EXPERIMENT STATION

OF THE

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FARM DEPARTMENT.

H. M. COTTRELL, M. S., Agriculturist.
D. H. OTIS, M. S., Assistant in Dairying.
J. G. HANEY, B. S., Assistant in Field and Feeding Experiments.

SOIL INOCULATION FOR SOY BEANS.

THE study of soil inoculation for soy beans was first made at this Station by D. H. Otis as a part of his work for the degree of master of science. His investigations indicated that if practicable methods of soil inoculation for large fields could be developed they would prove of great value in providing a cheap method of enriching long cultivated soils. Mr. Otis completed his work in 1897 and in 1898 the Farm Department began the work of inoculation on a field scale.

In this bulletin the work of Mr. Otis is given first, while the work of the department in inoculating large fields begins on page 112.

Root Tubercles and their Production by Inoculation.

BY D. H. OTIS, M. S.

GENERAL STATEMENT.—BY examining the roots of such plants as clover, alfalfa, beans, and peas, one will usually find, scattered over their exterior surface, tubercles of various sizes and shapes. These tubercles, are, with very few exceptions, peculiar to a certain order of plants known as Leguminosæ. These tubercles are the outgrowths of the plants themselves, and are produced by the action of certain micro-organisms working within the tissues of the root. Formerly these tubercles were considered abnormal appendages and as injurious to

the plants, but later observations revealed the fact that where these tubercles were wanting, the plants did not make the growth that was made by plants where the tubercles were present. Later examination has brought out the fact that these tubercles are the homes of minute microscopic bacteria (*Bacillus radicicola* Beyer). The bacteria have the remarkable property of taking the free nitrogen of the atmosphere and transforming it into available compounds for plant-food. So it is a case of symbiosis, the plant furnishing food and shelter for the bacteria, and the bacteria, in turn, furnishing the plant with nitrogen. This is what makes the leguminous plants so valuable as soil enrichers, and especially prized for green manuring.

All the problems connected with the assimilation of free nitrogen through the intervention of root tubercles have by no means been solved. Even the best authorities seem to disagree on some points. However, it is pretty well settled that the tubercles are the result of a micro-organism, but it has been proven that the organism producing tubercles on the pea or bean will not produce tubercles on clover and alfalfa, and *vice versa*. Whether these organisms are different species for different plants, or a modification of the same species, is yet a disputed question. Again, as the organisms attack the root, it is supposed that they exist in the soil, and the question would naturally arise as to whether they could be transported and spread with the soil, and, if so, whether that is the only way; or whether the seed from plants with tubercles will produce tubercles when grown in soil devoid of the organism adapted to that particular plant. To test some of these questions, and others connected with them, experiments were carried on with the soy bean (*Glycine hispida* Maxim).

EXPERIMENTS IN THE FIELD.

Methods of Inoculation.— Since 1890 soy beans have been grown at the Kansas Experiment Station, but frequent and numerous examinations of the roots fail to reveal the presence of any nodules or tubercles. Knowing that the Hatch Experiment Station, Amherst, Mass., had been successful in producing tubercles on the soy bean, it was proposed that an attempt be made to inoculate the Kansas beans with Massachusetts soil. The soil arrived in a dry, pulverized condition, not unlike the dust in our roads during a dry season. The field experiment was situated on a sandy loam soil with a western exposure, and consisted of two series of three plats each. Series I was planted with Yellow Soy beans, in which the plats were treated as follows: Plat A was inoculated with soil, plat B with extract, and plat C was not treated. Series II was a repetition of series I, with the exception that the Medium Green bean, a variety grown at the Hatch Experiment Station, was used instead of the Yellow Soy. The object was

SERIES I. **A**, inoculated with soil; **B**, inoculated with extract—(1) at time of planting, (2) once after planting, (3) three times after planting; **C**, not treated.

				1	2	3					
o	o	o		o	o	o		o	o	o	
o	o	o		o	o	o		o	o	o	
o	o	o		o	o	o		o	o	o	
o	o	o	Guard row	o	o	o	Guard row	o	o	o	
	—A—				—B—				—C—		
o	o	o		o	o	o		o	o	o	
o	o	o		o	o	o		o	o	o	
o	o	o		o	o	o		o	o	o	
o	o	o		o	o	o		o	o	o	

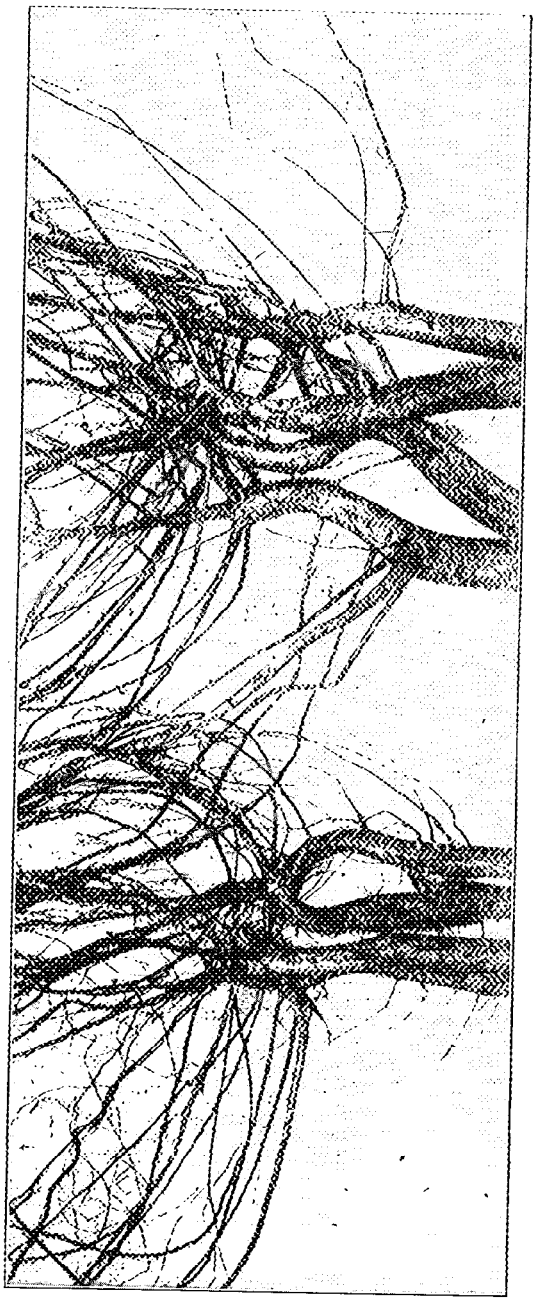
SERIES II: **D**, inoculated with soil; **E**, inoculated with extract—(4) at time of planting, (5) once after planting, (6) three times after planting; **F**, not treated.

				4	5	6					
o	o	o		o	o	o		o	o	o	
o	o	o		o	o	o		o	o	o	
o	o	o		o	o	o		o	o	o	
o	o	o	Guard row	o	o	o	Guard row	o	o	o	
	—D—				—E—				—F—		
o	o	o		o	o	o		o	o	o	
o	o	o		o	o	o		o	o	o	
o	o	o		o	o	o		o	o	o	
o	o	o		o	o	o		o	o	o	

to note whether there was any difference in the production of tubercles between a variety whose seed was obtained from plants grown in Massachusetts soil and seed obtained from plants grown in Kansas soil. Both series were seeded May 29, 1896. Each plat contained three rows two and one-half feet apart, and each row contained eight hills twenty inches apart. Between the plats was placed a guard row in which the beans were not treated and were planted in drills from two to three inches apart. The arrangement of the series and the plats is shown in the accompanying plan.

On plats A and D about one-twentieth of a pint of the pulverized Massachusetts soil was placed in the bottom of each hill and the beans placed on top of this. Plats B and E were treated with an extract of the Massachusetts soil. This extract was obtained by mixing a quantity of soil with about seven times its bulk of water, stirring thoroughly, and allowing the soil to settle, after which the water was poured off and used for the inoculation. The aim was to use about the same quantity of soil in obtaining the extract as was used on the same number of plants where the soil was applied direct. Rows 1 and 4 of plats B and E, respectively, were inoculated at the time of planting, *i. e.*, about one-sixth of a pint of the extract was poured in the bottom of each hill just previous to planting the beans. Rows 2 and 5, 3 and 6, were inoculated June 13, seven days after the plants were up, and rows 3 and 6 were again inoculated on July 2 and July 17, or twenty-six and forty-one days, respectively, after the plants appeared above ground. The extract reached the roots through a round hole made with a pointed stick. Plats C and F were planted in the same manner as the others except the inoculation. The purpose of these plats was to serve as a check on the others, and, at the same time, as a means of comparison with the inoculated plats as regards growth and general appearance.

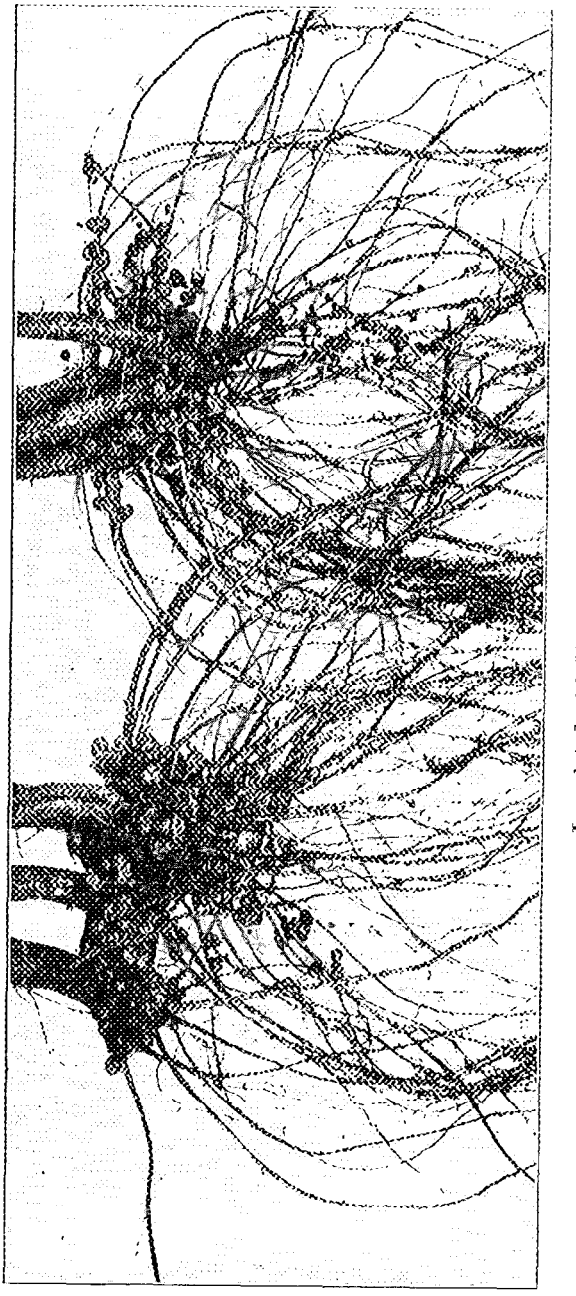
Culture and Growth.— The season was favorable to the growth of the beans. The beans were up June 6. On June 13 some of the extra plants were pulled up, and there were found several well-defined nodules on the roots of those inoculated with soil, but none were found on any of the others at this date. June 22 it was noted that the beans inoculated with soil appeared to have a little larger growth. The difference was not very striking, however. On July 14 the Yellow Soys were in full bloom, but the Medium Green, being a little later variety, did not appear in full bloom until July 20. Measurements were taken for the average heights of the plants on August 20, with the result that the Yellow Soy showed greater height than the Medium Green. This was due, however, to the difference in the variety, the latter being a late-maturing and a somewhat more bushy



Not inoculated.

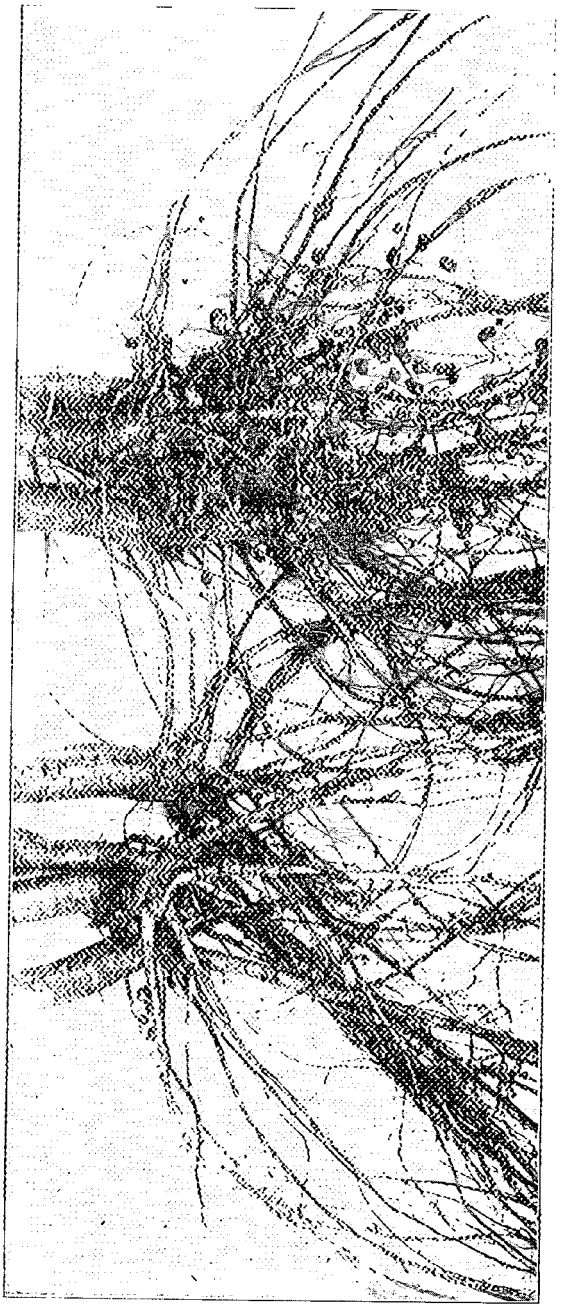
PLATE I.

PLATE II.



Inoculated with Massachusetts soil.

PLATE III.



Inoculated with extract.

plant than the Yellow Soy. It was also noticed that in plats B and E, rows 1 and 4, inoculated at time of planting, attained, on the whole, a little greater height than rows 2 and 5, and 3 and 6, inoculated subsequently to the time of planting. This would indicate that the best time to inoculate is at the time of planting. Furthermore, the plants inoculated with soil averaged a little greater height than the others. However, the differences above noted are not great, and, with the exception of the difference due to variety, would not be noticed by the ordinary observer without the application of a measuring rod.

Appearance of the Roots.— On August 27 two hills each of the treated plats and one of the untreated were dug up, together with about a two-foot cube of the soil surrounding each hill. These were placed in large tubs of water, and, after a thorough soaking, the roots were carefully washed out and examined for tubercles. The latter were found in great number and of large size on the inoculated plants, but not a single tubercle could be found on the plants not treated, from either the Yellow Soy or the Medium Green; nor were there any signs of tubercles on the plants in the guard rows between the inoculated plants. The tubercles on the plants inoculated with soil were fairly uniform and situated mainly on the upper portion of the roots, not far from where the soil was placed at the time of planting. In case of the plants inoculated with extract, there was a marked difference between the varieties; the tubercles on the Yellow Soy were very numerous and well developed, while those on the Medium Green were scanty and rather inferior. All the inoculated plants showed a greater diameter of the lower portion of the stem than the plants not treated. Pictures were taken of the different treatments, and are here given. (See plates I, II, and III.)

Nitrogen Content.— On September 17 an average sample of six stalks each was taken from plats D and F of series II for analysis, with the purpose in view of ascertaining whether there would be any difference in the content of nitrogen between the plants with tubercles and those without tubercles. The seed being the most constant in composition of any part of the plant, it was thought that the difference, if any, would be in the fodder; and so, after the samples were thoroughly dried, the beans were all shelled out and the fodder ground up fine. From this a sample was taken and pulverized for analysis. The per cent. of nitrogen is shown in the following table, together with the protein and water.

Table I.

TREATMENT.	Nitrogen.	Protein.	Water.
Inoculated with soil	1.439%	8.996%	7.89%
Not treated	1.395	8.719	7.30
Difference	0.044%	0.277%	0.59%

The analysis does not show any great difference in favor of inoculating, there being an increase of only .04 of 1 per cent. of nitrogen and .27 of 1 per cent. of protein in favor of the beans with tubercles. This would be .8 pound nitrogen and 5.4 pounds protein increase for each ton. But it must not be concluded that this is the only difference. The roots with the tubercles rich in nitrogen possess greater fertilizing properties than the roots with no tubercles, the results of which would be shown in the succeeding crop or crops. Furthermore, had the tubercles been grown on poor soil instead of rich soil, doubtless there would have been a still greater difference in favor of inoculating.

Data as to Yield.— Plats C and F, not treated, remained green longer than the inoculated plants, which tended to increase their fodder yield in comparison with the others. The results show that the Yellow Soys, plat B, inoculated with extract, yielded a little the best of both grain and fodder, but the difference is very slight. Of the Medium Green, plat F, not treated, yielded the most grain, and plat D, inoculated with soil, the most fodder. In all these cases the differences are not great, and, as the plats were very small, it would be impracticable to pass any judgment as to comparative yield. The benefits from inoculation lie largely in the increased fertility of the soil resulting from the decay of the nitrogenous roots, and would not be seen until after the growth of the succeeding crop.

EXPERIMENTS IN THE GREENHOUSE.

Repetition and Extension of Field Experiment.— Pots containing native soil were planted to beans, and treated in the same manner as in the field experiment, and were attended with practically the same results. The test, in this case, was extended so as to include other varieties of the soy bean, namely: The Edamame, Kiyusuke Daidzu, Yamagata Cha-daidzu, Early White, and the Medium Black. In all these cases, where the plants were inoculated with either soil or extract, numerous and well-defined tubercles appeared on the roots. In a few instances, however, one or two tubercles were found on the plants not treated, but these were isolated cases, and were undoubtedly due to infection resulting from the manipulation of tools and pots when the beans were planted.

How Soon Do the Tubercles Appear?— To obtain information on this point, a small bed was planted in the greenhouse June 19 and inoculated with Massachusetts soil, from which plants were taken up nearly every day to ascertain when the tubercles began to appear. They were first visible to the naked eye on July 3, thirteen days after the beans were planted, or eight days after they appeared above the ground. From this it would be inferred that the bacteria began their work very soon after the young roots are formed and increase their activity with the growth of the roots.

Effect of Sterilizing the Soil.— Pots of both Kansas and Massachusetts soil were sterilized by heating them to 200 degrees C. (392 degrees F.) The results obtained, both in the field and in pots, as well as by previous experience, showed that, as far as the soy bean organism was concerned, the Kansas soil was already sterile. In the case of the Massachusetts soil, however, these results show that the bacteria were killed at the above temperature, and plants grown in this soil produced no tubercles except when inoculated. It might be well to state in this connection that the heating of the soil produced other effects than those of a bacteriological nature, and the plants grown in it did not possess a healthy and vigorous appearance.

Plants Grown in Pure Massachusetts Soil.— (1) Since one-twentieth of a pint of Massachusetts soil was capable of producing such good results, both in the field and in pots, it was thought that plants grown in this soil alone would give still more striking results in tubercle formation. One pot each of Yellow Soy and Medium Green were grown in Massachusetts soil. The plants did well, and ranked among the best in the greenhouse, but on washing out the roots the tubercles were found to be only moderate in size, but fairly well distributed over the roots. In fact, they did not show up so well as plants which were inoculated with only a small portion of Massachusetts soil.

(2) Fearing the results obtained in the above experiment might be due to local conditions or disturbances, the subject was further tested by planting Yellow Soy beans in seven pots of pure Massachusetts soil and comparing with these seven pots of Kansas soil, all of which were inoculated with one-twentieth of a pint of Massachusetts soil. The results obtained were similar to those of the previous experiment, only that no appreciable difference could be seen in the results of the two treatments. Why a soil so thoroughly infected with micro-organisms as was this Massachusetts soil should not cause greater development of tubercles is a question not readily answered, and will bear further investigation.

Inoculating with Different Amounts of Massachusetts Soil.— To test the effect of varying amounts of Massachusetts soil on the number and size of tubercles produced, ten pots of Yellow Soy beans were grown, in which the soil had been inoculated with one-twentieth of a pint of Massachusetts soil for pot 1, two-twentieths for pot 2, and so on, increasing one-twentieth of a pint for each succeeding pot, until the tenth pot was reached, which received ten-twentieths or one-half pint of Massachusetts soil. No particular difference could be detected in the growth of the plants, and what was true of the upward growth was likewise found to be true of the roots and tubercles. The differences were slight, and these so irregular, that it could not be said that one was any better than the others. These results, taken in connection with those obtained from pure Massachusetts soil, seem to indicate that the micro-organisms are sufficiently numerous and active for ordinary inoculating in a comparatively small amount of the Massachusetts soil, and that an increase of this infectious soil does not perceptibly increase the number or size of the tubercles.

Inoculating at Top, Middle and Bottom of Pot.— To test the rapidity with which the organisms spread in the soil, three pots each of Yellow Soy and Medium Green were inoculated at the top, middle and bottom of the pots, respectively, with one-twentieth of a pint of Massachusetts soil. The washing out of the roots revealed the fact that the plants inoculated at the top of the pot produced tubercles on the upper portion of the roots, with only a few extending downward, and none on the lower portion of the roots. The plants inoculated at the middle of the pot produced tubercles about midway between the upper and lower portion of the roots; and, lastly, the plants inoculated at the bottom of the pot showed the tubercles on the lower portion of the roots, with a few tending upward. This is a very interesting point, and indicates that, without mechanical mixing, the micro-organisms spread very slowly in the soil, and that in spite of the fact that the plants were frequently watered on upper surface of pot, which one might suppose would have carried the bacteria deeper into the pots. The number and position of the tubercles are shown in the accompanying drawings. (See plates IV, V, and VI.)

Inoculating with Kansas Soil.— Will soil which has once been inoculated serve to inoculate non-infected soils? First, five pots were filled with soil taken from the immediate vicinity of roots previously inoculated. Second, five pots were filled with soil which had been soaked and washed out from plants that had produced tubercles in the field. Since nearly a two-foot cube was taken up with each hill, the number of micro-organisms must have been less in this instance than in the first five pots. Tubercles were produced in all the pots, but

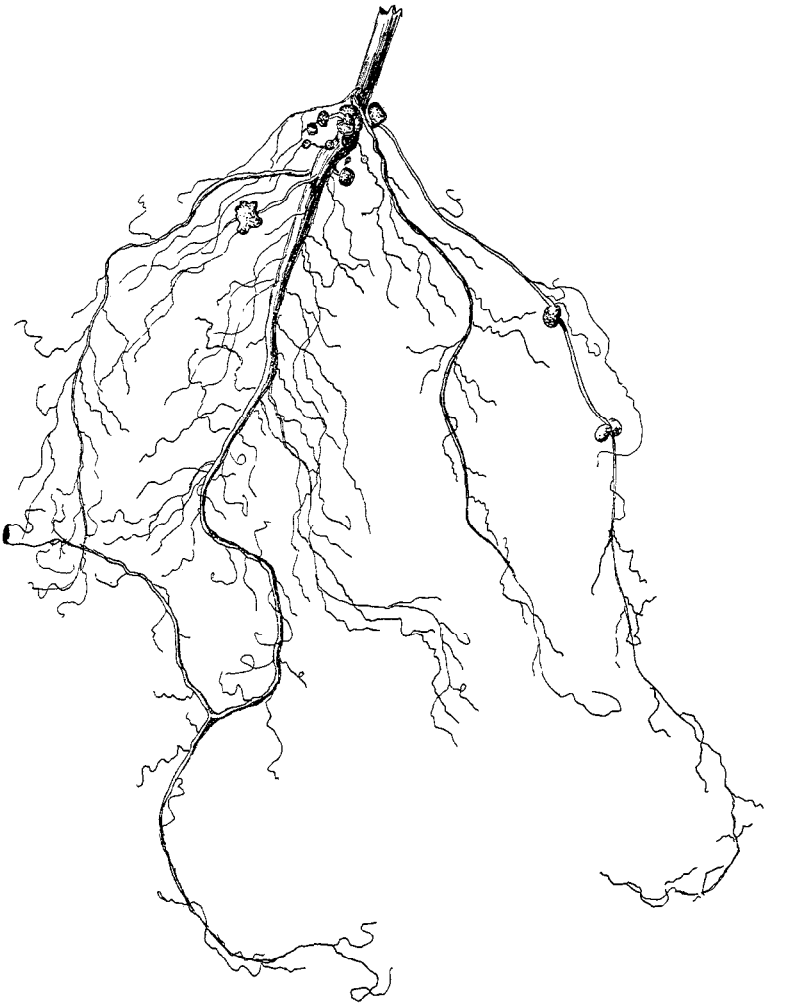


PLATE IV. Inoculated at top of pot.

the results, as might be expected, were somewhat more in favor of the first five. To test this matter still further, two pots were inoculated, each with one-twentieth of a pint of the above classes of soil, with the result that in both cases tubercles were shown in the same relative proportion to the above. This shows that Kansas soil, being once inoculated, can be used to inoculate other soils.

Inoculating with Tuberculous Roots.— After remaining in loose soil about a month, some of the roots which had previously produced tubercles were taken to inoculate a pot of Yellow Soy beans. The

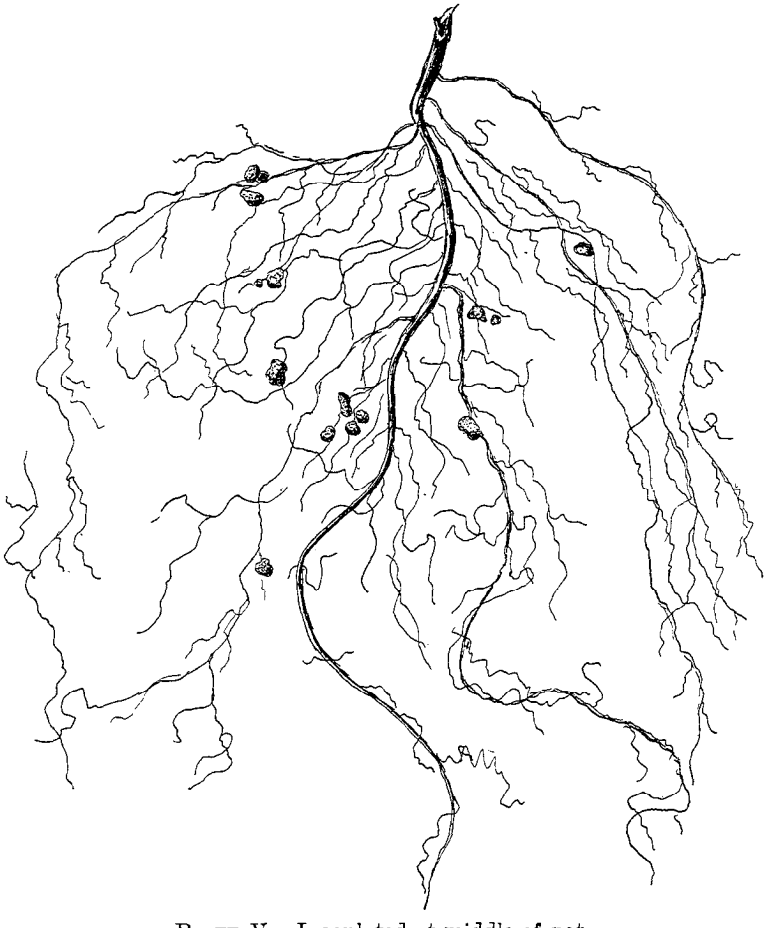


PLATE V. Inoculated at middle of pot.

plants grew well and ranked among the best in the greenhouse. On washing out the roots, large and numerous tubercles were discovered, which were by far the best of any produced in the greenhouse during this experiment. Likewise, washed roots that had been air dried in diffused light for about the same time were placed in another pot. Tubercles were formed but neither the growth of the plant nor the tubercles were equal to the above. In the former case the roots had more or less soil adhering to their surface, but in the latter there was practically none.

Effect of Inoculating Other Legumes with Massachusetts Soil.— Four pots each of the Adzuki beans *(Phaseolus radiatus),* cow-peas, Canada field peas, alfalfa, and Red clover were planted, half of these

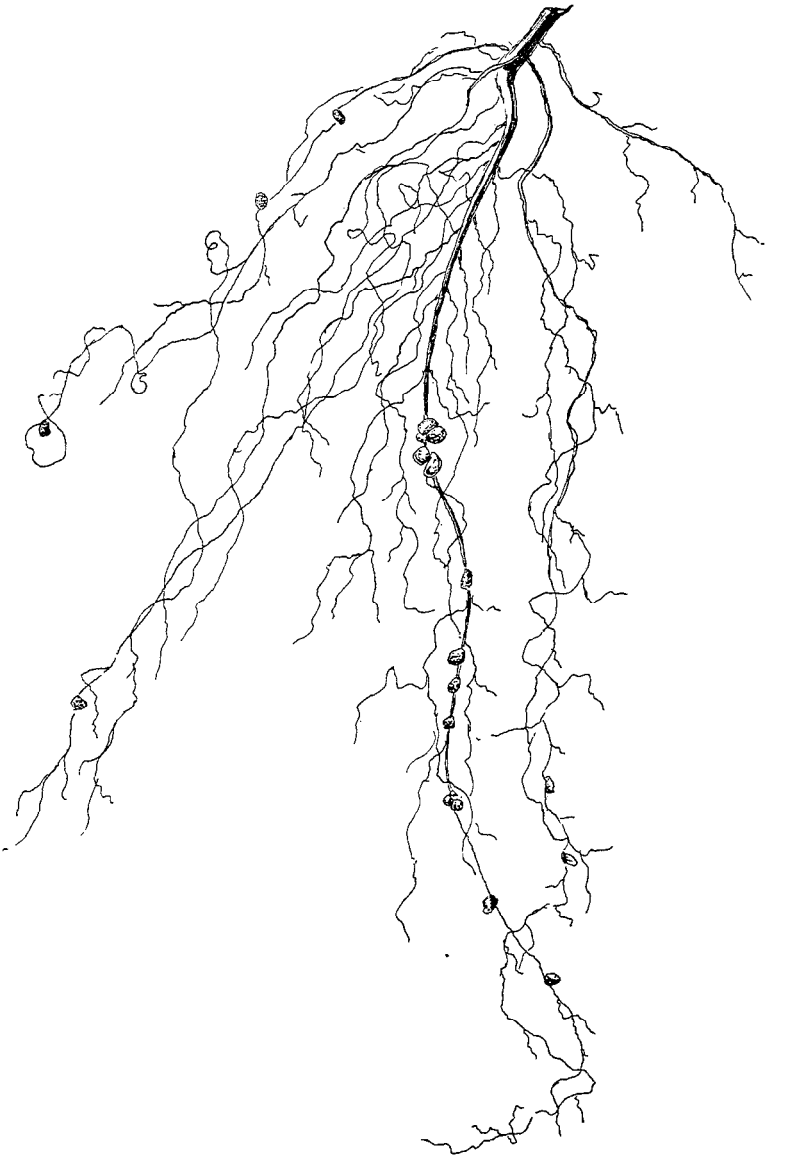


PLATE VI. Inoculated at bottom of pot.

being inoculated with Massachusetts soil and the other half not treated. On the roots of the Adzuki beans and the cow-peas, no nodules were apparent in any of the pots; the alfalfa showed several, and on the clover and Canada field peas they were very numerous, but no difference could be detected on any of them that was due to the Mas-

sachusetts soil. Evidently these plants were attacked by a different kind of organism than that attacking the soy bean.

EXTENT OF SOY BEAN MICRO-ORGANISM IN THE UNITED STATES.

After the success of inoculating the beans with imported soil was assured, it was thought to be an interesting point to ascertain how far these particular micro-organisms had spread in this country. Accordingly inquiries were sent out to all the experiment stations of the United States and the following table constructed from the replies:

Table II.

Micro-organisms indigenous to the soil.	Micro-organisms obtained through inoculation.	No tubercles found on the roots.	Have made no examination for root tubercles.	Too cold to successfully grow the soy bean.	Have not grown the soy bean.
Indiana. Louisiana. Mass. [Hatch]. North Carolina. Rhode Island. Tennessee.	Conn. [Storrs]. Kansas.	California. Florida. Iowa. Michigan. South Dakota.	Arizona. Arkansas. Colorado. Conn. [State]. Georgia. Illinois. Maryland. Missouri. Mississippi. Nebraska. New Jersey. N.Y. [Cornell]. N.Y. [State]. Ohio. Texas. Vermont. West Virginia. Wisconsin.	Minnesota. Washington.	Kentucky. Maine. Montana. Nevada. Pennslyvania. Utah. Virginia. Wyoming.
6	2	5	18	2	8

CONCLUSION.

The above experiments were not planned with a view to obtain comparative results as to yields. The main object was to ascertain whether or not a leguminous plant could be made to produce tubercles by inoculating with the soil impregnated with the right kind of micro-organisms. As the Kansas soil contained none of these organisms, the conditions were entirely under control, and results obtained which otherwise would have been impossible. The results show conclusively that inoculation is entirely possible; and this, taken in connection with the fact that it has been repeatedly proven that tubercles are valuable adjuncts to leguminous plants, both for yield and as a fertilizer, suggests the practicability of inoculating fields deficient in micro-organisms that would be beneficial to the particular leguminous crop to be grown. When we realize that in the Eastern states many farmers are paying from six to ten dollars an acre for fertilizers, which, in the aggregate, amount to a tax of millions of dollars, and as we in the West are fast tending in the same direction, should it not behoove us to lay hold of one of nature's most effective means of maintaining

and even increasing the fertility of the soil? Free nitrogen is around and about us in superabundance; it composes four-fifths of the air; but, without the aid of these bacteria working within the tubercles of the roots, plants have no power to make use of it. By growing leguminous crops in rotation, and inoculating the soil when the latter is deficient in the proper species of bacteria, and thus controlling the action of these microscopic plants, the farmer may find them to be among his best friends and strongest financial supporters.

Field Work in Soil Inoculation for Soy Beans.

H. M. COTTRELL, M. S., Agriculturist.
D. H. OTIS, M. S., Assistant in Dairying.
J. G. HANEY, B. S., Assistant in Field and Feeding Experiments.

The experiments made by Mr. Otis demonstrated that Kansas soil does not contain the bacteria which form tubercles on the roots of the soy bean, and that these bacteria can be introduced by the use of infected soil. In 1898 and 1899 the Farm Department made experiments to develop methods of inoculating soil that would be practicable in large fields under ordinary farm conditions.

FIRST EXPERIMENT.

Two acres were planted in the spring of 1898 to Early Yellow soy beans. The beans were planted in drills, with rows thirty-three inches apart, and the two acres were divided into sixteen plats. The inoculated soil used in this experiment was taken from a plat inoculated in 1896 with soil from the Massachusetts Experiment Station, and on which soy beans had been grown in 1896 and 1897.

This inoculated soil was taken up and dried until it would crumble easily and then applied as indicated. Inoculated water was made by soaking for three days half a bushel of inoculated soil in two-thirds of a barrel of water. Soy beans were placed in a sack and immersed in this water until thoroughly wet and then planted. Soy beans were mixed with the infected mud in this barrel, allowed to drain, and were then planted. On other plats the infected soil was applied as shown in the table.

Twenty average plants from each plat were carefully dug up, the soil washed from the roots, and the tubercles counted. The treatment given the plats and the results shown by this count are as follows:

	Tubercles on twenty plants.	Plants having tubercles.
1. Not inoculated; two plats	0	0
2. Beans inoculated in water	2	2
3. Beans inoculated in mud	2	2
4. Beans drilled with 150 pounds infected soil per acre	9	4
5. Beans drilled with 375 pounds infected soil per acre	35	5
6. Beans drilled with 750 pounds infected soil per acre	21	8
7. Infected soil broadcast before seeding, 100 pounds per acre.	0	0
8. Infected soil broadcast before seeding, 500 pounds per acre	1	1
9. Infected soil broadcast before seeding, 1000 pounds per acre.	1	1
10. Infected soil broadcast after seeding, 100 pounds per acre	1	1
11. Infected soil broadcast after seeding, 500 pounds per acre.	2	1
12. Infected soil broadcast after seeding, 1000 pounds per acre.	7	5
13. Infected soil drilled on top of row after planting three plats, 150, 375 and 750 pounds infected soil per acre	2	1

In this trial the only satisfactory results were obtained by drilling the infected soil with the seed.

In a plat inoculated with Massachusetts soil two years before, twenty plants bore 136 tubercles, one plant bearing thirty-five, and only one plant not having any tubercles. In another plat, inoculated Massachusetts soil was spread thickly in the bottom of the drill furrow, and the seed dropped in it. Twenty plants in this plat bore 509 tubercles on their roots, one plant having seventy-one, another sixty-nine tubercles, and only one plant not having any.

SECOND EXPERIMENT.

At the time the plats in the first experiment were planted, 11½ acres were planted to soy beans in another field. The entire field was treated, before planting, with inoculated soil sown broadcast at the rate of 1000 pounds per acre. The inoculated soil was distributed by hand from wagons as evenly as possible, and then mixed with the soil of the field by a disk harrow. The soy beans were planted in rows thirty-three inches apart.

A careful examination of hundreds of plants on this field failed to show a single tubercle, and this method, with the quantity of soil used, is a total failure.

THIRD EXPERIMENT.

The first and second trials convinced us that, to secure satisfactory results, the inoculated soil must be placed in contact with the seed as the seed lies in the ground, that the young roots may come in contact with the tubercle-forming bacteria as soon as possible.

We were anxious to develop a practicable method of securing this result the first year the trials were made, and after oats had been harvested from a field it was plowed and planted to soy beans. We had only an ordinary two-horse grain-drill. We put the beans in the grain box, stopping up all the holes but two, so as to make the rows the proper distance apart. A box was placed on top of the drill to

hold the inoculated soil. The drill planted two rows of beans. We took two large tin funnels, connected them with the drill holes by rubber tubing, and poured the inoculated dirt into these funnels with scoops. The team was driven slowly, and we could watch the inoculated soil and the beans falling together into the drill mark, every bean being thoroughly surrounded with the inoculated soil. The method was crude, but it put the inoculated soil and beans where we wanted them.

The beans were planted July 21, 1898, and 611 pounds of inoculated soil from the Massachusetts Experiment Station was drilled in with the beans on half an acre.

The result of this trial was all that could be desired. In ten days after the bean plants appeared above ground tubercles could be found on their roots, and when the plants became full grown the roots were thickly studded with tubercles.

EXPERIMENTS IN 1899.

In the spring of 1899 we purchased a grain-drill having a fertilizer attachment. Inoculated soil was taken from the rows of beans grown in the third experiment of 1898, spread on boards in the field until it became well dried, and was then powdered. The drill was set to sow 600 pounds of fertilizer per acre; all the holes were stopped except those connected with the spouts from which the seed was being dropped. The drill planted the seed and mixed the inoculated soil with the seed as fast as the team could walk. We inoculated forty-six acres of soy beans. The results were satisfactory, nearly all plants bearing a large number of tubercles.

PROFITS FROM INOCULATION.

Kansas farmers should raise soy beans because of their value as feed, and the benefits from inoculation give an extra profit. Soy beans are richer in flesh-, blood-, milk- and bone-making material than linseed-meal. They can be raised at a cost of thirteen to eighteen dollars per ton, and, pound for pound, are worth a little more than linseed-meal for fattening steers and sheep and in feeding dairy cows and young stock. In experiments made at this Station, soy beans, fed with Kafir-corn and corn in fattening hogs, made a saving in the amount of feed required to make 100 pounds of gain of from thirteen to thirty-seven per cent. Besides these qualities, soy beans stand drought as well as Kafir-corn or sorghum and are not touched by chinch-bugs.

The yield of crops of all kinds is increased where they follow soy beans, wheat showing in large fields an increase of five bushels per acre when following soy beans over that grown on adjoining land that

had not been in beans. This increase is shown where soy beans bearing no tubercles have been grown. Where no tubercles grow on the roots the soy bean does not add fertility to the soil but simply makes available for other crops the plant-food already in the soil. The soy bean is a strong feeder and can obtain plant-food from the soil that a weaker plant like wheat is unable to secure. Then, when the beans are harvested, their roots decay and the plant-food in them is in such a condition that wheat or other ordinary farm crops can easily use it.

Inoculated soy beans add plant-food to the soil. Nitrogen is one of the most needed elements of plant-food. The reduced yield from our long cultivated fields comes chiefly from the lack in the soil of nitrogen in a form which our field plants can use. Four-fifths of the air is pure nitrogen but ordinary plants can make no use of it. The bacteria that cause and live in the tubercles on soy-bean roots take this nitrogen from the air and put it in such a condition that our ordinary field plants can use it. In this way inoculated soy beans, while yielding a profitable grain crop, make the soil richer than before the crop was grown. Where the beans do not have tubercles no plant-food is added to the soil, but that already there is made available for the production of larger yields of crops following the soy beans, and in the end the land is made poorer.

INOCULATION FOR RENTERS.

Inoculation of the soil for soy beans is profitable for the farmer who owns his land. It is also especially adapted for the man who rents the land on which he raises crops. Most rented farms in Kansas are let from year to year. Alfalfa and clover usually require the loss of the use of the land for one year after seeding, and in many sections there is not a good market for the hay. This keeps the tenant from raising these crops; he grows one grain crop after another, and with slowly reducing yields and decreasing profits both to himself and the owner of the land. The renter can raise soy beans, inoculate the land, and have a profitable grain crop. The next year he can follow with any other crop desired. No time is lost, and only marketable crops need be raised.

If sufficient rain falls after harvest, soy beans may be planted after wheat or oats, and the ground inoculated and enriched without interfering with the regular crops.

HOW TO INOCULATE SOIL.

One hundred pounds of inoculated soil will be sufficient to start 500 feet of row for an inoculating bed. If a drill is not convenient, a shallow furrow may be opened by any convenient tool, the infected soil thickly spread along the bottom of this furrow, and the soy beans

dropped one to two inches apart in the row, and covered with the soil of the field in which the beans are planted. The plants growing in this row will be well supplied with tubercles. In harvesting, the soy beans are cut off just below the surface of the ground. This leaves the roots with the tubercles in the soil. In collecting the soil from this row, after the beans are harvested, take just a spade width in the row, and take up the dirt to a depth of four to five inches, going as deep as the tubercles extend. Spread this dirt on boards in the sun until it becomes well dried, and then sack it and store in a dry place. The soil from 500 feet of row will supply sufficient soil to infect several acres the second year.

Our experiments have not been conducted long enough to thoroughly test the matter, but it is probable that a field once inoculated will always remain inoculated, and that the bacteria will slowly increase in the soil. The bacteria live for a long time in the soil after the plants are removed. We have kept dry inoculated soil in sacks two years, where it became as dry as road dust, and it had full strength in producing root tubercles when used.