptible to infection by basidiospores. Spears produced by two-year-old crowns of the Washington variety were therefore snapped at 4 or 9 inches above the ground line and inoculated. After 10 days pycnial-aecial sori appeared on the adventitious growth of about one-third of the plants snapped at 9 inches. This infection took place on adventitious growth that was less than 48 hours old when inoculated. The basal portions of spears snapped 4 inches above the ground line dried up within a week.

Effect of planting programs. The relation of the spread of the rust to the asparagus planting program is one of the most important aspects of the epidemiology of the disease. Fields that are cut for 60 days escape primary infection from basidiospores produced by overwintered teliospores. Uncut fields are subject to primary infection and then serve as sources of inoculum for secondary spread to cut fields



Spread of rust in a 160-acre asparagus field in Ogle county, Illinois. Primary infection originated in a small 20-acre portion of the field where asparagus had been plowed under and replanted in 1949 and left uncut when the rest of the field was cut in 1950. Figures indicate percentage of infected plants in various portions of the field as determined on six dates in the 1950 growing season (I = aecial infection, II = uredinial, III = telial). (Fig. 7)

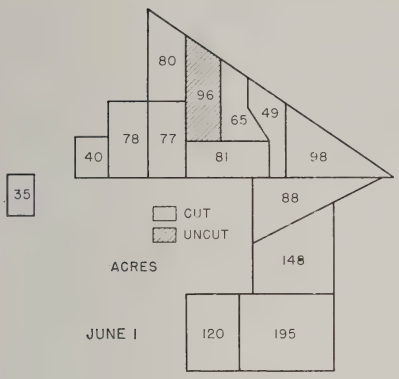
after the end of the cutting season. Severe outbreaks appeared in the Rochelle areas as a result of such primary infections in uncut portions in the center of large producing fields.

The spread of rust from uncut fields was observed at Rochelle during the 1950 and 1951 growing seasons. In 1949 a grower had plowed under a 20-acre section in both a 160-acre field and a 120-acre field because of a low stand, and then replanted them. When these fields were cut in 1950, the replantings remained uncut. Primary infection originated in these uncut areas and, within four weeks after the cutting season ended, the infection spread to the rest of these fields and to an additional 300 acres. The spread of the rust in the 160-acre field is shown in Fig. 7. In 1951 infection spread from an uncut two-year-old 96-acre field to adjacent cut fields, making a total of more than 1,200 acres infected within five weeks after the end of the cutting period (Fig. 8).

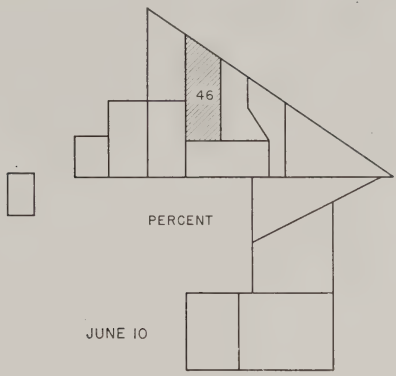
These data indicate that it is desirable to maintain as much of an asparagus-growing area as possible under full cutting in order to escape primary infection. When a number of new fields are to be started, they should all be started in the same year, so that in the long run there will be several years in which all the acreages in an area are cut. Thus primary infection will be avoided and the build-up of inoculum prevented.

Dissemination by wind, rain, and insects. Fields at Rochelle, Rossville, and Urbana were observed for indications of wind, rain, and insect dissemination of aeciospores and urediospores. The effect of falling rain on uredinial distribution was also studied. Ten percent of the aecia were found to be associated with heavy concentrations of uredinia located just below the aecium. This indicates that aeciospores were washed down. Most of the uredinia are not, however, located near aecia.

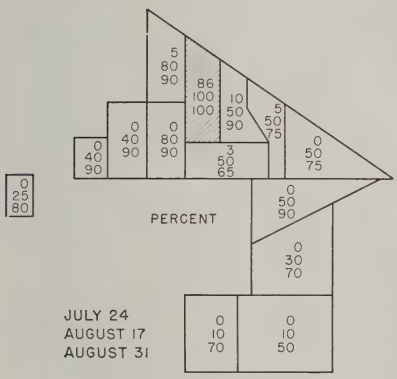
As for insect dissemination, it is doubtful that the asparagus beetle, *Crioceris asparagi,* disseminates spores since the adults and larvae are associated with the tips of lateral branches and the main stem axis, whereas uredinia are generally restricted to the basal portions of the main stems, lateral branches, and mature cladophyls during the greater part of the growing season. No correlation was observed between the populations of asparagus beetles and the severity of rust in the severe rust years of 1949, 1950, and 1951. Laboratory examination of over 100 beetles collected in severely rusted fields did not reveal the presence of rust spores.



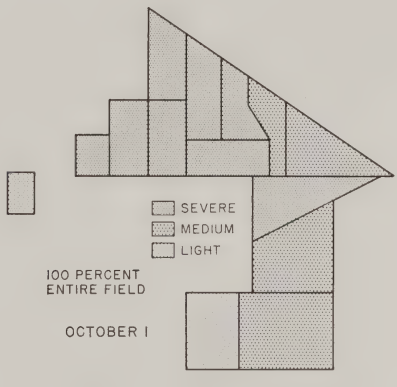
No infection on June 1



Primary infection on June 10, originating in 96-acre uncut field



Secondary infection after end of cutting season



Infection on October 1, at end of growing period

More than 1,200 acres of asparagus are represented here. The rust spread from the primary infection, originating in an uncut field, to the rest of the acreage after the end of the harvest season. On June 10 the adjacent fields were being harvested and therefore did not show infection. Ogle county, Illinois. (Fig. 8)

An example of wind dissemination of rust spores is shown in the spread of infection over the fields represented in the above diagram. Unilateral distribution of sori on the side of the main stem toward the source of inoculum was observed in more than three-quarters of the infected stems.

Field observations thus indicate that rain may be responsible for

some of the spread of infection on individual plants; that asparagus beetles are probably not important agents of spore dissemination; and and that the wind is the principal agent of spread.

Role of *Darluca filum.* Field observations indicate that this fungus, a hyperparasite of *Puccinia asparagi,* does not reduce rust severity in epidemic years. For example, in a 600-acre area of asparagus in Ogle county, primary infection originated in two 20-acre replantings. In these replantings *D. filum* was observed on 70 percent of the infected stems and in about 50 percent of the sori on the stems. Although the parasite of the rust fungus was abundant, the rust infection spread to the remaining 560 acres within four weeks, producing a 100-percent infection. Even though *D. filum* may prevent sporulation of a large number of sori, under favorable conditions enough uredinial sori sporulate to cause epidemics. *D. filum* is therefore probably not significant as a biologic control of asparagus rust.

Preliminary greenhouse and laboratory experiments were made to clarify the *Puccinia asparagi-Darluca filum-Asparagus officinalis* complex. The question was whether *D. filum* is parasitic on the rust fungus, parasitic on the asparagus, or saprophytic on the asparagus tissue within a rust sorus. Strong saprophytic tendencies are indicated in experiments which showed that *D. filum* grows and sporulates profusely on an agar or liquid culture medium consisting of inorganic salts, dextrose, soybean meal, and yeast extract. In addition *D. filum* sporulated abundantly on seedlings of pumpkin, tomato, radish, spinach, corn, and asparagus after the seedlings were killed by 10 minutes of steam under 15 pounds pressure. Since *D. filum* did not grow on healthy seedlings of these plants, even when they had been inoculated by spraying or by the injection of spore suspensions, this fungus apparently does not have plant parasitic tendencies. In addition, *D. filum* was never observed in the absence of *P. asparagi* under field conditions. Smith[45] illustrated and reported the presence of the mycelium of *D. filum* within urediospores of *P. asparagi,* but the writers have never been able to confirm this observation. Microtome sections were prepared in order to study this asparagus-rust fungus — hyperparasite complex, but all of the embedding methods used resulted in asparagus stem tissue that was too brittle for satisfactory cutting. Both fungi were present in the macerated tissue of this complex, but the hyphae of *D. filum* were never seen to be parasitic on *P. asparagi.* For better microscopic examination, attempts were made to separate the asparagus cells by tying up the calcium

pectate of the middle lamella with ammonium oxalate, but the results were no better than with macerated tissue.

In order to determine whether *Darluca filum* produced a toxin in liquid culture, the following experiment was made: The fungus was grown for two weeks in a medium consisting of soybean meal, yeast extract, dextrose, and inorganic salts on a reciprocal shaker. A spore-free extract was prepared from both the mycelium and the filtrate. Tomato and asparagus cuttings were immersed in these extracts as well as in sterile medium and in distilled water. The extracts did not wilt the cuttings. It was then concluded that no toxin, similar to that produced by *Fusarium* or *Verticillium,* was produced by *Darluca filum.*

Importance of dew. Many investigators who base their conclusions on field observations[38, 43, 44, 48, 49] have pointed out the importance of dew in asparagus rust epidemics. Results of greenhouse inoculation experiments (Tables 12 to 14) indicate that infection takes place only in the presence of free moisture. When dry urediospores were placed in sealed van Tieghem cells having 100-percent relative humidity, they did not germinate (Table 10). These field observations of the importance of dew in rust infections are confirmed by greenhouse tests on inoculation and by spore germination.

Variety and Species Susceptibility

Severe epidemics of asparagus rust have appeared in many asparagus-growing areas in Illinois, especially in the northern and eastern sections of the state. One-hundred-percent infections are not uncommon even though the Washington varieties are grown extensively.

Field observations reported by Fulton[13] for 1940-1942, by Tidd[52] for 1944, and those of the writers for 1949-1951 indicate that the Washington variety is no longer commercially resistant under Illinois conditions. In order to find potential sources of resistant stock for future breeding programs, seeds or roots of several varieties were therefore obtained from asparagus-growing centers in the United States, Canada, England, and France.

Varieties were inoculated in the greenhouse with urediospores obtained from Rochelle, Illinois, during the 1951 growing season. The method of inoculation consisted of dusting a urediospore-talc mixture on wet plants under a Glass-o-net moist chamber into which distilled water was atomized intermittently. These moist chambers, the urediospore-talc mixture, and artificial dews resulting from the atomized

distilled water are discussed on pages 24 to 28. It was necessary to cover each of the three chambers with kraft paper in order to exclude direct sunlight and thus prevent excessive temperatures within them.

Three tests designated as A, B, and C and consisting of 6, 10, and 14 varieties or strains respectively were set up in a split-plot design with four replications. The average number of sori per infected plant and the average percent of infection were evaluated in order to determine the extent of varietal (or strain) resistance or susceptibility. (Tables 22 to 24 give these evaluations for the three tests.) However, as noted in the analysis of variance, it was necessary in tests A and B to analyze the average number of sori per infected plant on the basis

Table 22. — Varietal Resistance or Susceptibility to Asparagus Rust: Test A, Analysis of Variance

(Varieties inoculated in greenhouse with urediospores)

Factor	S.S.	D/F	Variance	F value		
				Found	5 percent	1 percent
Percent of plants infected[a]						
Main plots	71.25	7	.....	....	....	....
Moist chambers (two)	18.75	1	18.75	11.07*	10.13	34.12
Replications	47.42	3	15.81	9.34*	9.28	29.46
Error A	5.08	3	1.69	....	....	....
Total	143.25	47	.....	....	....	....
Main plots	71.25	7	.....	....	....	....
Varieties	17.00	5	3.40	2.00	2.53	3.70
Varieties × moist chambers	4.00	5	.80	....	....	....
Error B	51.00	30	1.70	....	....	....
Average number of sori per infected plant[b]						
Total	240.92	11	.....	....	....	....
Varieties	123.42	5	24.68	1.41	5.05	....
Moist chambers	30.09	1	30.09	1.72	6.61	....
Error	87.41	5	17.48	....	....	....

Varietal averages

Variety	Accession No.	Mean percent of plants infected	Rank	Mean number of sori per infected plant	Rank
Washington	23	82.5	3	8.0	4
Palmetto	24	83.7	2	9.5	3
Paradise	25	76.3	5	8.0	5
Individual plant selection from "V35"	27	85.0	1	15.5	1
	28	77.5	4	10.5	2
	29	67.5	6	5.0	6
L.S.D. at 5-percent level		(−)	..	(−)	..
L.S.D. at 1-percent level		(−)	..	(−)	..
Tukey's test[c]		(−)	..	(−)	..

[a] Split-plot design (4 replications). *See* description on page 42 and following.
[b] Randomized-plot design (1 replication). *See* description on page 45.
[c] Tukey, J. W. Biometrics 5, 99-114. 1949.
* Statistically significant.

Table 23. — Varietal Resistance or Susceptibility to Asparagus Rust: Test B, Analysis of Variance

(Varieties inoculated in greenhouse with urediospores)

Factor	S.S.	D/F	Variance	F value		
				Found	5 percent	1 percent
Percent of plants infected[a]						
Main plots	30.17	11	.....	....	....	....
Moist chambers (three)	5.27	2	2.64	3.34	5.14	10.92
Replications	20.17	3	6.72	8.53*	4.76	9.78
Error A	4.73	6	.79	....	....	....
Total	125.97	116	.....	....	....	....
Main plots	30.17	11	.....	....	....	....
Varieties	28.47	9	3.16	4.28**	1.99	2.65
Varieties × moist chambers	9.73	18	.54	.73	....	....
Error B	57.60	78	.74	....	....	....
Average number of sori per infected plant[b]						
Total	14 238.67	26	.....	....	....	....
Varieties	10 737.34	8	1 342.17	7.50**	2.59	3.89
Moist chambers	636.23	2	318.12	1.78	3.63	6.23
Error	2 865.10	16	179.07	....	....	....

Varietal averages

Variety	Accession No.	Mean percent of plants infected	Rank	Tukey's test grouping[c]	Mean number of sori per infected plant	Rank	Tukey's test grouping[c]
Washington	23	85.8	10	2	9.00	9	2
Paradise	25	88.3	8	2	16.00	8	2
Conover's Colossal	37	100.0	1	1	54.67	3	1
Carter's Mammoth Emperor	38	98.3	2	1	60.67	1	1
Early Argenteuil	39	94.2	6	1	21.00	4	2
Late Argenteuil	40	95.0	4	1	16.67	7	2
Snowhead	41	98.3	3	1	59.33	2	1
Washington	43	86.7	9	2	17.00	6	2
Washington	44	90.0	7	1	19.67	5	2
Washington	45	95.0	5	1	([d])	..	..
L.S.D. at 5-percent level		6.99	..	..	23.16	..	..
L.S.D. at 1-percent level		9.27	..	..	31.92	..	..

[a] Split-plot design (4 replications). *See* description on page 42 and following.
[b] Randomized-plot design (1 replication). *See* description on page 45.
[c] Tukey, J. W. Biometrics 5, 99-114. 1949. Members of Group 1 differ significantly from members of Group 2, but there is no significant difference between members of the same group.
[d] Missing replication. *See* footnote b above.
* Statistically significant. ** Highly significant.

of one replication instead of on a split-plot design of four replications because three replications had low sorus counts. These three replications were inoculated with inoculum collected from uredinia produced during a cold, wet period. About half the spores obtained from these uredinia were dormant teliospores. In addition, these uredinia supported abundant saprophytic fungus growth (especially *Alternaria* spp.). Since subsequent inoculations with inoculum collected later in the growing season resulted in high pustule counts, the low sorus count and low percent of infection in the first three inoculations may be attributed to lower urediospore content and to interference by sapro-

phytic fungi. The uninfected plants of the first three replications of tests A and B were reinoculated in order to determine the percent of infection.

Except for Accessions 45, 50, and 52, which were represented by 90 plants in three replications, each variety or strain was represented

Table 24. — Varietal Resistance or Susceptibility to Asparagus Rust: Test C, Analysis of Variance

(Varieties inoculated in greenhouse with urediospores)

Factor	S.S.	D/F	Variance	F value		
				Found	5 percent	1 percent
Percent of plants infected[a]						
Main plots	1 689.55	11	.....	....	....	....
Moist chambers (three)	237.37	2	118.69	1.13	5.14	....
Replications	821.36	3	273.79	2.60	4.76	....
Error A	630.82	6	105.14	....	....	....
Total	7 249.12	161	.....	....	....	....
Main plots	1 689.55	11	.....	....	....	....
Varieties	925.45	13	71.19	2.06*	1.81	2.30
Varieties × moist chambers	805.30	26	30.97	.90	1.60	....
Error B	3 828.82	111	34.49	....	....	....
Average number of sori per infected plant						
Main plots	10 178.59	11	.....	....	....	....
Moist chambers	94.33	2	47.17	.13	5.14	....
Replications	7 978.74	3	2 659.58	7.58*	4.76	9.78
Error A	2 105.52	6	350.92	....	....	....
Total	14 659.95	161	.....	....	....	....
Main plots	10 178.59	11	.....	....	....	....
Varieties	1 674.70	13	128.82	5.72**	1.81	2.30
Varieties × moist chambers	305.17	26	11.74	.52	1.60	....
Error B	2 501.49	111	22.54	....	....	....

Varietal averages

Variety	Accession No.	Mean percent of plants infected	Rank	Tukey's test grouping[b,c]	Mean number of sori per infected plants	Rank	Tukey's test grouping[b]
Washington	23	93.25	12	1	12.75	5	2
Paradise	25	98.33	3	1	9.92	13	2
Washington	47	95.83	7	1	12.08	7	2
Washington	48	95.83	8	1	11.83	9	2
California 500	49	95.83	9	1	12.75	6	2
Washington	50	98.17	5	1	13.08	4	2
Washington	51	97.50	6	1	9.75	14	2
Washington	52	93.83	11	1	11.17	10	2
Washington	53	91.58	14	..	11.92	8	..
Washington	55	99.17	1	1	13.25	3	2
Washington	56	95.75	10	1	10.17	11	2
Washington bulk selection	57	99.17	2	1	22.92	1	1
Washington bulk selection	58	93.25	13	1	10.00	12	2
California 500	59	98.33	4	1	13.67	2	2
L.S.D. at 5-percent level		4.75	..	..	3.83	..	..
L.S.D. at 1-percent level		....	..	..	5.06	..	..

[a] Split-plot design (4 replications). *See* description on page 42 and following.

[b] Tukey, J. W. Biometrics 5, 99-114. 1949. Members of Group 1 differ significantly from Group 2 but there is no significant difference between members of the same group.

[c] No significant difference.

* Statistically significant. ** Highly significant.

by 80 plants in Test A and by 120 plants in Tests B and C. All these plants were arranged in split-plot design with four replications. Each of the three replications of Accessions 45, 50, and 52 consisted of 30 plants arranged as one row of ten plants randomized in each of three moist chambers. The chambers were analyzed as main treatments and the varieties as subtreatments. Successive replications were inoculated on alternate days during the first two weeks of August and reinoculated during the last week of August. Inoculated plants remained in the moist chamber about 40 hours. The percentage and severity of infection were determined after 24 days, although symptoms appeared on some plants in 10 days.

When three weeks old, the seedlings had been transplanted from flats to 2½-inch pots. The plants were eight to thirteen weeks old at the time they were inoculated and they averaged approximately 2½ stems about 10 inches long.

The analysis of variance for the percentage of plants infected shows that all the varieties (or strains) are susceptible but that there is a difference in their degree of susceptibility. Although the difference between some varieties is statistically significant, it does not appear to be of any consequence as indicating a source of resistance for the grower.

Analyses of the severity of infection in Tests B and C show that the difference between varieties in the number of sori per infected plant is highly significant at the 1-percent level. The Washington varieties in general show a significantly lower number of sori per infected plant than the other varieties such as Conover's Colossal, Carter's Mammoth Emperor, and Snowhead.[a]

[a] Eight collections of six varieties were inoculated on August 26 and 28 in Test D. Two varieties, Viking (Accession 63) and a collection of Washington (Accession 64), showed significantly less infection than the other varieties in this test; see data below:

Variety	*Accession No.*	*Mean percent infection, 2 replications*	*Variety*	*Accession No.*	*Mean percent infection, 2 replications*
Paradise	65	66.7	Washington	23	58.3
Palmetto	24	66.7	Paradise	25	55.0
KBF	62	60.0	Washington	64	26.7
4-5 × 3-9	61	60.0	Viking	63	18.3

Least significant difference at 5% level = 24.0; at 1% level = 32.67.

However, the authors do not feel justified in comparing Test D with Tests A, B, and C, nor in stating that the Viking variety and Accession 64 of the Washington variety are resistant. The average number of sori per infected plant was about 17 for all lines in Tests A, B, and C, but less than 3 for the lines in Test D (data not shown for Test D). Accession 23 and 25 in Tests A, B, and C showed about 87 percent infection, whereas in Test D these same accessions showed only 56.5 percent infection. It may be that infection was lower in Test D, not because varieties were so resistant, but because the inoculum, after lengthy storage, was less viable.

During the 1950 growing season the following lines were examined in the field for resistance to rust: two lines originating from Turkey — P.I.169010 and P.I.169013; Viking 35 (rust-resistant) from the Horticultural Experiment Station, Vineland Station, Ontario, Canada; Eden (rust-resistant) from the Central Experiment Farm, Ottawa, Canada; a commercial strain of Washington; and eight selections received from the Regional Vegetable Breeding Laboratory at Charleston, S. C. A severe outbreak of rust appeared as a result of field inoculations in which overwintered teliospores were used as inoculum. The two methods described on pages 29 to 30 were used to establish this infection. A 10-percent primary infection gave rise to a 99-percent secondary infection, with all lines showing extreme susceptibility. Nine plants out of approximately 1,500 were disease-free. The progeny of three (Accessions 27, 28, and 29) were tested, but did not show significant resistance (Table 22). The other six plants were transferred to the greenhouse and tested for resistance. Three of these six proved to be susceptible.

Asparagus sprengeri, A. plumosus, A. scandens var. *deflexus,* and *A. virgatus* were inoculated in the greenhouse. Under the same conditions that produced 100-percent infection in *A. officinalis,* none of these species showed rust symptoms. *Allium capa,* reported as a suscept for *P. asparagi*,[54] did not develop rust sori.

Additional data concerning the susceptibility of asparagus varieties and species have been presented in other sections of this publication in connection with inoculation experiments (Tables 11-16). Conover's Colossal, Palmetto, Paradise, Carter's Mammoth Emperor, Washington, and California 499 and 500 were used as test plants in these experiments. In general they were susceptible both as to the number of sori and as to percentage of infection.

DISCUSSION AND CONCLUSIONS

It is the authors' opinion that new resistant varieties of asparagus offer the most hope for ultimate control of asparagus rust, although the development of such varieties is a long-term project. The dioecious nature of asparagus is an obstacle to inbreeding for resistance. Consequently, until perfect flowers or monoecious types are developed, rust resistance from a genetic point of view is not in the near future. Although new sources of rust-resistant plants were sought for use in future breeding and inbreeding programs, none has been found. This

investigation nevertheless contributes to the evaluation of fungicides as a control measure and presents data from which the value of certain cultural practices as related to rust can be assessed.

Inoculation techniques

In order to locate sources of resistant stock, it is necessary to have methods for greenhouse and for field inoculation since even in areas of severe attacks natural outbreaks cannot be depended upon for regular appearances of the rust.

Type of spore is important. Aeciospores in general are not desirable for artificial inoculation because only limited numbers are produced in the field and in storage they remain viable only a short time. Urediospores appear to be particularly useful for greenhouse inoculations because they are produced in the field in almost astronomical numbers and may be stored as long as six months without loss of viability.

Teliospores are apparently not suited to greenhouse inoculation studies. Inconsistent results are usually obtained because in the greenhouse it is difficult to duplicate the field conditions that are favorable for both teliospore and basidiospore germination. If only a small amount of inoculum is required, however, teliospores can be used in field inoculations. Even a comparatively light aecial infection usually produces enough uredinia, whose urediospores are capable of forming additional uredinia in 10-day cycles, to build up inoculum to epidemic proportions.

Dusting and spray methods are efficient. Apparently the two most efficient of the several methods of urediospore inoculation evaluated are *the spray method,* in which the spores are suspended in distilled water and sprayed on the plants, and *the dusting method,* in which they are mixed with talc and dusted on.

The experimental data indicate that the dusting method produces a somewhat higher percentage of infection and three times as many sori per infected plant as does the spraying method. The superiority of dusting over spraying may be due to the fact that the talc particles adhere to asparagus tissue better than water droplets, especially on the older portions of plants, which are hard to wet. Apparently the talc particles, with their rough surfaces, are more efficient carriers than water. Other experiments show that dusting the urediospore-talc mixture on wet plants is somewhat better than dusting dry plants. It ap-

pears to the writers that the talc particles, carrying urediospores, which fall on water drops on the asparagus tissue, are easily wetted and form a mixture with a rather thick consistency. Thus the spore is not only in contact with the suscept tissue but is in an environment favorable for germination.

The presence of free water on the plant during the inoculation period is essential in greenhouse infection. Data indicate that the greatest amount of infection usually occurs when artificial dews are created in moist chambers from the intermittent or continuous atomizing of distilled water. Little, if any, infection occurred in the absence of these dews. Germination tests reveal that if precautions are taken to prevent water from condensing on dry spores, the spores do not germinate at even 100-percent humidity. Free water appears, therefore, to be essential in asparagus rust infection. These experiments confirm field observations as to the importance of dews in rust epidemics.

Age of plant to be considered. The age of the asparagus plant at the time of inoculation seems to be of some importance in greenhouse inoculations. For greenhouse tests, seedlings are more suitable than older plants because they are more susceptible to rust infections, take up less bench space, and in general, are easier to handle. Field observations also indicate that younger tissue is more susceptible since late-season infection usually appears on the needles of mature stalks and rarely on the stem of lateral branches.

Since the two-year-old plants in these experiments had at least five times as much surface area as two- to four-month-old seedlings, and therefore received five times as much inoculum, it might be expected that the severity of infection on a plant-to-plant basis would be greater in the larger plants. However, the experimental data reveal that the older plants averaged the same number of sori as the seedlings, or less. The sori on the older plants were generally restricted to the youngest tissues.

Two field methods developed. Two methods were developed for inoculating and obtaining infection on plants in the field. One method, which involved placing presoaked, overwintered asparagus stubble bearing telia around emerging spears under flower-pot moist chambers, resulted in aecial production on almost all the plants in 10 days. The other method, which consisted of placing unsoaked, overwintered stubble in the rows of emerging spears without the use of moist chambers, resulted in the production of aecia on about half the plants at the end of approximately 20 days.

The time differential required for symptoms was probably due to the more favorable environmental conditions under the moist chambers.

In the second method, apparently favorable natural environmental conditions did not occur for at least one week after the inoculum was placed in the field. The flower-pot inoculation method is particularly well suited for inoculation under unfavorable weather conditions. If the plants are left uncovered they are subject to the caprices of the weather, and under unfavorable conditions infection may not take place at all.

Variety and species susceptibility

No varieties are rust-resistant in Illinois. The greenhouse and field inoculations with Washington varieties of *Asparagus officinalis* from several sources throughout the United States confirm field observations which have indicated rather definitely that under Illinois conditions the Washington variety is not commercially rust-resistant. Some companies from which seed was obtained do not produce their own seed but act as jobbers. Consequently there may have been some duplication within these collections. Nevertheless, the authors feel that these collections represent a cross-section of what is available to the asparagus industry under the varietal name of "Washington."

None of the other varieties, lines, and selections of *A. officinalis* appears to have any degree of resistance to rust. Nine other named varieties, two Canadian lines, two introductions from Turkey, and eight selections from the Regional Vegetable Breeding Laboratory, Charleston, South Carolina, showed extreme susceptibility. The Canadian lines, Turkish introductions, South Carolina selections, and one line of Washington showed rust in epidemic proportions when inoculated in the field. The nine named varieties of asparagus showed extreme rust susceptibility in the greenhouse.

Marked difference in susceptibility. Although none of the varieties or selections tested are commercially rust-resistant, it is significant, that these varieties do exhibit a marked difference in their degree of susceptibility. The early American varieties, such as Conover's Colossal and Palmetto, and the European varieties, such as Carter's Mammoth Emperor, are apparently more susceptible than any of the collections of the Washington variety. Therefore, while no sources of rust-resistant plants are immediately available, if they are located it will most likely be in Washington stock. There is a possibility that varieties of asparagus, because of the marked difference

in susceptibility, might be useful as indicator plants in determining the existence of physiologic races of *Puccinia asparagi.*

Other species of *Asparagus,* including *A. sprengeri, A. plumosus, A. virgatus,* and *A. scandens* var. *deflexus,* showed no rust symptoms when inoculated in the greenhouse. These species appear to be potential sources of resistant stock in the event that interspecific crosses are feasible. However, a number of pollinations already attempted were not successful.

Fungicides were not effective

None of the protectant fungicides tested showed any promise in the control of asparagus rust. Possibly the reason these fungicides were ineffective was that tissue was produced so rapidly in the interim between applications that it was not possible to keep new growth covered with a fungicidal deposit. Applications even at two-day intervals were ineffective.

Other investigators have reported that a reduction in aecia occurs when the rate of application of dinitro-o-cresol is as high as 800 gallons per acre. The data in this investigation indicate also that this eradicant fungicide may reduce but does not prevent aecial production. When the same amount of dinitro-o-cresol was applied at a rate of 800 gallons per acre as at a rate of 200 gallons some reduction in aecia did occur at the higher gallonage. If the eradicant does not prevent aecial production but does suppress it to the point where a general spread of rust is postponed until late in the growing season, the damage due to the infection will not be as serious.

The main problem in an eradicant spray program is the difficulty in obtaining uniform coverage. If the eradicant is applied in the fall, the stubble is usually erect, so that it is exposed to the sprays; but since more stubble is present in the fall than later in the dormant season, more water is required. If the applications are made in the spring before disking, the stubble is usually prostrate, due to the weight of winter snows, and the lower surface is difficult to reach with sprays. If the applications are made in the spring after disking, the minimum amount of tissue is present, and therefore less water is required to wet the stubble but untreated teliospores are buried. Teliospores in the ground which have not been killed by the eradicant may produce basidiospores in the air spaces created by emerging spears.

The authors believe that control with eradicant sprays will depend on a number of factors, such as concentration and quantity of spray material per acre, condition of the stubble, and the time of making the application.

Epidemiology (Epiphytology)

Although not all rust epidemics can be traced to volunteer asparagus, the practice of destroying volunteer growth can be recommended. During the rust epidemics of 1949, 1950, and 1951, in northern Illinois, the writers did not observe aecia on wild asparagus near commercial fields, and therefore they are of the opinion that the primary infection for these outbreaks did not originate on volunteer asparagus. However, telial sori have been observed on volunteer asparagus, suggesting that these plants are potential sources of primary infection, especially in areas where there are no uncut fields.

Field observations have demonstrated that the wind is responsible for the spread of rust over large areas and from plant to plant, while the rain contributes to the spread of rust on individual plants. However, the opinion, supported by many asparagus growers, that the asparagus beetle, *Crioceris asparagi*, is important in spore dissemination was not substantiated. Observations reported herein indicate that rust outbreaks are not correlated with asparagus beetle populations. Spores were not observed on the exoskeleton of the limited number of beetles examined in the laboratory. Furthermore, the germ tubes of rust spores do not require insect wounds in the susceptible tissue in order to penetrate it. Theoretically, even large populations of beetles, each transporting 100 spores, could not compete with the efficiency of the wind in disseminating spores.

The asparagus planting and harvesting program plays a significant role in rust epidemics. Canners and growers in northern Illinois have long believed that fields in that region which are cut until around July 1 commonly escape primary infection. No data have been found in the literature to substantiate this theory directly. Observations during the present investigation have shown that primary infections originating in uncut fields have spread to large acreages of cut fields after the end of the harvest season. On the basis of these observations and the susceptibility of the Washington varieties, the authors believe that the asparagus growers of an area would greatly benefit if they would coordinate their planting programs so that all new fields would be planted in the same year instead of a few scattered fields being planted every year. Thus for several years all the fields in an area would be cut at the same time and would therefore escape primary infection. Also the build-up of inoculum in concentrated asparagus-growing areas would be prevented. The plowing under and replanting of small areas within large fields, which results in different lengths of cutting seasons, should also be avoided.

Observations on "snapping" in relation to the distribution of rust indicate that under certain conditions this method of harvesting spears may lead to primary infections. If 8 inches or more of the stalk remains attached to the crown after the spear is snapped, this stub usually produces adventitious growth, whereas shorter stubs usually wither and die. Greenhouse inoculation studies demonstrated that this adventitious growth is susceptible to infection by basidiospores. If the basal portion of the spear does not die as a result of the snapping operation, then it becomes a potential source of primary infection in cut fields.

It is the authors' opinion that *Darluca filum,* a fungus parasite of *Puccinia asparagi,* is not significant in any biologic control of rust, at least in years when severe outbreaks of the disease occur. *D. filum* did not appear to reduce the severity or impede the spread of the rust infection in the epidemic years of 1949-1951 in northern Illinois, although rust sporulation was prevented in many sori.

The metabolism of *Darluca filum* apparently adapts this fungus not only to a highly specific rust-fungus parasitism but also to a strongly saprophytic existence. That it is thus adapted is evidenced by its vigorous growth on artificial media and on steam-sterilized plant tissues. It appears, therefore, that *D. filum* may also live on either the dead asparagus tissue in rust sori or, if it produces a substance which kills the rust fungus, on the dead rust-fungus tissue.

SUMMARY

Greenhouse and field tests were employed in a study of the control of asparagus rust under Illinois conditions and in an investigation of the causal fungus, *Puccinia asparagi,* D. C.

A period of dormancy was demonstrated to be an essential factor in the germination of the teliospores of *Puccinia asparagi.* Chemical agents and controlled environmental conditions which break the dormancy of teliospores of *P. graminis tritici* or stimulate the germination of the spores of other fungi did not break the dormancy of teliospores of *P. asparagi.* Some factor or factors other than those tested must influence the length of the dormant period. The most efficient method for prolonging the viability of urediospores in storage was one in which uredinia were placed in sealed glass vials at about 38° F.

The most efficient method for inoculating asparagus plants in the

greenhouse was one in which a urediospore-talc mixture was dusted on wet plants in moist chambers. The presence of free water on inoculated plants during the period of infection was demonstrated to be essential. In the field a flower-pot moist chamber inverted over presoaked, overwintered asparagus stubble bearing telia, and placed around emerging spears, was capable of creating conditions conducive to infection even in the absence of favorable natural conditions.

The so-called "rust-resistant" Washington varieties were demonstrated to be extremely susceptible both in the greenhouse and in the field and may no longer be considered as commercially resistant under Illinois conditions.

No sources of potential rust-resistant stock were located in a collection of the Washington varieties from ten sources in the United States, in nine other named varieties including American and European representatives, and in twelve selections from Canada, Turkey, and South Carolina. A marked difference was found in the degree of susceptibility.

Asparagus virgatus, A. scandens var. *deflexus, A. plumosus,* and *A. sprengeri* did not develop rust symptoms when inoculated in the greenhouse under the same conditions that resulted in severe infections of *A. officinalis.*

Protectant fungicides, including sulfur, ferbam, zineb, phenyl mercury triethanol ammonium lactate, copper-zinc-chromate, tribasic copper sulfate, and combinations of some of these fungicides, were not effective in controlling asparagus rust when applied as dusts or sprays with ground equipment or as dusts from airplanes. It was not possible to cover the new asparagus growth even when fungicides were applied at two-day intervals.

An eradicant fungicide, dinitro-o-cresol, was not effective in preventing late outbreaks of rust, at either high or low rates of application, but at the higher gallonages it did reduce the number of aecia.

Although there are as yet no resistant varieties nor effective fungicides, the severity of rust infections can be reduced if certain cultural practices are followed by all the growers in an asparagus-growing center. Such practices include coordinated planting and harvesting programs and the eradication of volunteer asparagus. Snapping asparagus when harvesting it may lead to primary infection in cut fields.

Field observations in northern Illinois indicate that *Darluca filum,* a parasite of the rust fungus, was not important in any biologic control of rust during the epidemic years of 1949-1951. In addition to its association with *P. asparagi* in the rust sori, *D. filum* grew and sporu-

lated profusely, both on artificial media and on steam-sterilized plant tissues, indicating that it is also adapted to a strongly saprophytic existence.

Field observations indicated that wind was the principal agent which disseminated spores within an area and that rain contributed to the spread of rust on a given plant. The asparagus beetle, *Crioceris asparagi,* apparently is not significant in rust-spore dissemination.

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