"They not only work for nothing and board themselves, but they pay for the privilege."—*Davenport.*

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ALFALFA ON ILLINOIS SOIL.

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Many different farmers have tried to grow alfalfa in various sections of Illinois, but, in most cases, it has been pronounced a failure. Where alfalfa has been grown with success in Illinois, it has usually been necessary to sow it on very rich ground or to keep it well manured. This Experiment Station tried to grow alfalfa on Illinois soil several years ago, but the result was a failure, and this is found to have been a very common experience among Illinois farmers who have tried to grow this crop. The usual experience has been that the seed germinates well, a good stand of plants is secured, and, for a year or two, it grows about as well as it is reported to do where alfalfa is a successful crop; but, after two or three years, it weakens, stops its vigorous growth, and seems ready to die. It is then pronounced a failure and the ground is plowed up and used for other crops. This is the report which has been received by the Experiment Station from many Illinois farmers who have tried growing alfalfa, and it agrees with our own observations in a great majority of cases. And this experience is common not in Illinois alone, but from Indiana, Ohio, Michigan, Wisconsin, and Iowa come reports of similar experiences.

In theory, alfalfa ought to grow and do well on Illinois soils. and it ought not to require heavy and frequent applications of manures; because alfalfa is a very deep rooting crop and is thus capable of drawing upon the soil to great depths for the necessary mineral elements of plant food, and, being a leguminous plant, it has the power of "gathering" nitrogen from the inexhaustible supply of the air, by means of the bacteria which inhabit its roots.

Numerous observations made on several fields of alfalfa in different sections of the State during the past few years led me to question whether alfalfa has the power to secure nitrogen from the atmosphere, when grown on Illinois soil. First, because, in nearly every field examined, the plants presented the same peculiar appearance which plants show when grown under artificial conditions *with an insufficient supply of nitrogen*. Second, because, in none of the fields where alfalfa presented this appearance could there be found any tubercles, or nodules, upon the roots of the alfalfa. Third, because liberal applications of barnyard manure produced a vigorous growth and a natural and healthy appearance.

In order to investigate the question, why Illinois soil does not more generally produce good crops of alfalfa, a series of experiments was begun about a year ago. These experiments comprehended the application of various elements of fertility to Illinois soil, both singly and in combinations, and both with and without the inoculation of the soil with the alfalfa bacteria; that is, with the bacteria which are known to live upon the alfalfa root in other sections of the country. These experiments have been carried on in the pot culture laboratory under controlled conditions and also on plots of ground under field conditions.

POT CULTURE EXPERIMENTS.

The pot culture experiments were planned with a double purpose, or a two-fold object; first, to test the effect of applying different elements of plant food to the soil to determine the value of such applications for the growing of alfalfa, and, second, to determine the effect upon the growth of alfalfa of inoculating the soil with the bacteria which are able to live upon the roots of alfalfa and gather nitrogen from the air for use of the growing alfalfa.

APPLICATIONS OF DIFFERENT ELEMENTS[1] OF PLANT FOOD.

These pot cultures comprise a double set of our regular series of experiments adopted for investigating soils by pot cultures, which is as follows:

Twelve pots are all filled with the soil to be investigated and they are then treated with the following applications:[2]

Pot No. 1—Check. (Nothing applied.)
Pot No. 2—Lime.
Pot No. 3—Lime and Nitrogen.
Pot No. 4—Lime and Phosphorus.
Pot No. 5—Lime and Potassium.
Pot No. 6—Lime, Nitrogen, and Phosphorus.
Pot No. 7—Lime, Nitrogen, and Potassium.
Pot No. 8—Lime, Phosphorus, and Potassium.
Pot No. 9—Lime, Nitrogen, Phosphorus, and Potassium.
Pot No. 10—Nitrogen, Phosphorus, and Potassium.
Pot No. 11—Check.
Pot No. 12—Check.

This series of pot cultures shows what effect is produced by applying to the soil any of the three different important elements of fertility or any possible combination of them. Lime is applied to pots 3, 4, 5, 6, 7, 8, and 9 to correct any possible acidity and in-

1. Among the ten elements of plant food required for the growth of all plants; namely, carbon, oxygen, hydrogen, nitrogen, phosphorus, sulfur, potassium, calcium. magnesium, and iron, the three elements, nitrogen, phosphorus and potassium, are most likely to be deficient in the soil. Frequently lime (a compound of calcium and oxygen) is of great value in correcting the acidity of sour soils.

2. It may be stated that the elements of plant food, such as nitrogen, phosphorus, and potassium, may be applied in many different forms. All that is necessary is that the plant is provided with the element, and any fertilizer which will furnish the element in an available form is satisfactory. Thus, the element nitrogen is contained in sodium nitrate, in potassium nitrate, in ammonium sulfate, and ammonium phosphate, in dried blood, in ground meat, etc., etc., and any one of those substances is a nitrogenous fertilizer. Likewise, phosphorus may be applied in the form of ammonium phosphate (which is both nitrogenous and phosphatic), sodium phosphate, potassium phosphate, basic phosphate, bone phosphate, etc. Some common potassic fertilizers are: potassium chlorid (muriate of potash is a bad name for the same salt; potassium chlorid tells what the substance is made of; namely, potassium and chlorin), potassium sulfate, potassium nitrate (which contains both potassium and nitrogen), kainit, etc., all of which, except potassium nitrate (nitre), are obtained from the mines of the Kali Works in Germany. In this connection, it may be noted that the German word *Kali* is from the Latin *Kalium* and means potassium, and the symbol, or abbreviation, "K," is used for this element among all the civilized nations.

sure good physical condition. If the soil is acid, then pot 4, for example, might not give results which would show the real value or need of an application of phosphorus to the soil, although a much needed application had been made of the element phosphorus.

It will be observed that pot No. 1 receives no special treatment and, of course, it shows what the ordinary soil does with no application of additional elements of fertility. The first ten pots really make the complete series. Pots 11 and 12 are extras, or additional checks.

There is a double trial as to the value of an application of lime. First, by comparison between 1 and 2, which shows the effect of applying lime alone. Second, by comparison between 9 and 10, which shows the effect of applying lime after insuring a sufficent supply of each of the elements, nitrogen, phosphorus, and potassium.

Pots 3, 4, and 5 will show the effect of applying to the soil, singly, nitrogen. phosphorus, and potassium, respectively, after a sufficient quantity of lime has been added to neutralize acidity.

Pots 6, 7, and 8 contain all possible double combinations of those three elements, and by comparing pot No. 6, for example, with pots 3 and 4, we can see, first, the effect of applying phosphorus after the soil has been well supplied with nitrogen, and, second, the effect of applying nitrogen after sufficient phosphorus has been insured. Pot No. 9 is provided with an abundance of all of the elements of fertility and a comparison of the results from this pot with those from 6, 7, and 8 will show the effect of adding each element after a sufficient supply of the others has been provided.

Attention is called to the fact that this system really includes five separate tests for each of the three elements, nitrogen, phosphorus, and potassium. For example, if nitrogen is the only element of plant food which a soil lacks or which the growing plant is unable to secure from the soil in sufficient quantity for maximum development, then a marked effect should appear in all of the five different pots to which nitrogen is applied; namely, pots 3, 6, 7, 9, and 10.

In the following tables and in the photographs

0 (zero) means no fertilizer.
L means Lime.
N means Nitrogen.
P means Phosphorus.
K means Potassium (Kalium)

Inoculation with Alfalfa Bacteria.

As stated above. two series of pot cultures were made with alfalfa, each of which received the applications of the different elements of plant food as described above. One of these two series of twelve pots each was inoculated[1] with the alfalfa bacteria, the other series was not. In all other respects the two series were treated exactly alike. All of the pots were filled with ordinary Illinois black prairie soil, and 25 alfalfa seeds were planted in each pot. They were kept in the glass house and were watered with very clear rain water which was practically free of nitrogen, but which contained a trace of lime dissolved from a new cistern in which it was stored.

The pots were all planted in June, 1901. The seeds germinated quite well and a fairly uniform stand was secured in all of the pots. The small plants grew slowly and the different pots showed no very marked differences for several months. A small crop was cut from all the pots in the fall, but they all seemed very much alike and no weights of the cuttings were taken. During the winter the pots showed some marked differences in the growth of the alfalfa and the weights of the cuttings of each pot were taken on March 14, 1902. They are reported in the tabular statement.

It should be borne in mind that these young plants were not fully developed and that small yields of alfalfa were to be expected, indeed this crop from the pots corresponds to the second clipping in the field, which is usually too light to pay for the trouble of saving it for hay, and consequently it is usually left lying on the ground after the mower. For yields[2] of the more fully developed plants see Table 3.

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1. The inoculating solution was made by shaking 500 grams (about 1 pound) of soil (obtained from an old alfalfa field in Kansas) with 1,000 cc. (about 1 quart) of water, and allowing it to settle. One cubic centimeter of the liquid was used for each alfalfa seed planted.

2. The pots used were 10½ inches in diameter, so that one gram of produce per pot corresponds to one pound per square rod or to 160 pounds per acre (1 pound = 453.6 grams). While the exact yield per pot is given in grams in the tabular statement, the computed rate of yield in pounds per acre is also given and this rate of yield is used in the discussion in the text. This is relatively accurate and it is used because we are accustomed to the basis of pounds per acre. Another advantage is that the results from the pot cultures thus become more easily comparable with the actual field results which are given in the following pages.

TABLE I. ALFALFA POT CULTURES; CUT MARCH 14, 1902. WEIGHTS IN GRAMS PER POT AND POUNDS PER ACRE.[1]

Serial No.[1]	Pot No.	Treatment applied	Green alfalfa (gms. per pot)	Air-dry hay (gms. per pot)	Air-dry hay (lb. per acre)
1	25	0:	4	2	320
1	37	0: Bacteria	9	3	480
2	26	L:	4	2	320
2	38	L: Bacteria	8	2½	400
3	27	LN:	10	4	640
3	39	LN: Bacteria	14	5	800
4	28	LP:	10	3	480
4	40	LP: Bacteria	15	5	800
5	29	LK:	9	2½	400
5	41	LK: Bacteria	12	4	640
6	30	LNP:	18	7	1120
6	42	LNP: Bacteria	19	6	960
7	31	LNK:	17	6	960
7	43	LNK: Bacteria	14	5	800
8	32	LPK:	10	3	480
8	44	LPK: Bacteria	15	5	800
9	33	LNPK:	16	5	800
9	45	LNPK: Bacteria	11	4½	720
10	34	NPK:	11	4	640
10	46	NPK: Bacteria	15	5	800
11	35	0:	7	2	320
11	47	0: Bacteria	10	4	640
12	36	0:	8	3	480
12	48	0: Bacteria	12	4	640

Two facts are shown very distinctly by these results; first, that the addition of nitrogen to the soil increases the growth of alfalfa; and, second, that the inoculation of the soil with the proper bacteria produces a similar effect, which indicates that the presence of the bacteria enables the alfalfa to secure a supply of nitrogen from the air.

The average yield of hay per acre from the seven uninoculated pots receiving no nitrogen is 400 pounds, while 630 pounds per acre is the average yield of the corresponding seven inoculated pots. Among these seven pairs of pots (1, 2, 4, 5, 8, 11, 12) the inoculated

1. The numbers referred to in the discussion are the duplicate serial numbers, 1 to 12, but, to facilitate reference to the photographs, the tables also show the individual pot numbers.

pot produced a larger yield in every instance, and in several cases the inoculation nearly doubled the yield. The average yield per acre of five uninoculated pots receiving nitrogen (Series 3, 6, 7, 9, 10) was 830 pounds, more than double the yield of the uninoculated pots receiving no nitrogen. The inoculation of pots to which nitrogen had been applied produced no constant effect, which indicates that the bacteria are of no value if the soil is abundantly supplied with nitrogen. In fact, under this condition the uninoculated pots produced a slighly higher average yield.

It may be of interest to note that the highest yield secured from any single pot was 1,120 pounds per acre from pot 30 in series 6 to which phosphorus as well as nitrogen had been applied. There are some other results which indicate that an application of phosphorus to the soil increases the growth of alfalfa.

TABLE 2. NOTES ON ALFALFA POT CULTURES FROM MARCH 14 TO APRIL 23, 1902.

Serial No.	Pot No.	Treatment applied	Height of plants (inches)				Color of foliage
			Mar. 26	April 4	April 12	April 19	
1	25	0:	3	4	5	5	pale green
1	37	0: Bacteria	3	5	7	13	dark green
2	26	L:	3½	4	5	5	pale green
2	38	L: Bacteria	3½	5	6	13	dark green
3	27	LN:	6	7	7	8	dark green
3	39	LN: Bacteria	6	7	7	13	dark green
4	28	LP:	3	4	5	5	pale green
4	40	LP: Bacteria	6	7	10	13	dark green
5	29	LK:	3	4	4	5	pale green
5	41	LK: Bacteria	5	6	10	13	dark green
6	30	LNP:	8	8	12	13	dark green
6	42	LNP: Bacteria	8	8	12	13	dark green
7	31	LNK:	5	7	9	13	dark green
7	43	LNK: Bacteria	5	7	12	13	dark green
8	32	LPK:	3	4	4	4	pale green
8	44	LPK: Bacteria	6	8	13	15	dark green
9	33	LNPK:	6	9	12	13	dark green
9	45	LNPK: Bacteria	6½	9	13	15	dark green
10	34	NPK:	6½	9	12	13	dark green
10	46	NPK: Bacteria	6	9	13	15	dark green
11	35	0:	3	4	5	5	pale green
11	47	0: Bacteria	4	5	6	13	dark green
12	36	0:	3	4	5	5	pale green
12	48	0: Bacteria	4	5	7	13	dark green

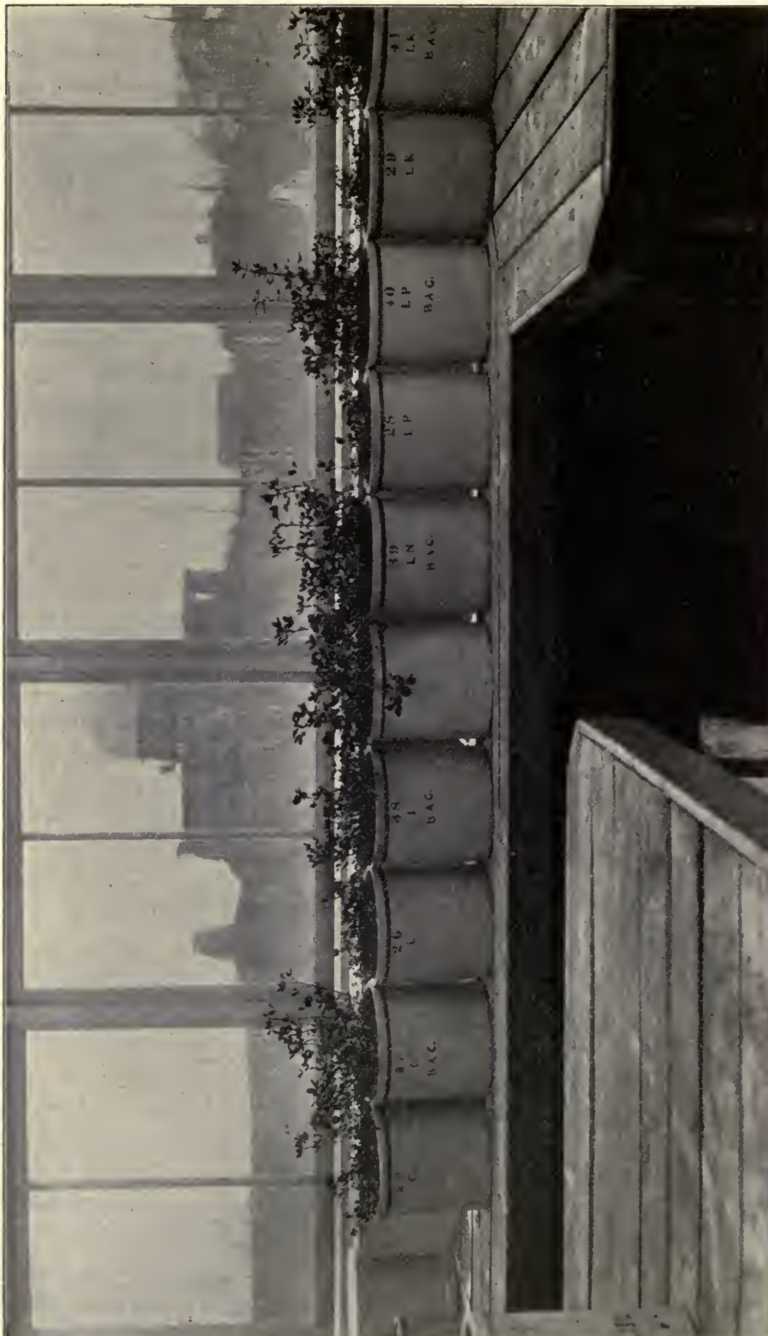

PLATE I. ALFALFA POT CULTURES, SHOWING EFFECT OF APPLICATIONS OF DIFFERENT ELEMENTS OF PLANT FOOD AND OF ALFALFA BACTERIA ON ORDINARY ILLINOIS BLACK PRAIRIE SOIL.

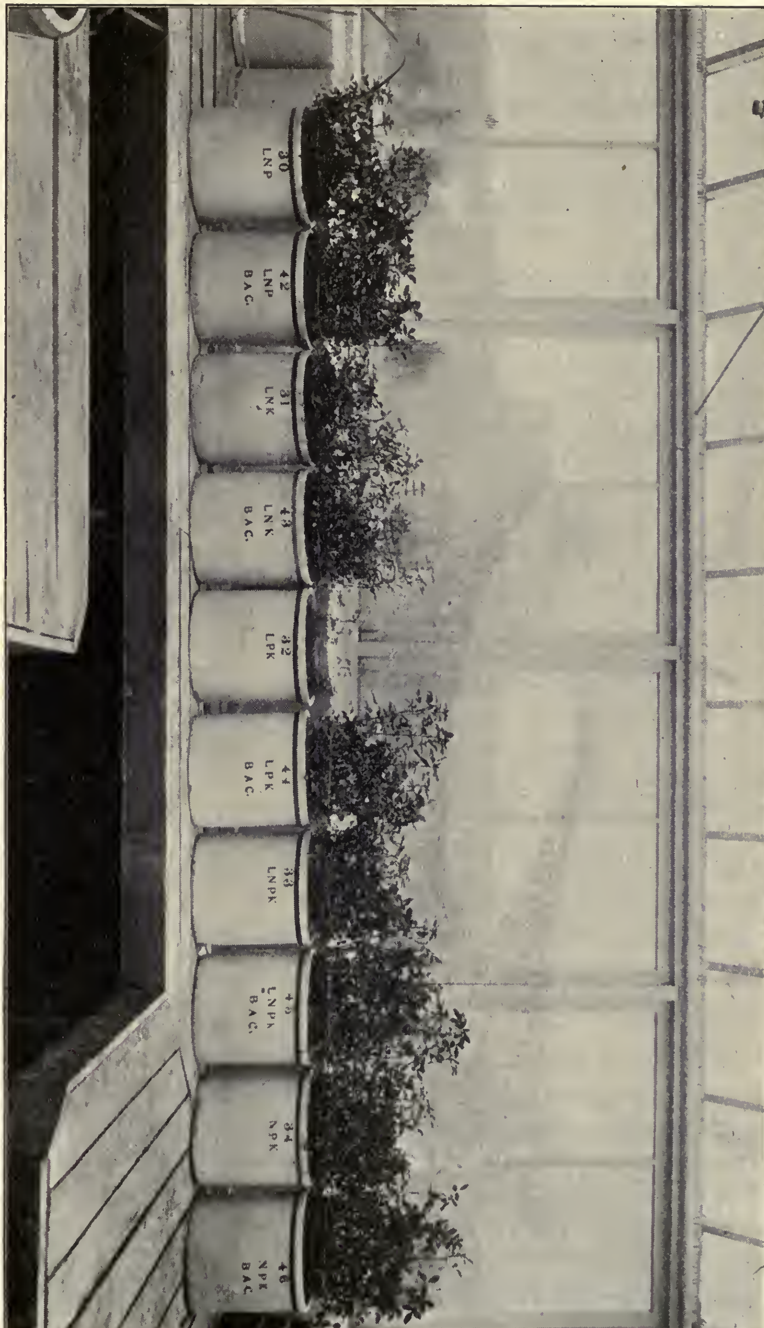

PLATE 2. ALFALFA POT CULTURES, SHOWING EFFECT OF APPLICATIONS OF DIFFERENT ELEMENTS OF PLANT FOOD AND OF ALFALFA BACTERIA ON ORDINARY ILLINOIS BLACK PRAIRIE SOIL.

The series of notes in Table 2 and the photographs which follow illustrate the growth and appearance of the alfalfa in the different pots, between March 14 and April 23. Another crop was cut from all of the pots on April 23 and the weights of the alfalfa secured from each pot are given in Table 3.

TABLE 3. ALFALFA POT CULTURES ; CUT APRIL 23, 1902. WEIGHTS IN GRAMS PER POT AND POUNDS PER ACRE.

Serial No.	Pot No.	Treatment applied	Green alfalfa (gms. per pot)	Air-dry hay (gms. per pot)	Air-dry hay (lb. per acre)
1	25	0:	9	2	320
1	37	0: Bacteria	37	9	1440
2	26	L:	12	2	320
2	38	L: Bacteria	34	7	1120
3	27	LN:	38	9	1440
3	39	LN: Bacteria	44	10	1600
4	28	LP:	7	1	160
4	40	LP: Bacteria	44	10	1600
5	29	LK:	7	1	160
5	41	LK: Bacteria	32	7	1120
6	30	LNP:	66	16	2560
6	42	LNP: Bacteria	79	19	3040
7	31	LNK:	55	11	1760
7	43	LNK: Bacteria	59	13	2080
8	32	LPK:	7	1	160
8	44	LPK: Bacteria	67	17	2720
9	33	LNPK:	65	16	2560
9	45	LNPK: Bacteria	85	22	3520
10	34	NPK:	68	16½	2640
10	46	NPK: Bacteria	100	20	3200
11	35	0:	10	2	320
11	47	0: Bacteria	24	5	800
12	36	0:	10	2	320
12	48	0: Bacteria	34	7	1120

The seven uninoculated pots receiving no nitrogen made comparatively small growth[1] and showed uniformly throughout the

1. It may be observed that the uninoculated pots receiving phosphorus or potassium or both, with lime, but without nitrogen, (4, 5, 8) yielded even less than the uninoculated pots which received lime only or no treatment whatever (1, 2, 11, 12). I know of no explanation for this unless it be found in the fact that the yield of the previous crops from these fertilized pots was larger than from the unfertilized pots and the supply of available nitrogen had been correspondingly reduced.

period of nearly six weeks the characteristic pale yellowish green color indicative of an insufficient supply of nitrogen. The yields from these seven pots are very small, in no case exceeding the rate of 320 pounds per acre, while 1650 pounds per acre is the average yield of the corresponding inoculated pots. The yield from the inoculated pots ranges from 2½ to 17 times the yield from the uninoculated pots. For example, the most favored pot receiving no nitrogen (serial No. 8), to which applications of lime, phosphorus, and potassium were made, yielded, when uninoculated, only 160 pounds of hay per acre, while 2,720 pounds per acre was the yield of the corresponding inoculated pot.

The crops produced on the seven uninoculated pots receiving no nitrogen would certainly be pronounced a failure, but the inoculated pots which produced yields from ¾ to 1¾ tons of alfalfa hay per acre in less than six weeks from the previous cutting give evidence of being a very decided success, considering that this is the third cutting and corresponds to the third clipping in the field, which is frequently too light to pay for saving.

Effect of Nitrogen and Bacteria.

The applications of nitrogen produced a very marked increase in yields, but it is interesting to note that even these artificial supplies of nitrogen had evidently become somewhat depleted by the removal of the previous crops and were no longer sufficient for the greatest possible growth of the alfalfa; and, consequently, in every case where pots receiving nitrogen were also inoculated, a notable increase in growth and yield occurred. In the most favored pots (serial No. 9), to which lime, phosphorus, and potassium were supplied with the nitrogen, this increased yield produced by the bacteria amounted to nearly one-half ton per acre, the uninoculated pot yielding at the rate of 2,560 pounds per acre, while 3,520 pounds was the rate of yield of the corresponding inoculated pot.

Applications of phosphorus or potassium without bacteria or nitrogen (4, 5, 8) are of no value to the alfalfa.

Effect of Phosphorus.

Phosphorus applied to the inoculated pots or to the uninoculated pots receiving nitrogen produced a very marked increase in yield in every instance. These results confirm the indications observed in the previous crops and prove conclusively that, after provision has been made for a sufficient supply of nitrogen, applications of phosphorus to this soil were greatly to the advantage of the alfalfa crop. For instance where lime and nitrogen alone were applied (3) 1,440 pounds of hay per acre were produced, while 2,560 pounds was the rate of yield where phosphorus was added (6). The treatment: lime, nitrogen, bacteria (3) produced a yield of 1,600 pounds, which was increased to 3,040 pounds by the addition of phosphorus (6). Under the most favorable conditions without phosphorus; that is, with lime, nitrogen, and potassium (7) the yields in pounds per acre were 1,760 and 2,080 without and with bacteria, respectively, and these yields were increased to 2,560 and 3,520, respectively, by the addition of phosphorus (9). The inoculated pot receiving lime and potassium (5) yielded at the rate of 1,120 pounds per acre, but, where phosphorus was added to this combination (8), the yield became 2,720 pounds.

Effect of Potassium.

Applications of the element potassium produced a slight increase in yield when added after sufficient nitrogen was provided, (3, 7), but the increase becomes more marked when the potassium is added after both nitrogen and phosphorus have been supplied. For example, with both lime and phosphorus added, and nitrogen accumulated by the alfalfa bacteria, the yield was 1,600 pounds without potasssium (4) and 2,720 pounds with potassium (8); and, when an innoculated pot was also given an application of nitrogen (6), it yielded at the rate of 3,040 pounds without potassium and 3,520 pounds with potassium.

The Relative Effect of Nitrogen, Phosphorus, and Potassium.

The relative value of nitrogen, phosphorus, and potassium for the growth of alfalfa may best be determined by the maximum yields produced when each of the elements in turn was not supplied.

Thus, the maximum yield per acre with no addition of nitrogen (either direct or by means of bacteria) was 320 pounds.

The maximum yield without addition of phosphorus was 2,080 pounds (7).

The maximum yield without addition of potassium was 3,040 pounds (6).

The maximum yield without the addition of lime was 3,200 pounds (10).

The maximum yield with all of these supplied was 3,520 pounds (9).

In other words, the losses resulting from a failure to add to the soil these different elements of fertility would be as follows:

With nitrogen not applied the maximum loss is 3,200.

With phosphorus not applied the maximum loss is 1,440.

With potassium not applied the maximum loss is 480.

These figures fairly represent the relative values of additions of nitrogen, phosphorus, and potassium (each after the other elements have been supplied) to the soil which was used in these pots. For field conditions the figures for nitrogen and phosphorus are probably nearly correct, relatively, but the figure for potassium is probably too high because of the fact that the subsoil is richer in potassium than is the surface soil, and under field conditions the alfalfa roots would have access to the potassium in the subsoil. As the subsoil usually contains somewhat less phosphorus and very much less nitrogen, than the surface soil, the field conditions would be but little better than the pots for furnishing those two elements. It should be remembered that no conclusions can be drawn as to the relative value of applying lime to the soil used because of the fact that the water used in all of the pots contained a trace of lime.

There is evidence that both phosphorus and potassium have an indirect value aside from their direct value as plant food for the alfalfa. This is the value of these elements to the bacteria. Bacteria themselves are living plants, and while they are microscopic in size they are almost infinite in number, and their multiplication and development are largely dependent upon the supply of available mineral elements of plant food. It will be observed that a yield of 2,080 pounds per acre (7) was secured without the addition of phosphorus. The yield became 3,520 pounds when phosphorus was applied (9). This increase of 1,440 pounds per acre may be due in part to the direct value of the phosphorus to the alfalfa and in part to its value in promoting the development of the bacteria and thus increasing the supply of nitrogen which the bacteria secure from the air and furnish to the growing alfalfa. Again, the addition of phosphorus to the combination, lime, potassium, bacteria, increased the yield from 1,120 (5) to 2,720 (8), an increase of 1,600 pounds per acre. The fact that the soil itself contained sufficient phosphorus to produce a yield of 2,080 pounds (7) tends to prove that the first 960 pounds of this 1,600 pounds increase was due to the increased development of the bacteria resulting from the additional supply of available phosphorus; the remainder of the increase, 640 pounds, is probably due to both the direct and the indirect value of the phosphorus.

Without addition of potassium the maximum yield was 3,040 pounds (6), consequently the increase in yield from 1,600 pounds

(4) to 2,720 pounds (8), resulting from the addition of potassium to the combination, lime, phosphorus, bacteria, was probably largely due to the increased development of the bacteria in the presence of a larger supply of available potassium.

The field experiments, which are described further on, give abundant evidence of the value of applications of lime in promoting the development of the alfalfa bacteria.

It seems probable that, after an alfalfa field has been inoculated for two or three years and the soil has become thoroughly infected with the bacteria, it will not be so necessary to add liberal supplies of the mineral elements of plant food as it is during the early stages of inoculation when there are comparatively few bacteria in the soil and their multiplication is so important. There are some results from the pot cultures and also from the field experiments which indicate that as the inoculation becomes more thorough, less benefit is derived from applications of the mineral elements.

The photographic reproduction of the six pots receiving no artificial fertilizer, three of which were inoculated and three uninoculated, as they appeared on May 11, less than three weeks after cutting off the crops discussed above, may be of additional interest.

Cuttings made from these six pots on May 21, just four weeks after the previous cuttings, gave the results shown in Table 4.

TABLE 4. ALFALFA POT CULTURES; CUT MAY 21, 1902. WEIGHTS IN GRAMS PER POT AND POUNDS PER ACRE.

Serial No.	Pot No.	Treatment applied	Green alfalfa (gms. per pot)	Air-dry hay (gms. per pot)	Air-dry hay (lb. per acre)
1	25	0:	7	1	160
1	37	0: Bacteria	42	12	1920
11	35	0:	8	2	320
11	47	0: Bacteria	33	8	1280
12	36	0:	6	2	320
12	48	0: Bacteria	33	10	1600

It will be observed that the highest yield of the three uninoculated pots was 320 pounds per acre, while the average yield of the three inoculated pots was 1,600 pounds,—five times as great. These results only serve to confirm those secured from the preceding crops, and to show the value of the inoculation in a most conclusive manner.

PLATE 3. ALFALFA POT CULTURES, SHOWING EFFECT OF INOCULATING ORDINARY BLACK PRAIRIE SOIL WITH ALFALFA BACTERIA.

When we remember that the twenty-four pots used in this series of experiments were all filled with the same kind of well mixed soil, and that this soil is fairly representative of thousands of square miles of Central Illinois land, that both series, of twelve pots each, were kept on the same table in the greenhouse, watered at the same times with exactly the same kind of water, and in every way treated exactly alike, except that one series was inoculated with alfalfa bacteria while the other series was not inoculated, then these most positive and conclusive results, as shown by the records of the experiment, including the color of the foliage, the height of the growing plants, the photographic reproductions, and the absolute yields per pot and rate of yield per acre, seem truly remarkable and appear to be of tremendous importance in solving the question, Why is alfalfa so commonly an unsuccessful crop on Illinois soils?

FIELD EXPERIMENTS WITH ALFALFA.

An acre of ordinary slightly rolling black prairie land was seeded with alfalfa in June, 1901. The soil was considerably better than ordinary cultivated soil (such as was used in the pot culture experiments). Previous to 1895, it had been in pasture for at least eighteen years, and since 1897 it had been in meadow; thus, only three grain crops (corn in 1895, 1896, and 1897) were grown on this soil during the past twenty-five years. The field which was 8 rods wide east and west, and 20 rods long north and south, exclusive of some border and division strips, was divided into two parts by a line running north and south, and into five parts by lines running east and west. The west part of the acre was inoculated with soil taken from an old alfalfa field in Kansas. The five divisions from north to south were fertilized as follows:

Plot No. 1—Check (nothing applied).
Plot No. 2—Lime.
Plot No. 3—Lime and phosphorus.
Plot No. 4—Lime and potassium.
Plot No. 5—Lime, phosphorus, and potassium.

The west part of each of these plots was inoculated; the east part was not inoculated. The arrangement of the plots can be plainly seen from the following diagram.

1.	No Fertilizer Bacteria	No Fertilizer ....
2.	Lime Bacteria	Lime ....
3.	Lime Phosphorus Bacteria	Lime Phosphorus ....
4.	Lime Potassium Bacteria	Lime Potassium ....
5.	Lime Phosphorus Potassium Bacteria	Lime Phosphorus Potassium ....

Plan of Plot Experiments with Alfalfa.

The rates applied per acre were: 320 pounds of air-slacked lime, 320 pounds of bone meal (containing 30 per cent. phosphoric oxid), and 160 pounds of potassium sulfate.

The infected alfalfa soil was applied at different rates of seeding on narrow strips running north and south on the west part of the field, the lightest application, 320 pounds, being on the west side, and, on successive strips eastward, the rates of application were 640, 960, 1,280, 1,600, and 1,920 pounds, respectively. Each of these strips was about one-half rod wide with a very narrow uninoculated division strip (about two feet) between them. A border strip about four feet wide on the extreme west side was not inoculated. A good stand of young plants was secured, but a very heavy rain storm, which occurred on July 2, washed the soil somewhat, and, as the west side of the field was somewhat higher than the east side, it was feared that the bacteria might be carried over the east plots and thus inoculate the whole field to some extent, which afterward proved to be the case, particularly along the east side where the water stood for a short time. The southeast quarter of the field was the lowest part, and, although it was tile drained, the water stood on it long enough to kill most of the alfalfa plants. Because of these occurrences, the results of the experiment are probably not so marked as they would otherwise have been.

During the summer of 1901, the alfalfa was clipped three times, the clippings being left lying on the field. During midsummer, the weeds seemed to grow faster than the alfalfa, but with each clipping the alfalfa improved, and in the fall the stand was good where it had not been injured by the water standing on it.

No marked differences were noted among the different plots, excepting that the alfalfa made a much more vigorous growth wherever phosphorus had been applied, the line being very noticeable where the application of phosphorus began.

In the fall tubercles were found in abundance upon the plants growing in the strips of land where the heaviest applications of infected soil were made, but none were found on plants in the uninoculated soil.

In the spring of 1902 the alfalfa began to grow vigorously and was entirely free from weeds, but within a short time some very marked differences appeared among the different plots. The effect of the inoculation became very apparent, all of the inoculated soil producing a much more vigorous growth than occurred on uninoculated soil, and the more vigorous growth was accompanied by a dark green healthy looking color in the growing alfalfa, while the plants on uninoculated soil took on a pale green color indicative of an insufficient supply of nitrogen. This difference in growth and color between inoculated and uninoculated plants was very marked even where no fertilizer was applied, but it was more marked where lime was applied and still more marked where both lime and phosphorus were applied. These differences are apparent in the photographic reproductions although the photographs do not fully bring out the striking differences which existed in the field and which were observed by several hundred farmers from different sections of Illinois who visited the University about the time these photographs were taken.

Plate 4 shows on the left uninoculated and unfertilized soil, on the right inoculated and unfertilized soil. The difference in growth is measured by the stakes and the difference between two shades of the same color is shown remarkably well for a photographic reproduction. The north line of plot No. 2, to which an application of 320 pounds per acre of air-slacked lime had been made, coincides with the top of the right hand label and the effect of the lime upon the growth and color of the alfalfa is very apparent. Undoubtedly the beneficial effect of the lime is indirect, the development and activities of the bacteria being promoted by the presence of a base and the neutralizing of the soil acids. The effect of lime upon the uninoculated soil on the left is very slight, and even this slight effect is produced in narrow crooked strips running to the eastward, which were evidently little water courses during the storm above referred to, and which became more or less infected with alfalfa bacteria. The still lower ground along the east side of the field was found to be thoroughly infected and the alfalfa there grew as vigorously as on the west side of the field where the application of infected soil was made. A close inspec-

PLATE 4. ALFALFA FIELD EXPERIMENT, SHOWING EFFECT OF INOCULATING ILLINOIS SOIL WITH ALFALFA BACTERIA.
(No fertilizer applied across the foreground where the stakes stand. Lime applied across the back ground beyond the line coincident with the top of the right hand label.)

PLATE 5. ALFALFA FIELD EXPERIMENT, SHOWING EFFECT OF INOCULATING ILLINOIS SOIL AFTER AN APPLICATION OF LIME.

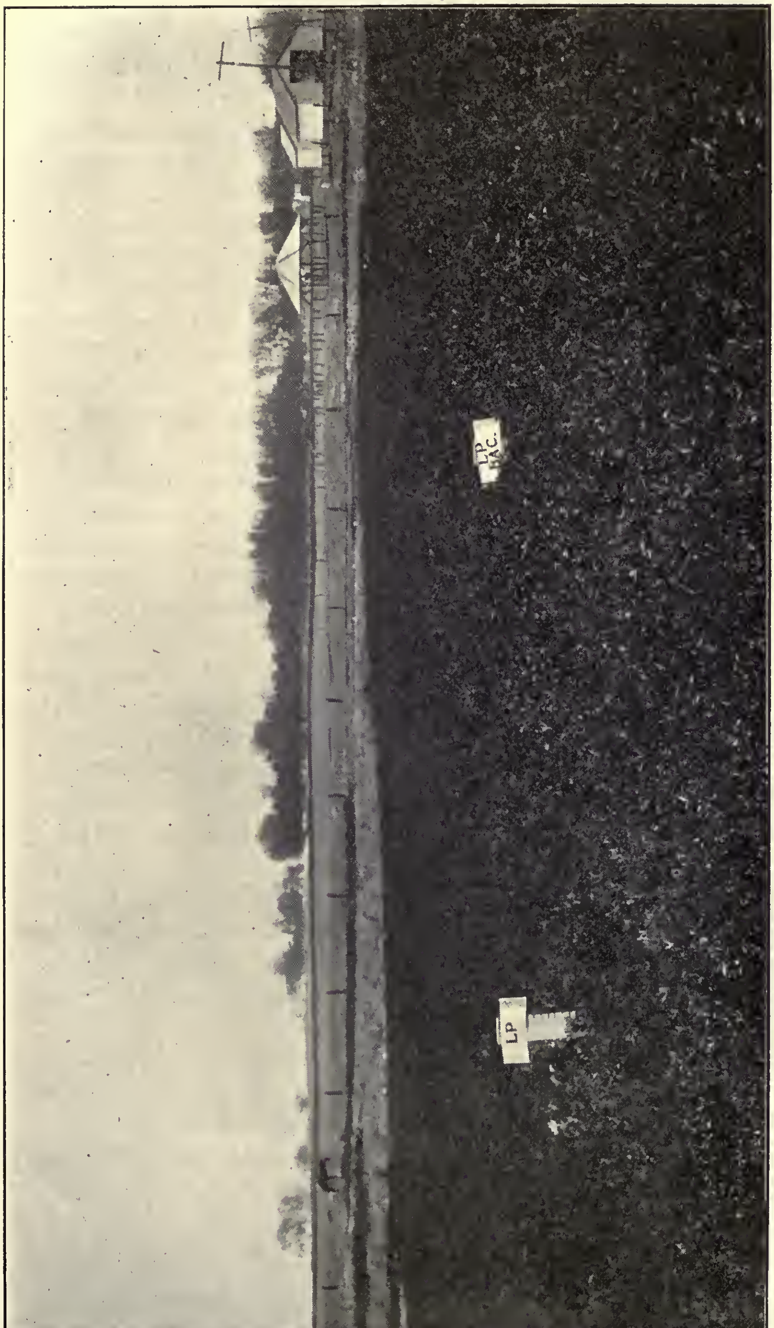

PLATE 6. ALFALFA FIELD EXPERIMENT, SHOWING EFFECT OF INOCULATING ILLINOIS SOIL AFTER APPLICATIONS OF LIME AND PHOSPHORUS.

tion of the right hand side of the field will discover light-colored narrow strips running north and south. These are the uninoculated two-foot strips between the different rates of application of alfalfa soil already explained.

Plate 5 shows very imperfectly the effect of the inoculation on the limed soil. These label stakes are *two feet*[1] high and serve as a measure of the height of the alfalfa. The difference in thickness of stand can be seen but the difference in color between the inoculated and uninoculated alfalfa is not brought out in the photograph.

Plate 6 shows the effect of inoculating soil to which both lime and phosphorus had been applied, the inoculated soil producing a markedly increased growth of alfalfa over the uninoculated soil. To the southwest may be seen the patch of ground where the alfalfa was destroyed by water, on account of which no results were secured from plots 4 and 5.

By comparison of Plates 4, 5, and 6, it will be seen that both lime and lime with phosphorus are applied to the soil under field conditions with marked advantage to the alfalfa provided with bacteria. It is true that the applications of lime and of lime with phosphorus to the uninoculated soil produced increased growth of alfalfa, but, as already explained, this occurred principally on narrow crooked strips or upon the lower ground which had become inoculated. Abundance of tubercles are found on the roots of the dark green plants growing in those places, while the pale green plants as a rule have no tubercles, although the entire field is fast becoming inoculated, the bacteria evidently being scattered over the field by wind and water and no doubt by the hay rake and other implements also.

Because of this cross inoculation no truthful results as to yield could be secured by harvesting the entire plots, but fairly reliable results were obtained by harvesting small plots, although in every case the yield from the uninoculated plot is undoubtedly too high owing to the cross inoculation.

Table 5 gives the yield per acre of air-dry hay from one-thousandth acre plots, the inoculated plots being measured off on the strip where the heaviest application of infected soil was made.

It will be seen that the inoculated plots yielded about twice as much hay as the uninoculated plots.

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1. The stakes shown in Plate 4 were 3 feet high.

TABLE 5. ALFALFA FIELD EXPERIMENTS; FIRST CUTTING 1902, MAY 28.
WEIGHT IN POUNDS PER PLOT AND PER ACRE.

Plot No.	Treatment applied	Green alfalfa (lb. per plot)	Air-dry hay (lb. per plot)	Air-dry hay (lb. per acre)
1	0:	5½	$1\frac{5}{16}$	1313
1	0: Bacteria	11	$2\frac{9}{16}$	2563
2	L:	6	$1\frac{7}{16}$	1438
2	L: Bacteria	12	$2\frac{7}{8}$	2875
3	LP:	7¼	$1\frac{15}{16}$	1938
3	LP: Bacteria	15	$3\frac{5}{8}$	3625

Plate 7 is made from a photograph of the bundles of alfalfa hay harvested from these thousandth-acre plots, and well illustrates the relative differences in the yield of hay from the inoculated and uninoculated plots; (1) with no fertilizer applied, (2) with lime applied, (3) with lime and phosphorus applied. For reasons already explained, no trustworthy yields could be taken from plots larger than one-thousandth acre on uninoculated soil.

The entire field of alfalfa was cut on June 7, and the exact yield of air-dry hay was taken on six fortieth-acre plots, all of which had been inoculated. The first two are duplicate plots from that part of the field which had been inoculated but had received no fertilizer. The second two are duplicates from the inoculated part which had received an application of lime. The third two are duplicate plots from the part of the field which had been inoculated and had also received lime and phosphorus. Table 6 gives the yields per plot and rate of yield per acre.

TABLE 6. ALFALFA FIELD EXPERIMENTS; FIRST CUTTING 1902, JUNE 7.
WEIGHT IN POUNDS PER PLOT AND PER ACRE.

Plot No.	Treatment applied	Air-dry hay (lb. per plot)	Air-dry hay (lb. per acre)
1-a	0: Bacteria	57	2280
1-b	0: Bacteria	57	2280
average.....	....	57	2280
2-a	L: Bacteria	97	3880
2-b	L: Bacteria	86	3440
average.....	....	91½	3660
3-a	LP: Bacteria	116	4640
3-b	LP: Bacteria	120	4800
average.....	....	118	4720

Plate 7. Alfalfa Field Experiment, showing Yield of Hay from Inoculated and Uninoculated Thousandth-acre Plots, (1) with no Fertilizer, (2) with Lime, (3) with Lime and Phosphorus.

It will be observed that after having been inoculated the plots receiving no fertilizer yielded 2,280 pounds of hay per acre, the plots receiving lime yielded an average of 3,660 pounds, and the plots receiving both lime and phosphorus yielded an average of 4,720 pounds, the yield on inoculated soil having been increased more than 50 per cent, by the lime alone, and more than 100 per cent, by applications of both lime and phosphorus. These differences are more marked than were the yields from the corresponding thousandth-acre plots, because the smaller plots were harvested more than a week earlier, and also because of the fact that the thousandth-acre plots were measured off in the strip which had been treated with alfalfa soil at the rate of nearly one ton per acre, while the fortieth-acre plots extended over the strips which had received lighter applications of the infected soil. The difference between the light and heavy inoculations was much more marked on the unfertilized soil than on the fertilized soil. The application of lime, and more especially that of both lime and phosphorus, seemed to so promote the development of the bacteria that even the lightest application (320 pounds of infected soil per acre) was very effective as compared with no inoculation.

Undoubtedly an application of one hundred pounds per acre of soil thoroughly infected with alfalfa bacteria together with three or four hundred pounds of lime would in the course of a year or two effect a very satisfactory inoculation of ordinary Illinois soil, and it seems very evident that an application of two or three hundred pounds per acre of some suitable phosphorus fertilizer, such as steamed bone meal, raw bone meal, rock phosphate, or basic phosphate, in the fall, or acidulated bone meal or other superphosphate, in the spring, would be to the advantage of the alfalfa and to the profit of the grower. If alfalfa hay is worth $8 a ton[1], then according to the results given in Table 6, the application of 320 pounds of air slacked lime, which increased the yield of air-dry hay from 2,280 pounds to 3,660 pounds per acre, a net increase of 1,380 pounds, was worth $5.52 to the grower for its effect upon the first cutting of the second year. Likewise the application of 320 pounds of acidulated bone meal (worth about $3.20) which produced an additional net increase of 1,060 pounds of hay, was worth $4.24 to the grower, and the total increase of 2,440 pounds of hay per acre, resulting from the application of both lime and phosphorus, would be worth $9.76 per acre, for one cutting.

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1. Alfalfa hay is worth about the same as red clover, which varies from $6.00 to $10.00 or $12.00 per ton in this section of the country.

On July 21 the second cutting of 1902 was made of alfalfa from the same inoculated plots referred to in Table 6; that is, from the inoculated plots which had received (1) no fertilizer, (2) lime, and (3) lime and phosphorus, the yields being taken, as before, on duplicate fortieth-acre plots. The yields of air-dry hay are given in Table 6 (b).

TABLE 6 (b). ALFALFA FIELD EXPERIMENTS; SECOND CUTTING 1902, JULY 21. WEIGHT IN POUNDS PER PLOT AND PER ACRE.

Plot No.	Treatment applied.	Air-dry hay (lb. per plot)	Air-dry hay (lb. per acre)
1-a	0: Bacteria	75	3,000
1-b	0: Bacteria	78	3,120
average.....	....	76½	3,060
2-a	L: Bacteria	104	4,160
2-b	L: Bacteria	100	4,000
average.....	....	102	4,080
3-a	LP: Bacteria	134	5,360
3-b	LP: Bacteria	130	5,200
average.....	....	132	5 280

These results are in accord with those obtained from the first cutting, on June 7, although the yields from the second cutting are somewhat larger. It should be stated that these yields are on the basis of thoroughly air-dried hay (not merely field-cured). The duplicate determinations agree well, and show an average yield of more than 1½ tons per acre on unfertilized soil, which was increased to two tons on the limed soil and to more than 2½ tons on the soil to which both lime and phosphorus had been applied.

After the inoculation with bacteria, the effect of the lime was to increase the yield by 1,020 pound, and a still further increase of 1,200 pound was produced by the phosphorus. Applications of both lime and phosphorus increased the yield over no fertilizer by 2,220 pounds per acre. The total yields of the first and second cuttings added together were 5,280 pounds of air-dry hay from the unfertilized soil, 7,740 pounds from the limed soil, and exactly 10,000 pounds (5 tons) from the soil which had received both lime and phosphorus.

THE FIXATION OF ATMOSPHERIC NITROGEN BY ALFALFA.

The investigations of Atwater in America, Boussingault and Ville in France, Hellriegel, Willfarth, and Nobbe in Germany, Lawes and Gilbert in England, et al., have fully established the scientific facts; (1) that leguminous plants, as the clovers, peas, beans, vetches, alfalfa, etc., have the power to gather, or accumulate, free nitrogen from the atmosphere; (2) that this fixation of free nitrogen is actually accomplished by microscopic organisms called bacteria which live in little nodules, or tubercles, upon the roots of the legumes; and (3) that, for different species of leguminous plants, there are also different species of "nitrogen gathering" bacteria. Many investigations have also been conducted to determine the amounts of nitrogen which can be fixed by different leguminous plants, but these experiments have actually been carried on in pure sand cultures under conditions which necessitate that all nitrogen which the legume secures *must* be obtained from the air.

There is abundance of evidence that leguminous plants secure some nitrogen from the air when grown in ordinary soil, if they are provided with the bacteria. Indeed, the presence of the tubercles upon the roots is one of the evidences that free nitrogen is being fixed, and another evidence of that fact is found in the beneficial effects of clover and other legumes in crop rotations. It is a simple matter to determine how much nitrogen is contained in a ton of clover; but, after the amount is determined, it still remains a question as to how much of the nitrogen was taken directly from the soil and how much was secured from the air, and a question very frequently asked is, How much of their nitrogen do leguminous crops obtain from the air and how much do they actually take from the soil?

The pot culture and field experiments described in the preceding pages were conducted on ordinary soil and in such a manner that it can be determined with a high degree of accuracy how much nitrogen was secured from the air by the alfalfa. This is due to the fact that, in all cases, alfalfa was grown not only with bacteria present but also in exactly similar duplicate pots or plots with bacteria absent, and the difference between the amounts of nitrogen contained in the crop from the inoculated soil, on the one hand, and in the crop from the uninoculated soil, on the other hand, represents the amount of nitrogen which was secured from the atmosphere by the bacteria. In no case will this amount be larger than the actual truth; but, if the soil which was not intentionally inoc-

PLATE 8. ALFALFA PLANTS, SHOWING AN UNINOCULATED PLANT ON THE LEFT AND AN INOCULATED PLANT, WITH ROOT TUBERCLES AND INCREASED GROWTH, ON THE RIGHT.

ulated was nevertheless to some extent infected with alfalfa bacteria by cross inoculation, then the amount of nitrogen actually secured from the air would be even larger than represented by these determinations. Plate 8 shows an uninoculated alfalfa plant on the left and on the right an inoculated plant with clusters of tubercles in which the bacteria live, upon its roots, and its increased growth illustrates, in no exaggerated manner, the effect of inoculation on individual plants.

Fixation of Nitrogen by Pot Cultures.

Table 7 gives in pounds per acre the amounts of dry matter and of nitrogen in the crops cut from the pot cultures on April 23, 1902; also the percentage of nitrogen in the dry matter and the

Table 7. Fixation of Nitrogen by Alfalfa in Pot Cultures: Crops cut April 23, 1902.

Serial No.	Pot No.	Treatment applied	Dry matter in crop (lb. per acre)	Nitrogen in dry matter (per cent)	Nitrogen in crop (lb. per acre)	Nitrogen fixed by bacteria (lb. per acre)
1	25	0:	280	2.61	7.31	
1	37	0: Bacteria	1300	4.09	53.17	45.86
2	26	L:	280	3.47	9.72	
2	38	L: Bacteria	1010	4.24	42.82	33.10
3	27	LN:	1280	4.48	57.31	
3	39	LN: Bacteria	1450	4.48	64.96	7.65
4	28	LP:	140	2.78	3.89	
4	40	LP: Bacteria	1440	4.08	58.76	54.87
5	29	LK:	140	3.59	5.03	
5	41	LK: Bacteria	1010	4.20	42.42	37.39
6	30	LNP:	2280	4.53	103.19	
6	42	LNP: Bacteria	2780	4.06	112.87	9.32
7	31	LNK:	1570	4.70	73.79	
7	43	LNK: Bacteria	1890	4.38	82.78	8.99
8	32	LPK:	140	3.15	4.41	
8	44	LPK: Bacteria	2480	3.82	94.74	90.33
9	33	LNPK:	2300	4.09	94.07	
9	45	LNPK: Bacteria	3230	4.00	129.20	25.13
10	34	NPK:	2370	4.14	98.12	
10	46	NPK: Bacteria	2940	4.36	128.18	30.06
11	35	0:	280	2.63	7.36	
11	47	0: Bacteria	730	4.34	31.68	24.32
12	36	0:	280	2.64	7.39	
12	48	0: Bacteria	1020	4.18	42.65	35.26

amounts of nitrogen per acre obtained from the atmosphere by the alfalfa bacteria in the inoculated pots.

Where neither nitrogen nor bacteria were added to the soil, all of the nitrogen removed in the crops[1] must have been derived from the original soil. In the three series of pots receiving no fertilizers (1, 11, and 12) the crops from the uninoculated pots contained 7.31, 7.36, and 7.39 pounds of nitrogen per acre, respectively, while 53.17, 31.68, and 42.65 pounds of nitrogen in the crop are the respective rates per acre of the corresponding inoculated pots. The average of these is 42.50 pounds for the three inoculated pots and 7.35 pounds for the three uninoculated pots, making an average difference of 35.15 pounds in favor of inoculation. In other words, as an average of three separate determinations, with no application of plant food, the bacteria "gathered" and "fixed" and furnished to the growing alfalfa more than 35 pounds of nitrogen per acre. At the present average price for nitrogen in commercial fertilizers (15 cents a pound) these 35 pounds of nitrogen are worth $5.25.

The addition of potassium without phosphorus (5) gave no increase in the amount of nitrogen fixed. With phosphorus added to the soil, the nitrogen in the crop was increased by the presence of the bacteria from 3.89 pounds to 58.76 pounds per acre, 54.87 pounds of nitrogen per acre having been fixed by the bacteria.

Under the most favorable conditions, when both phosphorus and potassium were applied (8), still more marked results were obtained, the nitrogen in the crop having been increased from 4.41 to 94.74 pounds per acre by the bacteria; that is, the bacteria gathered nitrogen from the air at the rate of more than 90 pounds per acre, which was utilized by the growing alfalfa. At market prices, the nitrogen gathered is worth $13.50 per acre.

It is of interest to observe that even in the pots to which applications of nitrogen had been made (3, 6, 7, 9, 10) some nitrogen was fixed when the soil was inoculated, ranging from 7.65 pounds per acre (3), with no addition of phosphorous or potassium, to 25.13 and 30.06 (9 and 10) pounds per acre under the most favorable conditions, with applications of all mineral elements.

1. The amounts of nitrogen given may possibly be too high for some of the uninoculated pots, because of some cross inoculation. The inoculated and uninoculated series of pots stood side by side on the same table, and either spattering of water or more likely the carrying of infected soil by ants (which were frequently found in the pots) or other insects, finally transferred some bacteria to the uninoculated series, which fact became evident, later in the season of 1902, by the development of tubercles, and the markedly increased growth of an occasional plant in the uninoculated pots.

Usually small immature plants contain much higher percentages of nitrogen than do more fully developed plants, but it will be seen from Table 7 that, without exception, the heavy crops of alfalfa contained much higher percentages of nitrogen than the lighter crops. Triplicate determinations of nitrogen in the crops from unfertilized pots (1, 11 and 12) showed 2.61, 2.63 and 2.64 per cent. of nitrogen in the dry matter from uninoculated pots yielding only 280 pounds of dry matter per acre, and 4.09, 4.34 and 4.18 per cent. of nitrogen in the dry matter from the inoculated pots with an average yield of more than 1,000 pounds per acre. A similar effect was produced in all cases, whether nitrogen was added as a a nitrogenous fertilizer or gathered by the bacteria,—all of which tends to prove that, with insufficient nitrogen, the plants make as much growth as possible until the fixation of carbon is practically stopped by the lack of nitrogen, as indicated by the pale yellowish green color of the folliage.

Table 8 shows the data relating to the fixation of nitrogen from the next cutting (May 21) of the six unfertilized pots (1, 11, 12), three of which were inoculated.

TABLE 8. FIXATION OF NITROGEN BY ALFALFA IN POT CULTURES; CROPS CUT MAY 21, 1902.

Serial No.	Pot No.	Treatment applied	Dry matter in crop (lb. per acre)	Nitrogen in dry matter (per cent)	Nitrogen in crop (lb. per acre)	Nitrogen fixed by bacteria (lb. per acre)
1	25	0:	140	2.69	3.77	
1	37	0: Bacteria	1720	3.52	60.60	56.83
11	35	0:	280	2.47	6.91	
11	47	0: Bacteria	1170	3.69	43.18	36.27
12	36	0:	280	2.61	7.31	
12	48	0: Bacteria	1460	3.66	53.48	46.17

These results only confirm those of the previous cutting and show that on ordinary unfertilized Illinois soil the alfalfa bacteria were capable of fixing 46.42 pounds of nitrogen per acre, as the average of the three separate determinations.

The average percentage of nitrogen in the dry matter of the crops from the three uninoculated pots was 2.59, while 3.62 is the average percentage from the three inoculated pots.

Fixation of Nitrogen in Field Experiments.

Table 9 gives the same data for the field experiments as are given in Tables 7 and 8 for the pot cultures. These determinations were made on the crops cut from the exact thousandth-acre plots on May 28, 1902.

Table 9. Fixation of Nitrogen by Alfalfa in Field Experiments; Crops cut May 28, 1902,

Plot No.	Treatment applied	Dry matter in crop (lb. per acre)	Nitrogen in dry matter (per cent)	Nitrogen in crop (lb. per acre)	Nitrogen fixed by bacteria (lb. per acre)
1	0:	1180	1.85	21.81	
1	0: Bacteria	2300	2.70	62.04	40.23
2	L:	1300	2.02	26.20	
2	L: Bacteria	2570	2.65	68.02	41.82
3	LP:	1740	2.03	35.40	
3	LP: Bacteria	3290	2.71	89.05	53.65

These results secured under field conditions on good black prairie soil are in perfect agreement with the results from the pot culture experiments, the amount of atmospheric nitrogen fixed by the alfalfa bacteria being 40.23 pounds per acre on the unfertilized plot, 41.82 pounds on the limed plot, and 53.65 pounds per acre on the plot receiving both lime and phosphorus. Almost two-thirds of the total nitrogen contained in the crop from the inoculated unfertilized plot (1) was secured from the atmosphere by the alfalfa bacteria. It should be borne in mind that nitrogen is required for root growth as well as for growth above ground and also that these amounts were obtained from a single crop of alfalfa, and that two or three more crops will be cut during the season. From the data already given, it will be seen that on the unfertilized soil four such crops as that cut on May 28 from the inoculated plot would mean at least 160 pounds of atmospheric nitrogen fixed by an acre of alfalfa during a single year, and this would require a total yield of only about five tons of alfalfa hay for the season, which is by no means a maximum yield for alfalfa on Illinois soil under the most favorable conditions, as will be shown in the following pages.

The percentage of nitrogen is much higher in the crops from the inoculated plots, the average being 1.97 per cent. in the dry matter for the uninoculated plots and 2.69 for the inoculated plots. This means, of course, that the hay produced on the inoculated plots is not only more in quantity, but it is also much better in quality, the percentage of protein averaging only 12.29 in the dry matter of the uninoculated crops, while 16.84 is the percentage for the inoculated plots.

THE PRESENT STATUS OF ALFALFA IN ILLINOIS.

As stated in the introduction, "many different farmers have tried to grow alfalfa in various sections of Illinois, but in most cases it has been pronounced a failure." Nevertheless, there are some notable exceptions to this most common experience, and it is very gratifying and encouraging to be able to state that alfalfa is now growing with marked success in a number of places in the state, and these places are not limited to Central Illinois, but are found as far south as Cairo and as far north as the Wisconsin line; but, so far as the writer has been able to learn, by personal investigations, and by examinations kindly made for me by other persons, wherever alfalfa is grown successfully it is either accompanied by the alfalfa bacteria (recognized by the development of tubercles upon the alfalfa roots) which are able to supply the growing plant with an abundance of nitrogen gathered from the air, or it is grown upon exceedingly rich ground and usually given large yearly applications of barnyard manure.

A field of five acres of ordinary upland prairie on the farm of Mr. C. A. Haines, near Champaign, Illinois, was seeded to alfalfa in 1899. The second year fair crops of excellent hay were secured. The third year the crops were poor and the plants looked yellow and suffering for nitrogen. The writer and about a dozen students searched over the field diligently at different times, but were unable to find a single tubercle on the alfalfa roots. A heavy dressing of manure had been scattered over a small part of the field near the barn yard and on this spot a most vigorous growth occurred, but no tubercles could be found even on the most vigorous plants. In June, 1901, the Experiment Station secured permission from Mr. Haines to inoculate a narrow strip across his alfalfa field with infected alfalfa soil. Later in the fall abundance of tubercles appeared on the alfalfa roots in this strip, and in the spring of 1902 nearly every plant examined in this strip was found to be provided with tubercles, and occasional plants outside of the inoculated strip were found with tubercles upon their roots, the bacteria evidently having been carried by water or wind or by the farm animals or implements. On a part of the field which was so situated that it could not have become infected by washings from the inoculated strip, no tubercles could be found in the early summer of the present year. Owing to the marked effect produced by the manure in 1901, Mr.

Haines applied more than 20 tons per acre of barnyard manure to the field (including the inoculated strip) during the past winter. Naturally the entire field is covered with a rank growth at the present time and no effect of the inoculation is observable; indeed, before the nitrogen in the manure is exhausted, probably the whole field will be more or less inoculated and one not acquainted with the facts may be led to suppose that manure has very lasting properties when applied to alfalfa.

On the farm of Mr. W. R. Goodwin, Jr. (Associate Editor of the Breeder's Gazette), near Naperville, DuPage county, Illinois, on the DuPage river, are ten acres of alfalfa. Two acres of this, on the river bottom land, were seeded in April, 1900 A good stand resulted and a very satisfactory growth occurred during that season. During 1901 four large crops of hay were cut from this field. a total of 21 tons, by actual weight, of field cured hay being hauled off from the two acres, making a total yield for the season of 10½ tons per acre of excellent hay.

In April, 1901, Mr. Goodwin seeded four acres more land adjoining the two-acre field, and in April, 1902, four more acres were seeded, making a total of ten acres now seeded to alfalfa. The later seedings are upon somewhat higher land than the first field seeded.

Upon invitation of Mr. Goodwin, the writer examined this alfalfa field on June 9 of the present year.

More favorable conditions than this field presents for the growing of alfalfa are hard to imagine. The soil is a rich deep loam varying in color from dark brown to black. It is underlaid with limestone, and some limestone gravel is usually found near the surface. Mr. Goodwin manures the alfalfa every year, and furthermore, the entire field is well provided with alfalfa bacteria. Even the young plants only six or seven weeks old had tubercles on their roots.

Plate 9 shows three alfalfa plants taken from Mr. Goodwin's field on June 9, 1902. On the left is a two-year-old plant, in the middle a one-year-old plant, and on the right a young plant six or seven weeks old. Tubercles were found upon the roots of each of these plants, but most of them were broken off in removing the dirt from the roots, although one or more bunches of tubercles are still showing upon the roots of each plant.

Several fields of alfalfa are growing near Cairo, Pulaski county, Illinois. They are chiefly on river bottom land and are making very satisfactory and profitable crops. A number of these fields were recently examined by Mr. W. O. Farrin, a graduate stu-

PLATE 9. ALFALFA PLANTS FROM FIELD OF W. R. GOODWIN, JR., NEAR NAPERVILLE.

dent of this College, and in every case alfalfa bacteria were found to be present. Alfalfa root tubercles have also been found by Mr. J. E. Readhimer, a field assistant in the Illinois Experiment Station, in several places in the state, including a field on rich black prairie loam near Normal, and in some other places in Illinois. Mr. D. S. Dalbey, assistant in Farm Crops, found tubercles in an alfalfa field belonging to Mr. Lehman, near Sidney.

The facts are that the bacteria are certainly present in some places in the state while in most other places they are certainly not present in sufficient number to become of appreciable assistance to the alfalfa within three or four years, and the question naturally arises how it happens that some fields are already infected while others are not. Of course, a definite answer to this question is not possible, neither is it necessary. We may suppose that the same bacteria live on some other plants besides alfalfa and one of these plants is native or has been introduced in certain sections. What seems more probable is to suppose that a few bacteria are always carried with alfalfa seed and that if the alfalfa is grown continuously or repeatedly in any place the soil will finally become thoroughly infected, and the bacteria will then be carried by flood waters, dust storms, etc., over adjoining fields and possibly for long distances, especially along river valleys. A single bacterium, or possibly a hundred, in an acre of alfalfa might not multiply and develop sufficiently to make their presence noticeable for several years and yet when we consider that a single alfalfa plant under favorable conditions may have many hundred of tubercles upon its roots, and that a single tubercle may contain a thousand million individual bacteria, we realize the possible rapidity of their multiplication; and the fact that a part of Mr. Goodwin's alfalfa field was flooded by the DuPage river in June, 1902, is a promise that any soils over which those waters subsequently flowed were thus inoculated to some extent.

This Experiment Station seeded and inoculated alfalfa experiment fields in about twenty-five different places in Illinois the past spring. We have also furnished small quantities of infected soil from the University field to farmers in different sections of the state. After the farmer has inoculated a few square rods of his alfalfa field and allowed the bacteria to develop for a year or so, he will then have a sufficient quantity of infected soil to inoculate large areas.

DIRECTIONS FOR GROWING ALFALFA.

The soil for alfalfa should be well drained and it should contain a good supply of the mineral elements of plant food in available form. On most soils in the state moderate applications of lime (400 to 800 pounds per acre) will undoubtedly prove profitable, and on some soils phosphates could be applied with profit. The ground should be prepared at least as well as for corn. April is probably the best month to sow alfalfa in Illinois, but May is also a good time, and under favorable conditions good stands may be secured from June, July, or even August seeding, but the late seedings are more liable to be injured by drouth and by freezing during the first winter. The seed should be sowed broadcast at the rate of about 20 pounds per acre and covered about one-half inch deep by a light harrow. It usually produces a good stand when seeded with light nurse crops, as beardless barley, or a thin seeding of oats, which, for the sake of the alfalfa, had better be cut early for oat hay. The more common practice, however, is to sow alfalfa without a nurse crop.

Two rules may be laid down for cutting alfalfa. For the first season the rule is, cut, or clip, alfalfa whenever it seems to stop growing vigorously, and this is to be done regardless of the size of the plants. If the plants are so small or the field has become so weedy that the crop is not worth taking care of, then clip it with the mower and let the clippings lie on the ground. In no case should the weeds be allowed to produce seed. The first rule then is, whenever alfalfa practically stops growing, cut it. It will then spring up from the rootstock with renewed vigor and in a few weeks make a larger growth than if it had not been cut at all.

The second rule applies to the second and subsequent seasons and is as follows: Cut alfalfa hay when about one-tenth of the heads are in bloom. This is a rule commonly followed by experienced and successful growers of alfalfa in the West, and it should be practiced even though the crop is a light one, because much more would be lost in subsequent crops than would be gained in the first one by allowing the alfalfa to reach full bloom before cutting. It should not be cut very close in the fall because of danger from winter killing.

In Northern Illinois three to four crops of alfalfa hay can be cut in a good season; in Southern Illinois, five crops may sometimes be cut.

It is not the purpose of this bulletin to discuss the value of alfalfa. It is undoubtedly the most profitable forage crop which grows, and it not only produces very profitable yields of most excellent hay and makes splendid pasture, but it is also very effective as a soil restorer, because of its deep rooting system and its power (when supplied with proper bacteria) to secure large quantities of the valuable element, nitrogen, from the free and inexhaustible supply of the atmosphere.

Alfalfa hay is cured and harvested in about the same manner as red clover. It must not be allowed to lie in the swath until it becomes thoroughly dry ; or the leaves, the most valuable part of the hay, will be broken off and lost in the handling. The partly cured hay is put in small piles and then allowed to dry out more completely before hauling.

Alfalfa hay and pasture tend to produce bloat in animals even more than red clover, and consequently it must be fed with some care.

SUMMARY OF BULLETIN NO. 76.

The past experience of many farmers and the past experiments of investigators have in nearly all cases shown that alfalfa is not a successful crop on Illinois soil.

The experiments and observations described in this bulletin establish the following facts:

1. Alfalfa bacteria are usually not present in Illinois soil, and, consequently, the alfalfa is not able to obtain nitrogen from the atmosphere (which it would be able to do by means of the proper bacteria) but it is entirely dependent upon the soil for its supply of this most valuable and important element of plant food.

2. To produce good crops of alfalfa without the "nitrogen gathering" bacteria requires exceedingly rich soil and liberal applications of barnyard manure or other nitrogenous fertilizer. (It may be observed that these are the conditions of soil and treatment recommended for alfalfa by most writers in the agricultural press of Illinois and other central states).

3. Even the rich black prairie soil of Illinois does not furnish sufficient available nitrogen for maximum crops of alfalfa. (No other crop grown in Illinois requires such large quantitities of nitrogen as alfalfa).

4. Applications of available nitrogen to Illinois soil produce crops of alfalfa which yield from two to four times as much hay as crops which obtain all of their nitrogen from the natural supply of the soil.

5. The inoculation of Illinois soil with the proper alfalfa bacteria enables the alfalfa to feed upon the inexhaustible supply of free nitrogen in the air and the inoculated soil produces just as

large crops of alfalfa as soil which has been heavily fertilized with commercial nitrogen. (Nitrogen costs about 15 cents a pound in commercial fertilizers, and about 50 pounds of nitrogen are required to produce one ton of alfalfa hay *and the weight of the free nitrogen in the atmosphere is equal to about 12 pounds to each square inch of the surface of the earth*).

6. On most Illinois soils, excepting limestone soils, applications of air-slacked lime as well as inoculation with bacteria, will be advantageous to the alfalfa and profitable to the farmer. (Most cultivated soils are more or less acid ; the lime corrects the acidity and promotes the development and activities of the bacteria, thus enabling the alfalfa to secure larger supplies of atmospheric nitrogen).

7. On some types of soil, probably phosphorus can be applied with profit, for the production of alfalfa.

8. Several places have been found in Illinois where the soil is already infected with alfalfa bacteria ; and, wherever the bacteria have been found, alfalfa is being grown successfully. (The infected soil which has been found has usually been in river bottoms, but this has not been the case in all instances. Fields of infected soil have been found in the extreme northern, in the central, and in the southern part of the state, showing that, while the alfalfa bacteria are by no means common in Illinois soil, they do exist in abundance in several widely separated sections).

9. Alfalfa bacteria have been introduced on the University farm at Urbana and alfalfa fields have been seeded and inoculated by the Experiment Station in about twenty-five different places in the state.

10. The Experiment Station advises farmers generally, in all sections of the state, to try to grow a few acres of alfalfa of which a small plot at least should be given the most favorable conditions for success, by applying infected soil, and, if needed, lime, phosphorus, or potassium.