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FLAX WILT AND FLAX SICK SOIL.

By H. L. BOLLEY.

Any farmer, teacher or student in the state may have this Bulletin mailed to his address, free of charge, upon application.

FARGO, NORTH DAKOTA, U. S. A.

STATION STAFF.

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C. B. WALDRON, B. S.,
Horticulturist and Entomologist.

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H. M. ASH,
Foreman in Ag'l. Dep't.

C. E. NUGENT,
Secretary.

FLAX WILT AND FLAX SICK SOIL.

By H. L. BOLLEY.

Group of young flax plants just beginning to wilt.

The cultivation of flax, in every country in which it has been grown extensively, has either been short lived or it has been necessary to introduce a long series of different crops between the flax crops. The best methods in Scotland, Ireland, Belgium, Germany and Russia make it quite plain that the principle of crop rotation has become a cardinal one in these countries where the culture of flax for fiber purposes is given so much attention. The late Dr. Otto Lugger of the Minnesota Experiment Station, who was thoroughly conversant with German and Belgian methods, published in his "Treatise on Flax Culture" * several series of rotations which Belgian farmers have, through long experience, found conducive to proper flax growth. A consideration of these shows that a large variety of crops is interposed in all rotations and that the time between flax crops is quite uniformly seven to eleven years. Flax is an important crop there, and it is evident that the energetic Belgians would grow it more often, were it possible to do so profitably. But Dr. Lugger says: "It is well known in Europe that flax is a plant unkind to its own offspring."** that is to say, flax cannot succeed flax upon the same soil and remain strong. Mr. James B. Taney, U. S. Consul at Belfast, Ireland, reporting upon the flax crops says: "The idea has prevailed among many that Ireland is flaxed out." ***

* Bulletin No. 13. Minnesota Experiment Station. p. 26.
** Bulletin No. 13. Minnesota Experiment Station. p. 23.
*** U. S. Consular Report for January, 1895, pp. 51-57.

In America, in each new locality in which flax has been introduced, it has been a short lived crop; at first making heavy growths upon the virgin soil, but later gradually failing. This is so characteristically true that the crop is generally known as a new land crop. In the west, Iowa was once the banner state for flax, then Minnesota, now North Dakota. In many localities of Iowa and farther east, the crop has been abandoned as no longer a profitable one; and it is a common expression among farmers that the soil is *"flax sick."* Others assert that flax quickly exhausts the land. I find that this prejudice against the crop is especially strong among European and English farmers who have located in the northwest. It has generally been considered a hard crop on land, quickly reducing its value not only for flax but also for wheat and other crops. In North Dakota, the opinion of the farming public has changed rapidly within the past few years, so that most farmers now state that wheat and other crops may follow flax to advantage, but that flax after flax becomes continually less productive. In short, it may be asserted that close or continuous cropping with flax never has been profitable in any country, no matter what the fertility; and there is abundant evidence that Minnesota and Dakota lands are not to be an exception. The farmers are beginning to report many areas of "flax sick" soil, upon which the flax either fails to come up or gradually dies off during the season.

Theories as to the Cause of the Trouble: There have been several theories as to the cause of this flax trouble: (1) that it is due to soil depletion; (2) that it is because flax is "unkind" to flax, leaving some substance in the soil which is detrimental to the health of following flax plants; (3) that it may be due to an infectious disease.

The work upon which this bulletin is based indicates that the first two propositions are untenable and, I think, demonstrates that the third is the correct theory.

Previous Work upon the Disease: Previous to the experiments and observations here recorded, and aside from the efforts of European farmers to find a proper series of crop rotation, there seems to have been but few definite efforts to determine the causative agent or to arrive at a preventive or a remedy. Of these attempts, the experiments of Professor Lugger * of the Minnesota Experiment Station, conducted during the summer of 1890, constitute the only work of importance done in this country.

* Minnesota Experiment Station Bulletin No. 13, pp. 21-25.

Dr. Lugger planned three experiments: (1) *"Series of Experiments to Observe the Effects of Fertilizers upon Land Exhausted by Flax."* He used as fertilizers, lime, acid phosphate, muriate of potash, salt, nitrate of soda, super-phosphates, land-plaster and ground oil-cake. After considering the results, his conclusion was: "Exhaustion of the soil by previous flax crops cannot be the cause of the disease, as all of the materials formerly removed by the plants (flax) had been added again to the soil in the most soluble state." (2) *"Series of Experiments to Observe the Effects of Fungicides on Plants Grown upon Infested Soils."* Professor Lugger pulverized the following fungicides and sowed them as a dry mixture with the flax; hypo-sulphate of sodium, air-slacked lime, sulphide of sodium, flowers of sulphur, sulphate of copper, sulphate of iron and corrosive sublimate. The conclusion from these experiments was: "It is not a specific vegetable disease which affects the plants because one or other of the fungicides would have shown the effects of its application." "Every single plant succumbed." He also says: "Large numbers of dissections were made, and thin sections, stained in various ways, were studied. But a specific organism causing the death of the plants could not be found." "A cure for the disease does not seem possible." The fact that Dr. Lugger used infested soil upon which to make the experiments and his failure to find any parasitic growth in the tissues of the plants examined caused him, I think, to draw the wrong conclusions. Similar experiments and observations with us lead to different conclusions.

(3) *"Series of Experiments to Show That the Old Straw of Flax Is the Cause of the Trouble."* In these experiments Dr. Lugger made effective soil infections by applying: "dry healthy chaff of flax," an extract from "healthy flax chaff in cold water," an extract from "healthy flax chaff in boiling water," an extract from "healthy green flax in boiling water," an extract from "diseased fresh flax in boiling water," an "extract from diseased fresh flax in cold water," and "green straw of healthy flax plants cut into small pieces." From this series, this conclusion was drawn: "We have not to deal with a disease, but the straw of flax itself is the cause of the trouble." My experiments show that diseased flax straw does convey the disease but healthy flax straw cannot. It seems probable that the flax straw, chaff, etc., used by Dr. Lugger was not healthy. Indeed he probably used disease bearing seed, and the results were also vitiated for that reason. Under such circumstances, the solutions used, even though themselves free from the disease, would bring about a

rapid propagation of the fungus which is now known to be the essential cause. Professor Snyder * has shown quite conclusively that a normal flax crop does not make a heavy draft upon the soil. He says: "Flax does not remove an excessive amount of fertility from the soil. An average yield of fifteen bushels of flax per acre will remove less fertility from the soil than one hundred and fifty bushels of potatoes, forty-five bushels of corn or thirty bushels of wheat." The following summary, taken from one of his tables compiled to show the approximate amounts of the chief plant foods which are taken from the soil by different farm crops, would seem to bear out his conclusion. There are also biological proofs that the soil upon which the disease is heavy has not lost its fertility. **

TABLE SHOWING COMPARATIVE DRAFT UPON SOILS BY DIFFERENT CROPS.

CROP.	Nitrogen lbs.	Phosphoric Acid lbs.	Potash lbs.	Lime lbs.	Silicon lbs.	Ash lbs.
Wheat................20 bu.	35	20	35	8	116	210
Barley................40 bu.	40	20	38	9	72	216
Oats..................50 bu.	50	18	45	11	75	205
Corn..................65 bu.	75	20	60	12	90	200
Peas.................30 bu.	..	25	60	75	10	240
Mangels..............10 tons	75	35	150	30	10	350
Potatoes.............150 bu.	40	26	75	25	4	125
Flax..................15 bu.	54	18	27	16	3.5	87

THE DISEASE IN EUROPE: As yet we have no definite proof that the disease of the soil and flax plant which we have under consideration is the one which has caused the apparent soil trouble in Belgium and other European flax districts. The general conditions, however, which compel the farmers there to interpose a long series of rotation crops between flax growths seem similar to the conditions which are found here in the northwest. In a report by Mr. Paul Nypels† to Royal Botanical Society of Belgium, a number of flax diseases are described, among which is one the author calls *"La brulure du lin."* In the Netherlands it is called

* Bulletin No. 47, Minnesota Experiment Station p. 5.

** See this bulletin p. 34.

†Compte-rendu de la seance du 5 decembre 1897 de la Societe royale de botanique de Belgique. Bulletin, tome XXXVI, deuxieme partie, pp. 183-275.

"*Vlasbrand.*" Nypels quotes from and summarizes the investigations of L. Boekema. ** From descriptions there given, I find certain statements concerning the soil conditions and the disease which are so similar to those found here that I have no doubt that "Vlasbrand" of Belgium is identical with the disease which causes flax-sick soil in North Dakota. The author quoted says: "The disease is very prevalent in Holland, Belgium and in North France. It exists also in Ireland and in Germany; but in Russia it does not appear or is hardly known." Of the damage done by the disease, he says: "Sometimes the disease is so destructive that the product is absolutely nothing." After making many experiments, which quite conclusively point to the conclusion that the disease is due to some parasite, Broekema concludes that the disease appears to be caused by a parasitic organism and thinks that the organism in question is probably of the nature of a bacterium. As in the case of Professor Lugger, a definite cause for the disease was not found.

IMPORTANCE OF THE QUESTION TO FARMERS OF THE NORTHWEST: As there are thousands of acres of new soil in the northwest which are free from this soil disease, one may readily understand the importance of ascertaining the exact or first cause that we may learn its habits and some method of preventing its spread and ravages. If, by careful farming, we can perpetuate the flax crop in this state, it means millions in wealth. The number of crops which can be grown in this northern latitude are limited; and farmers can ill afford, through careless methods, to strike flax from that list within the next few years. Professor Shepperd, using ordinary flax seed, not more generally infected with the disease than the average market sample, through six years of continuous cropping has placed a plot of the most fertile Red River soil in such a diseased condition that not a plant of flax can exist upon it longer than three weeks from the time of sowing. * The experiments made during 1900 and 1901 give much promise that the disease can, in large measure, be controlled through intelligent methods of prevention and culture. They also indicate that, if the attention of farmers generally is not quickly given to this matter, it will soon be too late, as the disease has means open to it for general distribution, which will be beyond control when many areas in the state once become thoroughly infected. It is

** Eenige Waarnemingen en denkbeelden over den vlasbrand. Landbouwkundig Tijdschrit, 1893, bl. 59 en 105.

* This plot of ground is known in the College Records as plot No. 30. One of the reasons for keeping it in continuous flax cropping was for the purpose of ascertaining what effects such methods would have in developing flax diseases.

a soil disease and can live in the humus from year to year; thus there will be many ways in which it may spread from field to field. Let every one experiment some and unite to stamp out the disease. We cannot hope that the disease may be less destructive in this region than elsewhere; for my experiments show that it is a lover of rich and alkaline soils.

DISTRIBUTION OF THE DISEASE IN THE STATE: I have seen the disease in the field at Fargo, Harvey, Larimore, Hunter, Val-

Photograph showing the effects of the wilt disease upon flax plants of various ages.

ley City and Casselton; I have received specimens of the diseased plants from Cando, Park River, Devils Lake, Grand Forks, Hillsboro, Sheldon, LaMoure and Barton; I have also found the spores of the parasite in numerous samples of seed received from other points in the state, and from several different counties in Minnesota. It is very probable therefore that many fields in different parts of the state have already been infected.

THE APPEARANCE AND CHARACTERISTICS OF THE DISEASE AS SEEN IN THE FIELD: The plants are attacked at all ages and die early or late in the stage of growth according to the time and intensity of the attack. If the soil is much infected, that is to say "flax sick," most of the plants are killed before they get through the surface of the ground. Such areas appear in a field of flax as centers of disease, which enlarge throughout the summer as new plants sicken, wilt, and die down around the margins of the spots, finally giving the whole field a spotted appearance. Young plants, two to five inches in height, wilt suddenly, dry up

Sketches showing clumps of young flax plants which have wilted, due to early attacks of the wilt fungus from flax sick soil. Original.

and soon decay if the weather becomes moist. Older plants which are quite woody take on a sickly, weak, yellowish appearance, wilt at the top, slowly die, turn brown, and dry up. Nearly mature plants which are attacked, but not yet dead, are easily pulled up, the roots breaking off easily at about the level of the furrow slice.

Upon examination, most of the smaller branch roots are found to be dead, as well as the tap root below the point at which it breaks off. These dead roots and the parts of the tap root already diseased have a very characteristic ashen gray color. Many nearly mature plants which are attacked late in life show this dead gray down one side of the tap root only. The leaves, side branches, and a strip of the main stem above this portion are dead, giving a peculiar one sided blighting, similar to the appearance of a tree struck by lightning.

If the disease is sowed with the seed upon breaking, but a few plants are attacked the first year; and, at flowering time, dead plants will be seen to be quite evenly distributed in the drills. If weather conditions are quite favorable, each new infection increases sufficiently in area to reach over and attack plants in two or three adjacent drills. These infection areas are nearly always circular in outline, and become much enlarged if flax is seeded there the following year. The first year these spots may reach a diameter of one to three or four feet. The second year these same areas are usually much more than doubled, so that it takes but three to five flax crops upon such lands to make the infection general. Mr. John Anderson of Hillsboro reports a typical case. "The field used was for many years a cow pasture and very fertile. The first year of flax in this soil gave a very fine crop, disease not noticed. The second year gave a fair yield per acre, but the field was spotted. The third year a very poor crop was grown, hardly worth harvesting. This year there were large areas in which no flax plants grew, and the crop became thinner and thinner until there was not a full stand of plants in any part of the field at harvest time." This case fairly represents what may be expected if disease bearing seed is sown each year.

Because of the peculiar and characteristic manner in which all young plants and the soft parts of more mature ones droop and wilt when attacked, as if through drought or intense heat, I have called the disease *flax wilt*. Though the trouble may be properly referred to as *flax sick soil*, I think *flax wilt* will prove distinctive.

EXPERIMENTS SHOWING THAT THE DISEASED SOILS HAVE NOT LOST FERTILITY OR ACCUMULATED CHEMICAL SUBSTANCES DETRIMENTAL TO FLAX: It seemed from the start desirable to determine whether Prof. Lugger's conclusion, that a flax crop leaves some substance in the soil which is "unkind" or poisonous to following flax crops, is tenable. It has been shown by Snyder's analyses * that a flax crop does not draw more heavily upon the important plant foods of the soil than other common crops. The Chemist of this Experiment Station has also arrived at a similar conclusion, through analysis of the soils taken direct from the rotation plots on the College Farm; and Prof. Shepperd ** has shown, by comparing actual yields, that wheat and other crops do especi-

* See this bulletin page 3).
** North Dakota Experiment Station Bulletin No. 39, page 451.

ally well after flax. I have also observed that common sorts of weeds are able to take full possession of the infested areas upon which flax can make no further growth, and in 1901 good crops of wheat, oats, corn, potatoes, and beets were grown upon the diseased plot, No. 30. All these features tend to prove that the soil is not rendered infertile by flax. It was found comparatively easy to prove this by means of a simple biological experiment.

Experiment No. 1. Soil was taken from rotation plot No. 30, upon which it has been found impossible to produce a mature flax plant since the year 1899, and was subjected to a process of steaming sufficient to kill all living organisms. Upon this soil flax seeds which were treated in any way that would kill or insure the removal of all disease germs produced a perfectly normal growth of flax.

Photograph of a pure culture of the flax wilt fungus (*Fusarium lini nov. sp.*) growing upon sterilized flax roots. (Original)

Several experiments of this type have conclusively settled the question of soil depletion. It also does away with the idea that old flax straw decaying in the soil can produce some substance which is poisonous or detrimental to the growth of flax plants, for there was plenty of such decaying matter in the soil used in these experiments. *

THE CAUSATIVE AGENT IS A FUNGUS PARASITE: By experiments in 1900 and 1901, I have been able to prove definitely that the disease is not due to soil impoverishment or to any chemical substance left in the soil by the decay of flax roots and stems. It is also proved that a definite species of fungus is the direct cause.

HISTORY: That we have been able to accomplish this so definitely is not due to an accidental or lucky find of a parasite. When I first met Dr. Lugger in the fall of 1890, he called my attention to the fact that "Flax is subject to the attack of a strange disease which has appeared in some counties of Minnesota." Since that date I have made each year some observations in flax fields, and have collected some specimens, attempting to ascertain a direct cause. Many microscopic sections were, from time to time, made and studied, but were negative in result until pure cultures, made during the summer of 1900, defined the organism to be looked for. Many previous attempts to obtain pure cultures had failed because of difficulties which were found hard to overcome, even when an abundance of diseased plants and soil was close at hand. This condition was made possible through the kind co-operation of Prof. J. H. Shepperd, the Agriculturist of this station. In the summer of 1893, Prof. Shepperd agreed to crop one of his regular one-eighth acre rotation plots continuously to flax until something should happen. This something came markedly to notice July 1st, 1900, when all of the young plants on the flax plot were found to be dead or rapidly wilting. The records for this plot show that in spite of improved drainage and cultural methods, which had sufficed to raise the standard of all other crops upon the adjacent plots, the yield of flax was less each year after 1895. In 1899 it dropped from 12.3 bushels, the yield of 1898, to 7.4 bushels. In 1900 all plants were dead by the Fourth of July. At this time Prof. Shepperd turned the plot over to the Botanical Department for investigation. I have since been unable to get any flax plants to reach maturity upon the soil of this plot. Indeed, most plants succumb before reaching a height of three inches. This plot is known in the College records as Rotation plot No. 30.

The following are a few of the observations which, from the first, led me to the conclusion that the disease must be due to a minute plant organism: (1) The disease was observed to be able quickly to destroy all plants over large areas; and plants of all ages died of essentially the same symptoms. These observations seemed sufficient to exclude the work of insects. No insect known could multiply with sufficient rapidity to accomplish such work, and the injury done was of too fine and even a type. (2) The disease was observed to spread rapidly and uniformly through the soil, and was able to persist in the infected areas several years without the crop which it attacks. These features especially pointed to a probable fungoid origin. (3) The disease was seen to spread most rapidly in the line of the surface wash waters. (4) In the infected spots, plants were often found which showed only one blighted side. This dead side is most often nearest the center of the soil infection. (5) The disease was found to spread most rapidly in fertile soils and more rapidly in those of a strong-

* Since this work was accomplished, I learn through the report by Nypels that Broekema had previously conducted a similar sterilization experiment, arriving at like results, though no mention is made of seed disinfection which is strictly essential to make the experiment of value in drawing the conclusion. (See reference cited on page 30 of this bulletin.)

ly alkaline type than elsewhere. These two features are especially characteristic of low forms of fungi, including certain bacteria. (6) Areas of diseased soil were often found at and adjacent to points where masses of flax straw had been allowed to decay, the areas of new infection being too great to be attributed to any chemical substance bleached from the straw. (7) The disease was often seen evenly distributed in the drill rows upon breaking, indicating the probability that it had been sowed with the seed.

These points, together with oft repeated experiments which showed that the infection of new soils could be accomplished through the use of infusions made from the soil of diseased areas and from sick plants, left slight doubt that the disease must be caused by a parasite possessed of such great powers of multiplication and disease production as are only found in the low forms of fungi. It also seemed probable that it must be able to live a part of its life as a decay form *(saprophyte)*.

Figure showing the normal growth and spore formation of *Fusarium lini* nov. sp. upon agar, ten days from date of inoculation. Magnification about 200.

THE FUNGUS AND HOW PURE CULTURES WERE OBTAINED: The fungus which produces the disease belongs to a genus of minute plants which botanists have called *Fusarium*. As it appears to be a species which is new to botanical descriptions, I shall call it *Fusarium lini* * after the plant which it attacks.

Much difficulty was experienced in procuring a pure culture of an organism which could attack a live flax plant. The difficulties arose chiefly from the presence of numerous miscellaneous fungi and bacteria which are always present in the soil, upon and within the decaying parts of the diseased plants. The fungus was first procured in pure form July 6th, 1900, by the following method: Stems of moderately

* FUSARIUM LINI Nov. sp. Vegetative hyphae, light colored, .7–3 m. m.

mature green flax plants, which were just beginning to wilt, were selected. Four inches of the apparently healthy main stem was cut out, stripped of its leaves, washed in distilled water and soaked two minutes in a solution of formaldehyde, made by adding two and one-half parts of standard formaldehyde to 1000 parts of water. Clippings made from the internal woody part of these stems were placed in a sterile moist chamber. In four days there grew out from the cut ends of these clippings a beautiful down-like white growth of filaments. (See figure in Petri dish.) By a series of baits made from sterile, decorticated, green, healthy flax stems, it was easy to get the fungus transferred to the usual solid culture medias. On these, it makes good growth and fruits abundantly, with quite characteristic effects upon slightly acid agar.

Upon all pure cultures and upon moist sterile soil, the growths made are very rapid, and profuse spore formation begins at once. The spores thus found gave the information needed

in diameter septate, branching irregularly, ramifying the tissue of the stems and roots of the host. Spore beds (Sporodochia) erumpent, compact, slightly raised, distinct but closely grouped upon the stems, pale cream to flesh colored. Sporophores rather short and closely branched, or conidia sometimes arising from wart-like or nearly sessile prominences upon a compact stromatic base. Conidia normally four-celled, fusiform, slightly curved or falcate, copiously produced in a bud-like manner from the stroma and from short branches of the sporophores, 27x3 m. m. to 38x3.5 m. m. Living in the humus of the soil, able to attack the flax plant, producing the disease known as "flax wilt", and causing the soil condition long described as "flax sick soil".

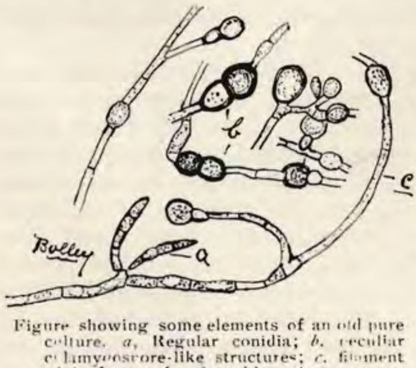


Figure showing some elements of an old pure culture. *a*, Regular conidia; *b*, peculiar chlamydospore-like structures; *c*, filament of the fungus, forming chlamydospore upon its end.

The fungus makes rapid growths under the artificial conditions furnished by the ordinary nutrient culture media, producing a profuse formation of downy white mycelium, from which numerous one-celled, two-celled and four-celled conidia are produced. These rise from the sides of the regular hyphae and upon shorter special side branches. Another form of spore-like body, perhaps of the chlamydospore type, is produced in old cultures and in the filaments found in decaying flax straws. Upon slightly acid pepton agar the fungus develops a beautiful wine color in the substratum. All the different types of spores germinate profusely whenever proper moisture and temperature is given, and they exhibit a peculiar fusion of the filaments similar to that exhibited by the sporidia of certain of the Ustilagineae. (See cuts.)

It may be that this same fungus is parasitic upon some other plant and thus may have been described previously. If so, no great harm can be done to botanical science in the addition of another synonym. Indeed, to the student of parasitology, synonyms prove of much value.

to cause the recognition of a fungus which had been observed with the disease before. Since that time it has been found associated with all specimens of the wilt examined, and it is always to be obtained in the soil of infected areas.

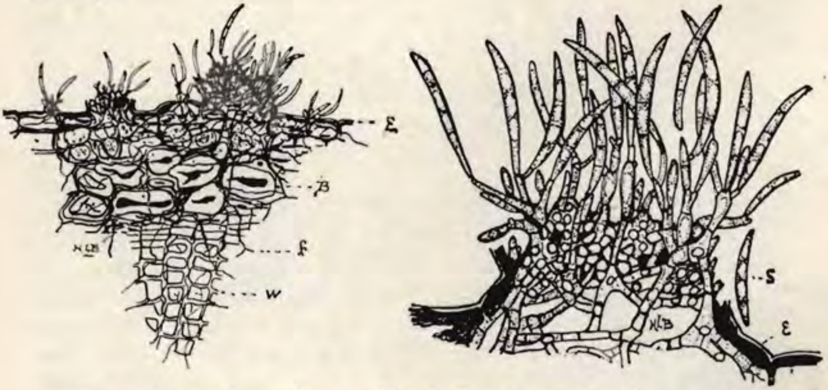
Although the different spore forms were found in 1900 by studies upon culture medias and upon humus and decaying flax rubbish in diseased fields, the typical Fusarium spores were not found upon living plants until July 11th, 1901. These spores seem to occur above ground only under certain favorable conditions.

Figure showing the ability of a pure culture of *Fusarium lini* to attack young flax plants when applied at different points. 5 and 1 young plants killed early, attacked from the soil. Plants 3 and 4 were attacked upon the sides of the stems and upon the seed leaves.

MODE OF ATTACK: Though living normally as a decay form, (*Saprophyte*) this low type of fungus can also invade the living tissues of its host. It produces spores quite normally, both in the humus and upon the tissues of plants which are just dying of wilt. As it can live and increase upon the decaying matter found in soils, especially upon old roots and stems of flax, it can readily thrive there for a long period. Observations made on the rotation plots of the College Farm and upon fields elsewhere indicate that it may not only remain in soil more than four years without the presence of a flax crop, but it can also gradually spread as shown by the effect upon following crops.

The filaments ramify the soil thoroughly and produce an abundance of spores, which may germinate at once. If any of the filaments come in contact with a young flax plant, they penetrate it at any point, through the seed leaves, stem or roots. As soon as the plant dies, it becomes food material for the fungus. On and in such dead parts, numerous spores are soon produced and are carried through the soil by washing of rainwater, etc. The more nearly matured plants are principally attacked by way of the roots. They die slowly and may even ripen seed, apparently maturing early. Sections through the stems and roots of such plants show that the parasite is able to penetrate the cell walls at any point, passing directly through any of the tissues, even including woody parts of the stem. The filaments are, however, in greatest abundance throughout the bark (*cortex*) layer of the stem and roots. This softer tissue of the flax plant is often quite disintegrated. Following the parasite, other decay forms rapidly complete the work of cell destruction, and the plant wilts.

The Fusarium produces spores normally upon the base of the main stems of the attacked plants. The spores get into the seed at threshing time, being rattled from the side of diseased straws. If the grain at the time is slightly damp, the spores get glued to the seeds, and thus are in position to attack the seedling as soon as germination occurs. Numerous plants are thus killed before reaching the surface. As the spores and particles of the filaments (*mycelium*) stand air drying for long periods, and are able to sprout as soon as moisture is applied, it will be clear to any one why the disease can spread so rapidly and do so much damage.



Figures showing clumps of spores which the *Fusarium* usually produces upon the sides of mature flax stems. The drawings are made from cross sections of a flax stem, through the spore beds. The figure on the left, in low magnification, indicates how the filaments ramify the tissues: *b*, bast fibers; *w*, wood cells; *f*, fungus filament; *e*, epidermis; *s*, mature spore. The magnification of the figure on the right is approximately 400 diameters.

THE INFLUENCE OF SOIL AND CLIMATE: The fungus does not seem to have a great preference for soils. I have found it upon all types of land in North Dakota. It probably will thrive upon any land which is sufficiently fertile to produce flax. It makes, however, a most rapid growth upon a rich humus; for example, in a number of indoor tests, it spread with greatest rapidity through a sample of well pulverized virgin sod. Other features being equal, it seems to be most destructive upon strongly alkaline lands, thus the application of lime seems to increase its development. The most general damage to the crop occurs under conditions of drought and upon loose, friable soils. Atmospheric conditions seem to have little to do with the disease, except in so far as they directly affect the physiological processes of the flax plant. A certain degree of moisture is, of course, necessary for a large development of the fungus in the soil, and the spores are produced in greatest abundance on the stems above ground in a humid atmosphere.

How New Areas May Become Infected: Apparently this disease will be a more difficult one to deal with than wheat-smut; because the fungus of flax wilt can live and spread through the soil. Outlines of a few of the experiments, which have proved the disease to be an infectious one, will make this point plain.

INFECTION EXPERIMENTS IN THE FIELD: These Experiments were conducted upon a field, which probably had never previously borne flax.

Experiment No. 1, July 4, 1900. Some fine dirt particles were taken from plot No. 30 and were scattered upon the surface of a bed of young flax. Result: Many plants died of the disease before maturity. A check bed kept for the purpose remained free from the disease.

Experiment No. 2, July 4, 1900. Some young flax plants were watered with water in which some soil from plot No. 30 had been soaked. Result: The young plants were soon attacked, showing many wilted ones on the date, July 19th.

Experiment No. 3, July 4, 1900. Some plants which were just coming through the soil were watered from a cold infusion, made by soaking wilted flax plants. Results: July 19, the disease took full charge of the bed, and plants were found dying.

Experiment No. 4, July 4, 1900. Diseased flax straw was buried in a bed and flax was seeded over the top of it. Result: Plants became thoroughly diseased.

Experiment No. 5, July 22, 1900. A number of young plants were watered with a few quarts of water into which was stirred the fungus growth from several pure cultures upon agar. The plants at this time were about three and one-half inches high. Result: Six of the plants out of a possible eighteen died of wilt before reaching maturity. It was found that a thorough boiling of any one of the infection materials caused it to lose the power of producing disease.

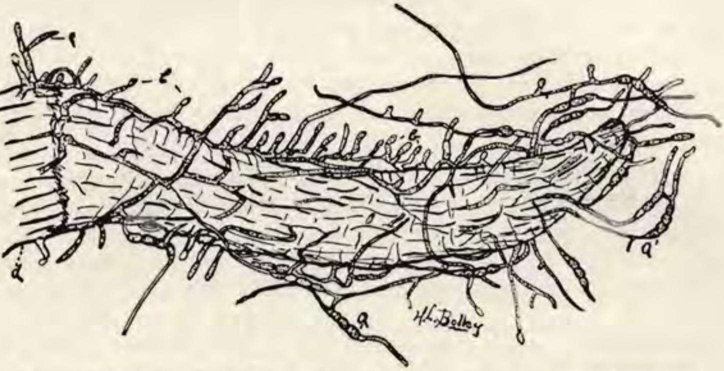
Experiment No. 6, July 10, 1900. Flax seed was received from Mr. John Anderson of Hillsboro. Mr. Anderson stated that his flax crop had been a "spotted failure" in 1899. Some of this seed was sowed. Result: Nearly 50 per cent. of the plants which came up in this bed died of wilt before reaching maturity.

Experiment No. 7. The area of ground upon which these experiments were conducted in 1900 was seeded to flax in 1901. The seed used was treated to kill any flax wilt spores which might happen to be in it. Results: One could easily find the spots upon which the infection experiments were made in 1900 by the presence of the dead and dying plants. Each spot was much enlarged and no flax could live in the center of any one of the spots.

INFECTION EXPERIMENTS IN THE LABORATORY: Many different kinds of infection tests have been carried out in the laboratory.

Experiment No. 1, June 17, 1901. Virgin soil was taken from beneath native prairie sod. The plants were watered with distilled water. Fifty seeds were planted in each of eight rows.

Row 1, seed from Christ Bang, McCanna, quality weak.
Row 2, seed from N. E. Kringler, Buffalo, scaly.
Row 3, seed from D. A. Langworthy, Corinne, fair quality.
Row 4, seed from Grandin Farm, Mayville, fair quality.
Row 5, seed from J. M. Thompson, Ayr, rather weak.
Row 6, seed from point unknown, of weak quality.
Row 7, seed from N. A. Kloster, Aneta, quite sound.
Row 8, seed from College Farm, fair quality.



A rough sketch, showing the mode of attack upon a young root tip of a seedling flax plant. *a*, germinating spores which have sent their filaments into the root; *b*, new spores beginning to form upon filaments arising from the tissues of the root after infection; *c*, a nearly mature conidium; *d*, unattacked part of young plant.

Results: June 26, Row 1, 26 plants up, all sound, ground not infected from seed.

Row 2, 13 plants up, seed leaves dead in some cases, and soil infected from many of the dead seeds.

Row 3, 33 plants up, from strong seeds, 11 wilting from the disease, fungus seemed to be growing from many of the seed pods, ground infected from almost all seeds.

Row 4, 30 plants up, one attacked by wilt.

Row 5, 32 plants up, none attacked by wilt. No infection of the soil from the seed.

Row 6, 21 plants up, 7 dead from wilt.

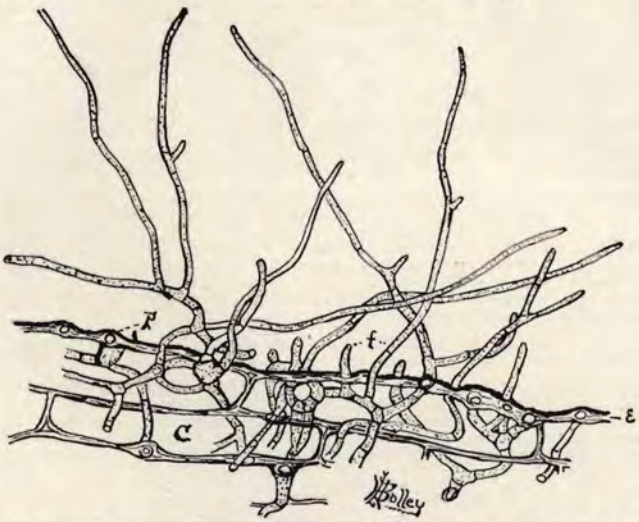
Row 7, 33 plants up, 3 dead from wilt. Wilt spreading in the soil from these three and from some dead seed.

Row 8, 40 plants up, 7 killed by wilt fungus and the soil infected in several spots. The plants in this experiment were sufficiently distant from each other to allow one to note the spread of the fungus in the soil, which can readily be done under the conditions of indoor culture. July 4th the fungus had spread sufficiently from infection spots to reach and kill all plants.

Experiment No. 2. Seeds from the College Farm were treated with hot water so as to kill all spores upon them. They were planted in virgin, sterile soil and watered with distilled water. The plants remained healthy and the soil free from disease until artificially infected. The infection was accomplished in each of the following ways. 1st, from spores taken from old flax straw; 2nd, from seeds which had not been disinfected; 3rd, from soil particles taken from a flax sick spot in a field; 4th, from dried filaments of the fungus, air dried one year; 5th, from a pure culture of the fungus, which had withstood air drying in the laboratory one year; 6th, from fresh spores raised on pure cultures; and 7th, from bits of chaff and flax straw one year old. In the case of the seven tests, the infecting elements were the three different types of spores which the fungus produces, and also new growths from old filaments. (hyphae.)

The conclusion from these experiments would seem to be that the disease is widely distributed throughout the state, that some samples are much more thoroughly infected than others, and that new fields may become infected in any of the following ways: 1, by means of soil particles carried in any manner from diseased areas; 2, by drainage waters from such diseased spots; 3, by diseased flax straw; 4, by flax seed which has been threshed from a diseased crop. It was also learned that the virgin soils of the prairie are probably quite free from this species of the Fusarium; and that the fungus which is pictured in this bulletin is the real cause of the flax wilt disease, and of "flax sick soil."

EXPERIMENTS TO DEMONSTRATE THAT THE DISEASE MAY BE PREVENTED BY SEED TREATMENT: Various experiments have been made to find some substance and method which may prove effective in seed treatment for prevention of the disease; for it is evident that there can be no hope of escape from this soil trouble unless all flax seed is disinfected before planting.



A p rtion of a longitudinal section of a young root of flax, attacked by th *Fusarium* of flax wilt. *c*, cells of the root; *e*, epidermal wall; *p*, note openings in the walls, showing how the fungus bores its way through the cell walls; *f*, aerial filaments of the fungus extending into the soil.

The *hot water* method helped to show that the disease may be communicated by the seed, and that the spores can be killed without killing the seeds, but it is not a practical method as the seed soon softens and gums, or masses like a poultice. The dipping process has proved a failure with all sorts of solutions for a like reason. It can be done for experimental purposes but cannot be carried into field practice. Treatment with gas from formaldehyde seems difficult to control; both seeds and spores are killed or injured with great irregularity. However, a method of treatment has been found possible and successful. The following is an outline of some of the preliminary experiments:

EXPERIMENTS WITH FORMALDEHYDE: Experiment No. 1. The seed used was from the College Farm and known to bear Fusarium spores. The strength of solution was one part of formaldehyde to 400 of water. The seed was soaked from one to sixty minutes, then allowed to dry. Each sample was planted on a field which was free from disease. Results: All seeds, dipped longer than three minutes failed to grow. The treatment was too strong in all cases, but no plants produced the wilt fungus. A check plot from the untreated seed produced many wilted plants.

Experiment No. 2. The seed used was much infected, strength of solution, 1 part to 200. The seed was treated by a fine spray, and at the same time was thoroughly shovelled over. All grains became evenly damp but not wet enough to gum or mat. Result: There was a good growth of plants in the field, but the treatment was heavy enough to injure some seeds. The crop at harvest time was free from wilt.

Experiment No. 3. The seed used was mixed with pulverized chaff and broken straw from plants which died of wilt in 1900. The strength of solution used was 1 part to 200. The grain was treated by the sprinkling and shovelling method. Results: The disease made its appearance in some places in the beds. These infections were found to arise from the bits of chaff and straw. Studies were made of such particles of diseased straw, and it was found that filaments of the Fusarium could grow out from the tissues after the latter had been soaked in a solution of much greater strength than flax seed can withstand. The solution failed to reach the fungus under such protection. In the untreated check on this experiment, the disease was so heavy that practically all plants died before maturity.

Experiment No. 4. The seed used was weak, screened from college flax, and was full of wilt spores. The strength of solution was 1 part to 200. The method was by sprinkling and shovelling until the grain was evenly damp. It was left slightly piled one day before it was seeded. To finish the treatment it took approximately one-half gallon of solution per bushel of seed. Result: Fine crop of plants at harvest time and no wilt appeared in the bed during the season. The untreated bed from this seed produced scarcely half a crop and was thoroughly sick with the wilt disease.

Experiment No. 5. The Effect of Formaldehyde upon Fusarium Spores and upon Flax Seed. In these tests the spores and seeds were dried at once.

Test No. 1. The strength of the solution was 1 part to 400. The seed and spores were each soaked for five minutes, ten minutes and thirty minutes. Results: The seeds were not materially injured by immersions of five to eight minutes, but were much weakened by the longer treatment. The spores were killed in all cases, but the filaments which were located in bits of bark remained able to grow.

Test No. 2. Strength of solution used was 1 part to 250, time of soaking two minutes and five minutes. Results: Seeds were just perceptibly injured by dipping and drying at once, were considerably reduced in strength by soaking two minutes, and were injured fully 50 per cent. by the five-minute treatment. Spores were all killed by simply dipping and drying, but filaments of Fusarium grew from bits of straw after soaking five minutes.

Test No. 3. Effect of Formaldehyde upon Fusarium Spores:

(a) Spores soaked in 1 part in 1,000, 15 minutes—some grew.
(b) Spores soaked in 2 parts in 1,000, 5 minutes—some grew.
(c) Spores soaked in 2 parts in 1,000, 10 minutes—some grew.
(d) Spores dipped in 3 parts in 1,000—some grew.
(e) Spores soaked in 3 parts in 1,000, 5 minutes—some grew.
(f) Spores soaked in 3 parts in 1,000, 10 minutes—no growths.
(g) Spores dipped in 4 parts in 1,000—no growths.

(h) Spores soaked in 4 parts in 1,000, 2 minutes—no growths.
(i) Spores soaked in 4 parts in 1,000, 5 minutes—no growths.
(j) Spores dipped in 5 parts in 1,000—no growths.
(k) Spores soaked in 5 parts in 1,000, 2 minutes—no growths.
(l) Spores soaked in 5 parts in 1,000, 5 minutes—no growths.
(m) Spores soaked in 5 parts in 1,000, 10 minutes—no growths.

This experiment gave opportunity to notice the effect of formaldehyde upon the structures of the spores. It is easy to observe when the formaldehyde becomes sufficiently strong to vitally effect the living substance of the spores. The protoplasm becomes granular and more or less shrunken and dead spores have a crenated appearance. If not too strongly affected, a spore may regain its plump form when water is applied. Sometimes one or more cells are killed, the others remaining able to germinate.

The results of these experiments favor the conclusion that a rather strong solution of formaldehyde acting a short time will work most satisfactorily upon flax seed. It was also proved that such a treatment cannot destroy the filaments of the Fusarium which are located inside of bits of flax straw; hence to succeed in

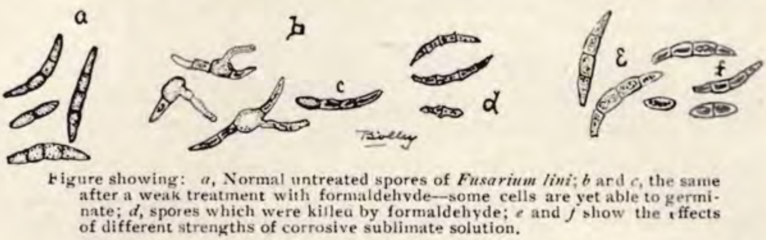


Figure showing: *a*, Normal untreated spores of *Fusarium lini*; *b* and *c*, the same after a weak treatment with formaldehyde—some cells are yet able to germinate; *d*, spores which were killed by formaldehyde; *e* and *f* show the effects of different strengths of corrosive sublimate solution.

treatment for prevention, farmers must clean the flax thoroughly, so as to remove everything except the seeds which are to be sown, before subjecting the grain to the treatment. The chaff, etc., should either be burned or so disposed of that it does not get into the manure pile; for the fungus could easily be taken from there to new fields.

Experiment No. 6. A Study of the Effectiveness of the Sprinkling and Shovelling Method. Two grades of seed were used in the trial: that of grade No. 1 was a very fair quality, well cleaned but infected: that of grade No. 2 contained many seeds of weak and scaly type. The grain in each case was placed in a pile upon a tight floor and shovelled and hoed over rapidly, while the solution was sprayed upon the pile by means of a small spray pump. * The seed of grade No. 1 was treated with a solution of the strength of 1 part to 200; that of grade No. 2 with a strength of 1 part to 400. The grain, in each case, was made thoroughly damp throughout, but not wet enough to gum together. This was accomplished by much shovelling while the water was applied. A portion of each was spread so as to dry at once, the rest was left piled about one foot deep. The next day both piles were found to be dry; the moisture had in part evaporated and in part been absorbed.

GERMINATION RECORDS FOR THIS EXPERIMENT: (a) Test of seeds from grade No. 1: 100 bright, plump seeds were taken from the center of the pile, 100 from the seeds on the outside of the pile, 100 from those which were dried at once, and 100 similar untreated seeds. Results: On the 4th day, it was evident that the seeds from the center of the pile were less strong than

* A fine nozzled sprinkling can will do for this work, provided one is careful not to sprinkle on too much solution before shovelling over.

those from the outside of the pile and those which were dried at once, while the latter were quite as strong as those from the untreated lot. On the 8th day the plants were counted.

1, from center of pile, 74 normal plants, 19 imperfect and 7 dead.
2, from outside layer, 92 normal plants, 6 imperfect and 2 dead.
3, from seeds dried at once, 96 normal plants, 3 imperfect and 1 dead.
4, from untreated seeds, 78 normal plants, 14 imperfect and 8 dead.

The Fusarium, an Alternaria, and some common moulds attacked the untreated plants, while the treated grains remained clean. This, perhaps, accounts for the final growths from numbers 2 and 3, being better than those from the untreated seed.

(b) The tests of seeds from grade No. 2 gave the following:
1, from center of pile, 82 plants of normal form, 10 imperfect, 8 dead.
2, from outside layer, 72 plants of normal form, 10 imperfect, 18 dead.
3, from seeds dried early, 71 plants of normal form, 14 imperfect, 15 dead.
4, from untreated lot, 73 plants of normal form, 12 imperfect, 15 dead.

In this set of tests some Fusarium spores grew on seeds of 2, 3 and 4. No. 1 gave best results.

Experiment No. 7. Germination tests upon infected seeds, treated and untreated and planted in sterilized soil to note the effectiveness of seed treatment for prevention: The seed used was infected, scaly flax of weak and immature type.

1, untreated; 2, dipped in formaldehyde 1 to 1,000; 3, dipped in 1 part to 400; 4, dipped in 1 to 250; 5, in 1 part to 200. The seeds were planted at once after treatment on July 10th. Results:

On July 15th the conditions were as follows: No. 1, 56 plants up, eleven plants attacked, lots of infection.
No. 2, 62 plants up, two or three soil infections from the seed.
No. 3, 57 plants up, one wilt infection found.
No. 4, 47 plants up, no wilt infections.
No. 5, 59 plants up, no wilt infections found.

The tests under experiment No. 7, considered in connection with many others, indicate that the proper strength of formaldehyde solution to be used in the sprinkling and shoveling methods is about 1 part to 330 parts of water (approximately one pound to 40 gallons), and that the best strength of flax germination will be obtained by shoveling or handling the grain over after treatment sufficiently to get it dried out at once.

OTHER TREATMENTS POSSIBLE: Numerous tests have been made with other fungicides and with various substances which gave promise that they might be more easily applied in practice than formaldehyde. Rather satisfactory results have been obtained from some of them, but as none are yet under proper control, the details of the tests will not be given at this time. The following stubstances have been studied as to their effects upon the growth of flax seed, and upon the development of the Fusarium: salt, lime, hot water, hot air, alcohol, flowers of sulphur, iron sulphide, copper sulphate, formaldehyde gas, corrosive sublimate, creolin, creosote, kerosene, gasoline, turpentine, gasoline and turpentine, gasoline and creosote, gasoline and creolin, gasoline and carbolic acid, and carbolic acid.

Of these substances copper sulphate and corrosive sublimate prove quite effective, but show no quality which in farm practice would give them preference over the formaldehyde.

As flax seed when wet readily gums or masses in cakes, it has been thought very desirable to obtain some dry treatment. As yet this has not been accomplished. Salt, lime and sulphur are ineffectual against the spores, indeed, appear beneficial to the growth of the fungus, when applied in strengths which are injurious to flax. Hot water gums the seed at once. Formaldehyde gas is unmanageable in practice, and the seeds are killed irregularly.

It would prove very acceptable to farmers if one could develop a quick drying liquid process. For this reason gasoline and turpentine each seemed promising. Seed treated with these substances dries at once and becomes very mobile, suitable for running through the drill; but, strange as it may seem, both flax seeds and the spores of the Fusarium withstand soaking in these

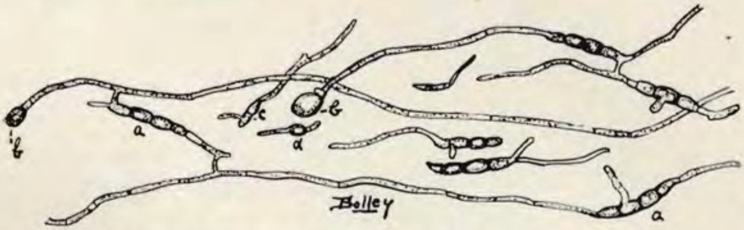


Figure showing the characteristic germination of the regular spores, conidia, of *Fusarium lini*, nov. sp. *a*, regular spore; *b*, secondary spores formed just after germination; *c*, two-celled spore; *d*, one-celled spore. Note the peculiar fusion of filaments. This seems to occur before the secondary spores begin to form.

oils for long periods of time without effect upon their powers of germination. Thus, both germinated freely after being immersed for three days in gasoline of commercial strength. Both spores and seeds germinated well after soaking 15 minutes in a 50 per cent solution of *turpentine* in gasoline. A few trials with 5 per cent *carbolic acid* in gasoline also showed that this substance only slightly retards the growth from the spores.

Further efforts will be made along these lines, but even gasoline has many qualities which would be against its use in farm practice. It is thus pleasing to know that it is really but little more difficult to apply the formaldehyde treatment to flax, per acre, than for oats. The only point with regard to the difficulties encountered in treating flax is that it must be cleaned thoroughly before treatment, and one must be somewhat more careful when applying the treatment. The solution must be applied slowly and evenly and not too much, just enough to evenly dampen the surfaces of all seeds. One must also be very careful to dry the flax out at once after the treatment.

POSSIBILITY OF SOIL TREATMENT: Tests have been made to determine the effects of various chemical substances and different fertilizers upon the disease, by applying such substances in large amounts directly to infected areas.

Experiment No. 1. July 4, 1900. The soil used was that of rotation plot No. 30. There had been five crops of flax upon this land. At this time the sixth seeding had just finished dying by wilt, the oldest plants being from 3 to 5 inches high. A portion of the plot was spaded into a number of garden beds, 4x4 feet each. Three rows of the same kind of flax seed were planted in each bed. The seed was planted in shallow drills, and one-half of the substance to be applied in each case was sprinkled in the row, around and over the seed. After the drills were covered, the other half of the substance was scattered evenly over the surface of the bed and slightly raked in. All of the substances used were first thoroughly pulverized, and the following beds were planted: Bed 1, untreated; Bed 2, kainite, 1 pound; Bed 3, nitrate of soda, 1 pound; Bed 4, "Complete fertilizer", 1½ pounds; Bed 5, superphosphate, 1 pound; Bed 6, cow-dung, 2 quarts; Bed 7, sheep dropping, 3 quarts; Bed 8, potassium sulphate, ½ pound; Bed 9, carbonate of soda, ¼ pound; Bed 10, chloride of lime, ¼ pound; Bed 11, oxalic acid, ¼ pound; Bed 12, iron sulphate, ¼ pound; Bed 13, potassium nitrate, ¼ pound; Bed 14, calcium phosphate, ½ pound; Bed 15, sodium chloride, ½ pound; Bed 16, calcium sulphate, ¼ pound; Bed 17, magnesium sulphate, ¼ pound; Bed 18, untreated; Bed 19, composted barnyard manure, 1 peck; Bed 20, copper sulphate, ¼ pound; Bed 21, lime, air slacked, one quart, evenly distributed in the top inch of soil. Results: July 19, 1900. The flax came up rather evenly and well in all beds after several good showers, but commenced to wilt at once with the disease, many being dead at this date. August 8th, all plants were found to be dead. They were killed by the wilt fungus, as shown by studies made in the laboratory.

Experiment No. 2. May 13, 1901: Professor D. B. Halsted has recommended flowers of sulphur as a fungicide to be used in infected soil. * It has been found to be ineffective against the flax wilt fungus, as is shown by the following tests. In each case flax wilt spores were sowed with the seed.

Test No. 1. 4 parts of sulphur were sowed with one part of seed flax. Results: Jan. 27, good stand of flax, many sick of wilt; Sept. 4, crop matured, but fully one-half of the plants had died of wilt.

Test No. 2. same as No. 1, only a large quantity of the sulphur was hacked into the bed between the rows. Results: About as in test No. 1.

Test No. 3, July 12. Soil was taken from beneath virgin sod, placed in flower pots and steam sterilized. Flowers of sulphur were then mixed with the soil as follows: Pot 1, 1 oz. of sulphur to 5 oz. of soil; Pot 2, 2 oz. of sulphur to 5 oz. of soil; Pot 3, 3 oz. of sulphur to 5 oz. of soil. Fusarium spores were planted beside each seed used. Results: Three days after planting the fungus was seen to be making a heavy growth. Later, some plants came up in each pot, but most of the seedlings were killed by the Fusarium before getting through the ground. Finally all plants died of wilt, but the Fusarium made a luxuriant growth in the yellow mass. It invaded the porous sides of the pots and produced spores in quantity upon the outside in the open air. Indeed sulphur seemed to increase the growth of the Fusarium.

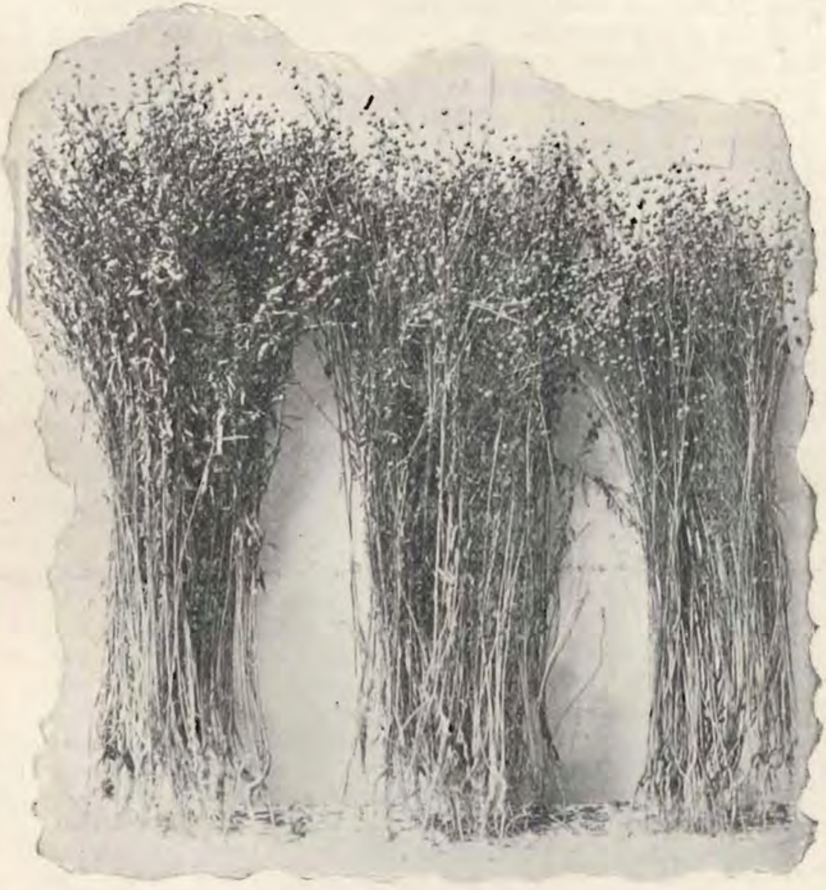
Experiment No. 3, July 12. Special Experiments with Salt: The soil used was prepared the same as in test 3 of experiment 3, salt being used instead of sulphur. Pot 1, ⅛ oz. of salt to 5 oz. of soil; Pot 2, ¼ oz. of salt to 5 oz. of soil; Pot 3, ½ oz. of salt to 5 oz. of soil. Results: July 24, salt too strong, no growths of plants in any pot but the Fusarium had rapidly invaded the soil and was producing spores in abundance.

Experiment No. 4, July 12. Air slacked lime was applied in the same manner as that indicated for sulphur and salt. As a chemical treatment of soil, it also is a failure. The Fusarium makes better growth when it is present in excess than in ordinary soils.

It is evident that fertilizers and manures cannot help the flax to resist the disease, and that one can have little hope of finding

* New Jersey Experiment Station Report for 1895, page 267.

any chemical substance which will destroy the fungus in infested soils without killing the germinating flax. We must therefore probably look to seed treatment and proper crop rotations to overcome this soil trouble.



A photograph illustrating the effectiveness of a proper treatment of flax seed for the prevention of flax wilt. Bundle No. 1 shows the growth from a formaldehyde treatment; bundle No. 2, from untreated seed; bundle No. 3, from untreated seed planted with an extra infection of the spores of the flax wilt fungus. Each bundle represents the entire crop from the same area of ground.

CROP ROTATIONS: As yet nothing very definite can be said along this line. We have only the experience of Belgian and other European flax growers to draw from. Their rotation series are always long ones, introducing more kinds of crops than we can well do here, in our extensive field cropping. In the best flax growing districts of the Netherlands, the land is used for that crop about once in ten or eleven years. In this way the crop is kept up to the standard. It is possible that such long rotations rid the soil of this and other destructive diseases. Professor Lugger has said that he could find no apparent common system in these rotations. They seem to be matters of local origin and are kept up simply because they give good results in the crops concerned. The following series will illustrate about the average type of rotation used there upon heavy lands: turnips, oats, clover, clover, wheat, flax, wheat, beans, wheat, potatoes, wheat, oats, and flax. It will be an advantage to us to find some shorter cut from flax to flax. To that end, we are conducting at the station a series of 12, hand cultivated, rotation beds upon plot No. 30 (the diseased plot). There is much room for hope with us, because it is probable that the Belgians as well as others may have been sowing diseased flax seed each time that flax was placed upon their lands. They may also have applied the disease to new lands by the use of manures infected from diseased flax. Now that we know how to avoid spreading the disease afresh each year, it would seem that the farmers of this state and region ought to have a great advantage over older flax countries in dealing with the trouble.

The method which we intend to follow may be indicated as follows: The soil selected is thoroughly infected, but is fertile. No flax plants can now live upon it. By special methods we find that we can always detect the presence of the fungus in the soil. The plot is laid off into twelve distinct beds 30x33 feet in area. Each bed will be spaded and worked with sterilized tools. Each bed will have its own drainage system and is separated by an alley-way 7½ feet wide. Before each crop is planted, an analysis will be made to determine how abundant the Fusarium is in the bed, how deep it extends into the soil, etc. After the crop is taken off, the analysis will be repeated. The crops placed upon the beds each year will depend upon results of these tests. The yields will be recorded and no fertilizers will be applied.

In 1901, the beds were handled as follows: No. 1, bare fallow (no kinds of plants allowed to live); No. 2, wheat; No. 3, potatoes; No. 4, beets; No. 5, bare fallow; No. 6, oats; No. 7, oats; No. 8, bare fallow plus 20 pounds of salt; No. 9, bare fallow plus 20 pounds of sulphur; No. 10, flax (died when three weeks old); No. 11, sowed corn; No. 12, idle, grew up to heavy growth of all sorts of weeds.

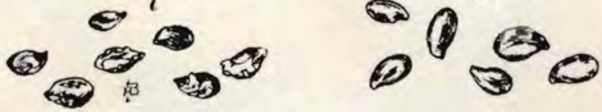
Until more is known upon this matter of rotation, the farmers of the state are earnestly recommended not to sow flax upon land which has previously borne flax, until a number of other crops have intervened. If possible, I think it would be beneficial to take off a crop of wheat; a crop of corn, potatoes or other hoed crop; a crop of oats, barley, or millet; then follow these by some years of grass and pasture. It may be better to have a small area of flax giving a heavy yield every few years than to have to go out of the business entirely. There are reasons for believing that a brome grass sod will have a most beneficial effect toward regenerating such "flax sick" soil.

A photograph showing the appearance of a pure growth of *Fusarium lini* filaments arising from the inside of bits of flax straw which had been treated heavily with formaldehyde. This teaches that such bits of straw should be removed before treatment. (Original.)

MEANS OF DISTRIBUTION: *Drainage.* It is evident from all observations that the disease areas tend to enlarge most rapidly in the direction of the surface drainage. From the nature of the spores, and from the fact that great numbers of them are produced in the soil and upon particles of decaying roots and straw, and on the sides of the roots and stems of the sick plants, it is plain that the spores may be carried long distances in the drainage waters after heavy rains. It would seem to be a matter of wisdom to arrange the general drainage of flax fields so that the water may not be carried over other lands.

The Influence of Wind: This is an element of unknown influence in the distribution of the disease. By our experiments we have found that very small particles of soil from the surface of infected areas are sufficient to start the disease in clean soil. We also know that the spores are very numerous and light, and that they stand air drying for long periods of time. It is thus possible that they may be blown from field to field. Many careful observations, however, have failed to convince me that this method of distribution occurs to any marked extent. In rotation experiments upon the College farm, the disease seems to stay pretty well confined to the particular plots attacked. It does not spread very rapidly to the immediately adjacent plots.

Other Means of Distribution: Besides wind and water there are a few ways in which the disease can quite certainly be carried from infected areas to new plots or fields. This may be done by cattle walking over the diseased areas in a wet time, thus easily carrying masses of germ bearing mud and dirt from place to place. Harrows and plows may serve a like end; and the manure pile may easily become the source of much infection, on account of the presence of old flax straw. It is not now known what effect proper composting of manures may have upon the life of the Fusarium.



Sketches showing, *1*, scaly flax seed, and, *2*, smooth, plump flax seed. Farmers should screen out all scaly, immature seeds. They harbor the spores of flax wilt.

THE NECESSITY OF CLEANING AND GRADING THE SEED: One of the most important points in the entire range of flax culture lies in the proper cleaning and grading of the seed. In this state, flax is usually one of the weediest of our crops. This is because farmers have been careless about cleaning the seed for this crop. There are also no types of our farm plants which may suffer more harm from the presence of weeds than flax. This alone would be sufficient excuse for thoroughly cleaning the seed before sowing upon the land, but there are other good reasons for doing so. I have found by experiments that the week, immature, scaly or chaffy seeds are able to carry great numbers of the spores of the wilt disease lodged in the scales or creases. Such seeds are usually soft at threshing time and thus, if spores fall upon them, they become glued to the seed. In one experiment seeds from the screenings taken from a lot of flax seed which was diseased contained a very much greater percentage of flax wilt spores than the plump seed from the same sample. The test showed but two soil infections from 100 of the plump seed taken from the cleaned sample. This sample had been run through the fanning mill but once. The weak, scaly seeds taken from the screenings produced thirty-seven soil infections from one hundred seeds planted. It is thus quite certain that a thorough cleaning and grading of the flax seed would greatly reduce the possibility of infecting new soils with the flax wilt fungus. I earnestly recommend that

Figures showing various grades of diseased growths from immature scaly flax seed. All are more or less attacked by the wilt fungus.

those who do not think that they have time to treat their seed flax, or are afraid to do so for fear they may, through inexperience, injure the seed, should clean the seed thoroughly. This will remove all weak seeds and tend to cause an even stand of the flax, which is much to be desired, as it is very important in a flax crop that the plants should be of even strength so that they may ripen evenly. The spores of the flax wilt do not seem to be able to cling to good, smooth, plump seeds, unless the flax has been wet or damp at some time. When such good seeds are run through a fanning mill, the loose spores and bits of chaff and dust which carry the disease are blown away.

HOW TO TREAT FLAX SEED.

There are some difficulties connected with treating flax which are not encountered in handling other grains. When I first recommended the formaldehyde treatment for wheat and oats, a number of farmers complained that they injured their seed. In so far as I have been able to investigate any of those cases, the trouble has been due to some defect in the manner in which they carried out the work. I hope that no farmer will undertake to treat his flax seed until he has read the directions here given very carefully. While the amount of seed to be handled over is much less than in the case of oats and barley, one must do the work very much more carefully. I have only to call attention to the fact that the mere wetting of flax seed, unless it is quickly dried, is injurious to its germinating qualities. One ought, therefore, in treating flax, to be very careful not to use a bit more of the solution than is necessary to dampen the grain. If by accident you should chance to supply more moisture to a batch of seed than you ought to do, throw in some more dry seed at once and stir it over rapidly. The dry seeds will withdraw the excessive moisture from those which are too wet, and thus prevent injury to the latter.

I would not recommend that any one should undertake to treat all his seed flax this year. Try a sufficient amount to sow an area large enough from which to harvest the seed for next year's crop. By another year you may learn to avoid many errors which might now arise through inexperience.

The Method of Treatment: Use formaldehyde at the rate of one pound of the standard strength to forty or forty-five gallons of water (the same strength used for wheat and oats). Spread the seed upon a tight floor or upon a canvas and sprinkle or spray on a small amount of the liquid (a fine spray is best). Shovel, hoe, or rake the grain over rapidly. Repeat this spraying, shoveling, hoeing or raking until the surfaces of all of the seeds are just evenly moist, not wet enough to mat or gum, but evenly damp. (This can be done without matting if the grain is well hoed or shoveled over while the solution is slowly and evenly sprayed upon it). When the seeds are just evenly moist, cease applying the solution, but continue to shovel the grain over so as to get it dry as soon as possible. Avoid any excess of moisture. If flax seeds are dipped in the solution or are allowed to get wet enough to soften the seed coats so that they will stick together, they will be considerably injured or even killed.

It takes less than one-half gallon of the solution to properly moisten one bushel of flax seed.

Caution: One must treat flax with much more care than that usually taken in treating wheat or oats for smut. The solution recommended is strong enough to kill all seeds, if they are made thoroughly wet, or if they are allowed to stay quite damp for some hours.

The grain must be handled over immediately after treatment until it is found to be dry.

Note: The seed should be thoroughly cleaned by running through a fanning mill before it is treated because the solution is not strong enough to kill the disease *(fungus)* which is inside of bits of straw and chaff.

SUMMARY WITH NOTES.

1. There is a diseased condition of flax soils which has long been known to farmers in flax producing regions as flax sick soil.

2. If flax is sowed rather continuously for a number of years upon the same soil this disease tends to thoroughly infect the soil so that flax growing becomes no longer profitable.

3. The disease may be spread by way of the seed flax.

4. The plants attacked die at all ages as if attacked by wilt; hence I have called the disease the flax wilt disease.

5. The direct cause is a minute fungus parasite which grows on the inside of the flax plant, starting either from the seed, or by attacking the roots of older plants if the soil has previously been infested.

6. There are many ways in which the infection might reach new fields, but the chief one is by way of the seed.

7. The seed (spores) of the parasite get into the seed flax at threshing time, rattling off from the sides of the flax straws which have been attacked by the parasite.

8. When such infected flax seed is sown, the spores of the fungus germinate and at once attack the young plants. Those attacked early die at once and there may be no stand even from good seed if the spores of the parasite are abundant. When once in the ground the fungus spreads rapidly, attacking new plants throughout the season. It can live from year to year upon the humus of the soil, hence the soil is soon ruined for flax. Six years

of continuous seeding of flax upon the same plot at the Agricultural College thoroughly filled the soil with the parasite and no plants of flax can live there longer than three weeks.

9. All other farm crops do well upon the flax sick soil. It has not lost fertility for flax, as is proved by experiments which destroy the spores without injuring the soil.

10. The fungus belongs to a genus of plants which botanists have called Fusarium. As this is a new species, we shall call it Fusarium lini.

11. Much of the soil of this state has not yet been infected; but about 50 per cent. of all samples of seed flax yet examined show the presence of the Fusarium spores. It is probable that no sample of flax seed is entirely free from infection.

12. When the soil is once infected no way is known to rid it of the parasite. The fungus is able to live in the soil for many years without the presence of a flax crop to feed upon.

13. The seed flax should be thoroughly graded and cleaned in a fanning mill before treating. This will remove all of the bits of diseased flax straw and chaff which would not be sufficiently treated to kill the fungus inside of them.

14. After treating, it may be well to sow two or three quarts more per acre, as some of the weaker seeds are apt to be killed.

15. Scaly flax seed and seed which has been wet is always very poor for seed. Such seeds harbor the spores of fungi which kill the young plants as soon as the seeds germinate.

16. Cease sowing flax year after year upon the same land. Put at least one cultivated crop and two or more other crops between flax crops.

17. Burn as much of the old flax straw and stubble which remains upon the ground as possible.

18. Raise your own flax seed, grade it up to the best. Watch for diseased areas and notify the station. Thresh your seed, when you can, in your own machine from a patch of strong healthy flax and store it in a clean bin.

19. Keep all the flax straw out of the barnyard, unless it is intended to put all manures through a several years composting process. I cannot say that this process will be successful in de-

stroying the fungus. It is destructive to most weed seeds and to the spores of many fungi.

20. Avoid the evil effects of deep planting. Much damage is done to the flax crop of the state by too deep planting. The flax wilt disease does more injury to the seedlings when the seed is placed deep in loose soil than when planted shallow. One-half inch to three-fourths inch is the best depth. The seed bed should be of even texture and quite compact.

HENRY L. BOLLEY,
Agricultural College, N. D.

March 1st, 1901.

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