

The story of Field A of the
Massachusetts Agricultural
Experiment station. A Review
of Experiments with Nitrogen
Fertilizers

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By Fred W. Morse

The year 1932 marks the fiftieth anniversary of the formal organization of agricultural research at Massachusetts State College. It was in November of 1882 that the Experiment Station was established, and field plot experiments begun the next year represent some of the first activities. It seems fitting, therefore, after this fifty-year period, that results from this work be compiled and recorded in permanent form. This bulletin represents such an effort.

MASSACHUSETTS STATE COLLEGE
AMHERST, MASS.

THE STORY OF FIELD A OF THE MASSACHUSETTS AGRICULTURAL EXPERIMENT STATION

A REVIEW OF EXPERIMENTS WITH NITROGEN FERTILIZERS

By Fred W. Morse, Research Professor of Chemistry

Field A is the field first to be devoted to fertilizer experiments at the Massachusetts Agricultural Experiment Station. The experiments have been described with more or less detail in the annual reports of the Station. It is now attempted to bring together the disconnected reports and summarize the results in a relatively brief article as a background for future work on these plots.

A clear description of the field is given in excerpts from the report by Professor Manly Miles in the First Annual Report of the State Agricultural Experiment Station in 1883.

THE FIELD PLATS

After a careful examination of the area assigned for field experiments and a detailed study of its previous history as to cropping, with reference to its present agricultural condition—in which I was materially aided by the advice and suggestions that were kindly given by Hon. Levi Stockbridge, ex-president of the Agricultural College—two series of plats were selected that presented the required conditions of uniformity and surface soil and exposure.

When the trenches for laying the tiles had been dug, it was likewise found that the subsoil in each series of plats was quite as uniform in its characteristics as the surface soil. . . .

The plats are two rods wide and eight rods long, giving an area of one-tenth of an acre each. . . .

The east tier of plats (with odd numbers¹) have been under ordinary field culture, and for several years past in grass, which is badly "run out," the hay having been removed without the return of an equivalent in the form of manure; so that their present condition, as represented by their past history, is well adapted to the proposed permanent experiments. . . .

A main drain of round tiles laid four feet deep has been made along the east side . . . (four feet from the line of plats), with wells of sewer pipe opposite the middle of each plat, for the purpose of collecting samples of the drainage waters from the lateral drains which open into them. . . .

The laterals, of two-inch round tiles, are laid through the middle of each plat, and have their outlet in the wells twelve inches above the grade of the main drain. . . .

The work of digging trenches for the tile drains was begun April 16th, and the laterals on the east tier of plats were completed May 10th. . . .

EXPERIMENTS WITH INDIAN CORN

In accordance with the plan of experiments, . . . corn was grown on the east series of plats . . . without manure, and under the same conditions as to management, for the purpose of testing the relative fertility of the plats. . . . The plats, of one-tenth of an acre each, are two rods wide and eight rods long, and they are separated by a space four feet wide, on which no crop is grown.

The soil is a friable loam, with a retentive subsoil of clay that is nearly filled with gravel and small stones in the lower strata.²

There is a remarkable uniformity in the soil and subsoil of the different plats, both as to apparent fertility and physical condition, with the exception of plat 0, where a large manure pile had formerly been made. . . .

In all operations of ploughing, cultivating, planting, hoeing and harvesting, the work was done lengthwise of the field, and consequently across the plats, so that each plat received the same treatment, as far as possible. . . .

¹ Later renumbered 1 to 10 and designated Field A.

² The Bureau of Soils classified this soil as Norfolk sandy loam but changed it later to Merrimac. "Soils of the United States." U. S. Dept. Agr., Bur. Soils, Bul. 55, p. 158.

"Longfellow corn" was planted June 2, in hills, forty-four inches apart each way As the first and second days of June were the first really warm days of the season, the late planting did not at the time seem to be a serious disadvantage. . . .

The plats were quite free from weeds on the start, and the repeated cultivation and hoeing left the crop perfectly clean in its subsequent growth.

On the night of September 3 a hard frost severely injured the corn as we were dependent on the farm for labor, we were obliged to wait until the 7th inst., when the crop was cut close to the ground and put in stooks to cure. . . . The corn was husked October 18 The corn and stalks were hauled to the barn and separately weighed. . . .

It should be noted that from an error in marking and planting, made by the unskilled hands assigned me, it became necessary to transplant several rows of corn on plats 13, 15 and 17,* the transplanted hills were checked in their growth and never fully matured. This will, in part at least, account for the lower yield of both corn and stalks on these plats.

Professor Miles was not connected with the experiments after the first year. The arrangement of the plots and the drains has been unchanged and the method of cultivation across the plots has been maintained. Until 1896, the experiments were directed and reported by Dr. Charles A. Goessmann, the first director of the Experiment Station. In 1884 he reported:

During the past season the field has been planted again with corn, for corn fodder, without the application of manure of any description. . . . the corn (variety: Clark) was planted in drills, two and one-half feet apart, at the rate of two bushels per acre, on the 24th of May The plants started well in the spring, yet began soon to fall behind, in general appearance, other fodder corn-fields in the vicinity, upon fertilized lands.

At the beginning of blooming it turned gradually yellow, failed to produce grain-bearing cobs,

The corn was cut on the first of September and stacked in the field for drying. The entire yield of corn fodder from this piece of land, one and one-tenth of an acre in size, amounted to 5,040 pounds, with a moisture of thirty per cent.

The soil is evidently in suitable condition for studying the special effects of various forms and kinds of plant food

SOIL AND FERTILIZER TEST WITH CORN

Corn was the crop grown for the next five years upon these plots. A variety of flint corn known as Clark was used each year, and the seed was planted in hills 12 to 14 inches apart in rows 3 feet and 3 inches apart. The time of planting was in the latter part of May each year, and the crop was cut in the earlier part of September. Under the conditions of the experiment, until the season of 1889, the corn did not mature ears sufficiently to be husked and was consequently weighed from each of the plots as fodder, after being cured in shocks until October.

The use of fertilizers was begun in 1885. The amount of each fertilizer and its allocation to the different plots was varied somewhat each year until 1889. The arrangement of plots and their fertilizers is shown by a chart and the yields of corn are given in Table 1.

The table includes the yields for 1883 but omits those of 1884 because in that year the crop from the field was weighed as a whole and then divided equally among the plots. The amount, 458 pounds per plot, was less than any yield of the previous year.

Only one kind of fertilizer was used upon any plot in 1885, and Plot 0 of the previous years was omitted from the records until 1889.

* In Table 1, these plats are numbered 7, 8, and 9.

FERTILIZER PLAN WITH CORN
1885-1888

Plot	1885	1886	1887	1888
1	25 lbs. sodium nitrate.	50 lbs. sodium nitrate.	50 lbs. sodium nitrate. 50 lbs. muriate of potash.	50 lbs. muriate of potash.
2	Nothing.	Nothing.	Nothing.	50 lbs. sodium nitrate.
3	30 lbs. dried blood.	60 lbs. dried blood.	60 lbs. dried blood. 100 lbs. dissolved boneblack.	100 lbs. dissolved boneblack.
4	Nothing.	Nothing.	Nothing.	Nothing.
5	25 lbs. ammonium sulfate.	50 lbs. ammonium sulfate.	50 lbs. ammonium sulfate. 97 lbs. sulfate of potash-magnesia.	97 lbs. sulfate of potash-magnesia.
6	Fallow.	Fallow.	Fallow.	Nothing.
7	50 lbs. dissolved boneblack.	100 lbs. dissolved boneblack.	100 lbs. dissolved boneblack. 50 lbs. muriate of potash.	50 lbs. muriate of potash.
8	Nothing.	Nothing.	Nothing.	50 lbs. ammonium sulfate.
9	25 lbs. muriate of potash.	50 lbs. muriate of potash.	50 lbs. muriate of potash.	50 lbs. muriate of potash.
10	48.5 lbs. sulfate of potash-magnesia.	97 lbs. sulfate of potash-magnesia.	97 lbs. sulfate of potash-magnesia. 60 lbs. dried blood.	97 lbs. sulfate of potash-magnesia. 100 lbs. dissolved boneblack.

In his report for 1885, Director Goessmann states:

... we notice that the application of potash compounds alone, ... has had a marked effect on the quantity ... of the corn fodder raised, ...

... it seems justifiable to conclude that a deficiency of the soil in available potassa controlled more than that of any other essential article of plant food the final yield of the crop.

In 1886, without changing the kinds of fertilizers, the quantities used were doubled. There was no change in the order of crop yields, however.

In 1887, the fertilizers on some of the plots were added in pairs. The addition of potash to nitrogen on Plots 1 and 5, and to phosphoric acid on Plot 7, doubled the yields which had been obtained with those elements alone. Phosphoric acid

TABLE 1—YIELD OF CORN
(Pounds per plot.)

Plot	1883		1885	1886	1887	1888	1889	
	Ears	Stover	Fodder	Fodder	Fodder	Fodder	Ears	Stover
0	326	578	.....	.....	.....	.....	158	342
1	233	445	N 480	N 430	NK 720	K 617	172	476
2	227	410	310	250	165	N 303	201	376
3	241	437	N 350	N 310	NP 240	P 150	192	426
4	221	400	300	250	130	114	97	284
5	217	383	N 360	N 280	NK 635	K 564	129	359
6	219	390	Fallow	Fallow	Fallow	193	175	367
7	197	356	P 280	P 255	PK 730	K 676	41	484
8	174	340	250	195	165	N 191	121	238
9	191	355	K 945	K 840	K 655	K 553	58	417
10	219	400	K 845	K 895	NK 940	PK 737	172	467

N—Nitrogen. P—Phosphoric acid. K—Potash.

1883. Grass-land plowed and planted without fertilizer of any kind.

1889. All plots fertilized with phosphoric acid and potash.

Plots 1, 2, 3, 5, 6, 8, and 10 received nitrogen; Plots 4, 7, and 9 did not receive it. Plot 0 received farm manure.

added to nitrogen on Plot 3 did not improve the yield in the least. Nitrogen added to potash on Plot 10 increased the yield a little when compared with the previous year.

In his report for 1887, Dr. Goessmann said:

The beneficial influence of a potash supply on the yield of fodder, upon our experimental plots, is in every instance unmistakable.

The continuation of the experiment in a similar manner in 1888 brought about a change. The continuous use of potash alone brought about a marked deterioration in yield on Plot 9. Nitrogen was withheld on Plots 1 and 5, with the result that potash alone did not maintain the yields obtained on these plots the previous year. The withholding of phosphoric acid on Plot 7 produced a similar result.

Dr. Goessmann's report in 1888 contained the following statement:

A manuring for three successive years with potash alone has sufficed in our case to terminate its beneficial effect on the natural productiveness of the soil, as far as the corn crop is concerned. More complete manures are required to restore a desirable degree of fertility of the soil.

The application of nitrogen to Plots 2 and 8 resulted in a positive increase over the preceding year; while the substitution of phosphoric acid for nitrogen on Plot 10 did not maintain the yield of the previous year.

The fertilizer plan was changed in 1889 with the object of studying the influence of different kinds of nitrogen compounds as fertilizers when the soil was supplied with ample quantities of available phosphoric acid and potash in standard materials.

Corn was again the crop and was handled as in the preceding years. Three of the plots, (4, 7, and 9) did not receive any nitrogen and had not received any

since the field was first plowed in 1883. All the other plots received equal amounts of nitrogen, but in different kinds of fertilizers. Plot 0 was again included. For this year it is sufficient explanation to mention that all the plots received fertilizers supplying phosphoric acid and potash in amounts like those of 1885, while all but three received nitrogen as in that year.

We have then a crop of corn liberally fertilized which can be compared with the first crop on unmanured soil. It will be noted that not one of the plots equals the first year, with the exception of 10, which in total crop barely exceeds its first year. In all cases the yields of ears are lower in this fertilized crop. The crop of 1883 was grown upon new land, even though it was "run out" as a producer of hay. The turf underlying that corn evidently contained a reservoir of fertility fully equal to that added in the fertilizers of 1889. The poor yields on Plots 4, 7, and 9 are especially striking and will be recalled later in this article.

In the report for 1889, there is the statement that the larger part of the late summer was cold and wet and for this reason unfavorable for raising fodder corn. A difference in average temperature between the two seasons would affect the development of the corn crop in a way that could not be wholly overcome by fertilizers. The first crop was frost-bitten early in September, which would cause a quickened drying of the leaves and possible losses by breakage of them in handling. Hence we have in each season under comparison a weather condition which cannot be evaluated in weight of crop.

During the recorded history of this field there have occurred variables which have affected the field unevenly for a time. The most common variables were weather conditions such as a drenching rain at a critical stage, an unseasonable frost, a severe drought, or a hard winter. Theoretically, all parts of a field are equally exposed to the weather. Actually, variations in soil or fertilizers are much exaggerated by an extreme change in weather. Sometimes the variable was due to the lack of facilities encountered in pioneer work as in these early experiments.

It is now well known that it is difficult to find a field of an acre or more that is truly uniform in soil and subsoil throughout its area. This experimental field, like the experiment station itself, has developed under changing conditions which could not be foreseen and to which adjustments were necessary.

COMPARISON OF NITROGEN FERTILIZERS

Beginning in 1889 and continuing with but little change until 1919, a fertilizer experiment was planned with the object of comparing three distinct kinds of nitrogen fertilizers represented by the standard chemicals of that period, viz., sodium nitrate, ammonium sulfate, and dried blood. The other essential elements of soil fertility, phosphoric acid and potash, were supplied to all plots alike in standard chemicals of the times. Phosphoric acid was contained in dissolved boneblack. Potash was applied in two distinctly different compounds, muriate of potash and sulfate of potash-magnesia. In the long run this comparison of two potash compounds showed them to be equally effective and cannot be said to have influenced the comparison of the nitrogen fertilizers.

The quantities of chemicals for the different plots are given in the following chart. In terms of pounds per acre they would contain 45 pounds nitrogen, 80 pounds available phosphoric acid, and 125 pounds potash. In 1894 and 1895 the quantities of phosphoric acid and potash were doubled but with no appreciable

effect. In 1917, because of war conditions, the quantity of potash was reduced 40 per cent to 75 pounds per acre and the reduction was maintained until the close of this study.

FERTILIZER PLAN FOR THIRTY YEARS
1889-1918

- Plot 0.—800 lbs. manure, 32 lbs. sulfate of potash-magnesia, 18 lbs. dissolved boneblack.
- Plot 1.—29 lbs. sodium nitrate, 25 lbs. muriate of potash, 50 lbs. dissolved boneblack.
- Plot 2.—29 lbs. sodium nitrate, 48.5 lbs. sulfate of potash-magnesia, 50 lbs. dissolved boneblack.
- Plot 3.—43 lbs. dried blood, 25 lbs. muriate of potash, 50 lbs. dissolved boneblack.
- Plot 4.—No nitrogen, 48.5 lbs. sulfate of potash-magnesia, 50 lbs. dissolved boneblack.
- Plot 5.—22.5 lbs. ammonium sulfate, 48.5 lbs. sulfate of potash-magnesia, 50 lbs. dissolved boneblack.
- Plot 6.—22.5 lbs. ammonium sulfate, 25 lbs. muriate of potash, 50 lbs. dissolved boneblack.
- Plot 7.—No nitrogen, 25 lbs. muriate of potash, 50 lbs. dissolved boneblack.
- Plot 8.—22.5 lbs. ammonium sulfate, 25 lbs. muriate of potash, 50 lbs. dissolved boneblack.
- Plot 9.—No nitrogen, 25 lbs. muriate of potash, 50 lbs. dissolved boneblack.
- Plot 10.—43 lbs. dried blood, 48.5 lbs. sulfate of potash-magnesia, 50 lbs. dissolved boneblack.

The arrangement of plots for the comparison of the fertilizers was influenced by the treatment they had received in the previous period, and at the outset the different plots were not as nearly uniform in their fertility as they apparently were in 1883.

Plot 0 had been omitted from the experiment after 1884 because it showed the residual effects of a manure pile which had been upon its surface at some previous period. During this omission from the records it had probably been planted with corn without fertilizer. It was restored to the experiment in 1889 and was fertilized with stable manure supplemented by boneblack and sulfates of potash and magnesia. The amount of manure, 800 pounds, was calculated from the average composition determined by numerous analyses and contained an amount of nitrogen equal to that in the chemical fertilizers used. The supplementary phosphoric acid and potash were necessary to equalize Plot 0 with the other plots. This plot was the only representation of this treatment and must stand on one annual result.

Plots 1 and 2 were selected for nitrate of soda because they had each received that fertilizer at one time or another in the previous years. They adjoined and were frequently fairly close together in yields. In 13 years out of 33, their individual yields were within 1 per cent or less of their average. Plot 1 definitely excelled Plot 2 in 14 harvests, while the latter excelled in 6.

Plot 3, which received dried blood in the new plan, had also been dressed repeatedly with it alone in the previous years. It was paired with Plot 10 at the other end of the field. In the subsequent years, Plot 10 excelled Plot 3 in 15 harvests, while it was excelled by the latter 13 times. In five seasons, their yields were so nearly alike that they may be considered as equal.

Plots 4, 7, and 9 were selected as check plots because they had not received any nitrogen during the preceding years. Otherwise they had not been treated alike and had yielded different weights of crops. Their records have been carefully compared to ascertain whether there were consistent differences in their native fertility; but none could be discovered. Sometimes one plot has been the best of the three and at others it has been the poorest. Plot 7 has been the highest producer 12 times and the lowest 8 times; while Plot 4 has been highest 14 times and lowest 15 times; and Plot 9 highest 7 and lowest 10 times. Plot 9 may perhaps be considered nearest the average as a producer.

On the whole, the choice of Field A as a reasonably uniform field has been borne out by the successive harvests.

The three plots which were chosen for the applications of ammonium sulfate had an uneven start insofar as their records for the early years bear witness. Plots 5 and 8 had each received ammonium sulfate, but otherwise had been treated quite unlike and had borne unequal harvests. Plot 6 had been treated unlike any of the others for three years and this will be shown by Director Goessmann's report for 1888.

. . . during the years 1885, 1886 and 1887, the plot was ploughed, harrowed and treated with the cultivator in the same manner and at the same time as the remaining plots. During that entire period no manurial matter of any description was applied. The appearance of every description of vegetation was, as far as practicable, prevented by a timely use of the cultivator.

At the beginning of the past season, after having produced no crop for three succeeding years, it was prepared in the same way and at the same time as the other plots. . . . No manurial matter was on that occasion applied to plot 6. The date of planting the corn, and the subsequent treatment of the crop to the time of harvesting, was the same in all cases. The yield of fodder corn upon plot 6 was the third lowest in the scale including all plots; . . . It was also the poorest-looking crop upon field "A" during the larger portion of the season . . . Our observation in this connection confirms the results of more recent careful investigations into older systems of agricultural practice. Black fallow, as a rule, does not materially benefit the productiveness of an exhausted soil, . . .

These three plots had one thing in common in 1889, the first year of the new series. They had deteriorated markedly from their yields in 1883.

Plots 5 and 6 adjoined like Plots 1 and 2 and each had a check plot without nitrogen beside it. Plot 8 was separated from the other two by a check plot and had a check plot on the other side also. For years the individual yields of these plots were erratic. Sometimes one of the plots would yield less than the plot without nitrogen, which was beside it. Ultimately, the problem was solved. Bulletin 204 of this experiment station is devoted to these three plots in comparison with those without nitrogen, but the data will be included in this study.

Interest in fertilizers is centered primarily in their effects on plants, the measure of which is the yield by weight or volume of the portions of plants that have economic importance. The clearest presentation of a mass of data accumulated over a long term of years from a variety of crops is accomplished by grouping together the annual yields of one kind of crop and comparing the relative effects of the different fertilizers season by season.

Oats

Oats constitute the first group of crops because oats in 1890 were the first crop to follow the corn crop of 1889. Winter rye followed in 1891. Then in 1892 began a rotation in which soy beans alternated with oats for several years

with the object of building up the plots that did not receive nitrogen in fertilizer, because it had become definitely established that leguminous plants, of which the soy bean was one type, were able to use nitrogen from the air for their growth and their stubble and roots would thereby enrich the soil with the nitrogen contained in them. Consequently, the oat crops of 1893, 1895, and 1897 followed soy beans; the roots and stubble of which were left in the soil.

The effect of the first soy bean crop appeared beneficial, especially in the production of oat straw which was double the quantity produced in 1890. Nitrogen is regarded as a promoter of vegetation rather than fruit. The Plots 4, 7, and 9 were especially improved in both straw and grain.

The crop of 1895 showed no gains over 1893 in production of straw, except on Plot 8. This plot had received a dressing of 200 pounds of air-slaked lime the year before, which stimulated a larger yield of soy beans and apparently increased vegetation in the oats of this year. The yield of grain was larger than in 1893 on 8 of the plots, which included all the different kinds of fertilizer.

In 1897, the production of straw decreased on all but the nitrate plots, 1 and 2, and the yields of grain were less on all but Plot 8. Plots 4, 7, and 9 had shrunk in both grain and straw to a lower point than in 1890. The rotation with soy beans had not resulted in any permanent improvement in soil fertility.

Before sowing the oats in 1898, the entire field was limed with approximately 2000 pounds per acre of freshly slaked lime. The yields on all plots were much lower than in 1897 and excepting Plot 8 even less than in 1890. This is similar to the result of repeated crops of corn ending in 1889.

TABLE 2—YIELD OF OATS
(Pounds per plot.)

Plot	Form of nitrogen	1890		1893		1895		1897		1898*	
		Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
0	Manure	120	195	131	399	134	254	125	220	83	125
1	Nitrate	128	234	135	555	160	330	159	500	103	150
2	Nitrate	129	236	146	454	150	330	147	400	115	175
3	Organic	116	229	166	534	149	331	122	215	96	155
4	None	90	170	160	430	110	233	69	120	56	80
5	Ammonia	141	219	79	551	190	360	137	340	103	135
6	Ammonia	124	261	102	498	155	405	97	275	109	160
7	None	110	210	119	431	136	292	77	120	72	95
8	Ammonia	59	161	95	325	92	458	127	350	123	155
9	None	101	189	110	370	123	217	75	130	76	95
10	Organic	140	255	125	485	169	381	126	220	112	135

*Lime applied.

The comparative efficiency of the four different kinds of nitrogen fertilizers is not readily determined in these successive oat crops. There is but one manure plot against two plots with nitrate, two with blood and three with ammonia. Manure must necessarily stand by its one annual crop. The two nitrate crops may be averaged and also the two blood crops. It is problematical how to compare the ammonia crops fairly with the others. It has been thoroughly demonstrated that ammonium sulfate should have the benefit of the presence of calcium

carbonate in the soil in order to be most productive as a nitrogen fertilizer. The other kinds may or may not be more efficient in the presence of lime. During the years of this comparison of nitrogen fertilizers, ammonium sulfate did not uniformly have the conditions for good results. In some seasons, the material seemed to have been positively injurious. Therefore, for the purpose of this review the best two yields in each year are averaged for comparison with nitrate and blood.

The crops of oats in this group consisted of two distinct parts, grain and straw. The total of the two weights will be used as the standard for rating the different fertilizers, because nitrogen is especially effective in promoting growth. In this group of crops there were but two instances where grain and straw had to be combined for comparison. Ammonium sulfate was foremost in productiveness in 1890, 1895, and 1898. Sodium nitrate led in 1897 and blood was ahead in 1893. Manure was least effective. The ratio of grain to straw varied from year to year, being widest in 1893, the maximum year of both grain and straw, and narrowest in the year of least production, 1898. While variety of seed oats was changed from year to year, the trend of grain to straw indicated that a generous development of stem and leaf was necessary for a big crop of grain. There was no constant difference in ratios that could be attributed to any one nitrogen fertilizer, but the check plots without nitrogen had narrower ratios of grain to straw than any of the plots with nitrogen, which accords with the trend of the years.

Soy Beans

The next group of crops is soy beans, and consists of two subgroups. The crops of 1892, 1894, and 1896 were alternated with the oats previously discussed. A different variety was planted each year and the crop was cut for the silo and weighed green. The first crop was a late variety and did not reach the blossom stage. The second crop was an early variety and bore pods at harvest time. The third crop was a medium season type and was well filled with pods but was a much larger type of plant than the early one of 1894.

The most striking yields in these three crops are those without nitrogen. Soy beans were not apparently accomplishing much at obtaining nitrogen from the air. This was possibly due to the lack of the specific bacteria in the soil at this period, since soy beans had been introduced only a few years before.

The behavior of Plot 8 illustrates the benefit of lime as an accompaniment with ammonium sulfate. No better than plots without nitrogen in 1892, it responded to the liming of 1894, which carried it to the highest standing of all in 1896. Why Plot 8 was most frequently the least productive of the three plots treated with ammonium sulfate has never been solved.

Plot 10, supplied with nitrogen in dried blood, was apparently no better than the plots without nitrogen in 1892. In the report for that year, the suggestion was made that this might have been due to a scanty seeding, as it was the first plot to be sown with the seed drill.

The crops of 1901 and 1903 were preceded and followed by potatoes. The soy beans were matured and separated into seed and straw. Soy beans continued to respond to nitrogen fertilizers although by now the soil had become well inoculated with their specific bacteria. Dr. Brooks states in his report for 1901:

The development of nodules upon the roots of the crop this year was very abundant. In spite of this fact, . . . the crop on the no-nitrogen plots stands considerably below that on the other plots.

The inferiority of the crop of 1903 was due to the season, which was reported to be "highly unfavorable to the growth of the crop, which is one requiring protracted warm weather."

The relative effectiveness of the different nitrogen fertilizers is again difficult to measure. In the first year, 1892, the nitrate plots stood out as superior; but after Plot 8 was limed in 1894, the two best ammonia plots exceeded the nitrate plots both in that year and in 1896. In the matured crops of 1901 and 1903, the manure plot was slightly superior to the average of any other pair of plots. The ammonia plots in 1903 appeared to have lost the benefit of the liming, which all plots received five years earlier in 1898.

Brooks mentioned an interesting observation about the nitrate plots in his report for 1903:

It has been repeatedly noticed that where nitrate of soda is the source of nitrogen, the leaves, especially in the early stages of growth, assume a crinkled or wrinkled appearance, and fail to reach full size and normal development. . . . As the season advances, the soy bean plants as a rule show a more normal leaf development; and, although the crinkling this season was excessive, the yield on the nitrate of soda plots does not appear to have been materially decreased, as a consequence.

The ratio of seed to straw was nearly constant for the crops on manure, nitrate, and organic nitrogen plots, 1 : 1.41-1.45. Ammonia gave a wider ratio, 1.61 and 1.57, while without nitrogen the ratio varied from 1.50 to 1.67.

Soy beans, although a legume, were always benefited by nitrogen fertilizers; but no one of them was consistently most efficient.

TABLE 3—YIELD OF SOY BEANS
(Pounds per plot.)

Plot	Form of nitrogen	1892	1894	1896	1901		1903	
		Green	Green	Green	Seed	Straw	Seed	Straw
0	Manure	2210	600	1760	190	270	138	201
1	Nitrate	2290	625	1850	182	275	119	170
2	Nitrate	2290	700	1840	189	250	144	208
3	Organic	2090	525	1510	166	260	96	201
4	None	1440	405	1130	167	280	99	170
5	Ammonia	1935	645	1582	162	230	97	148
6	Ammonia	1970	615	1870	179	305	68	116
7	None	1430	480	1240	149	235	64	112
8	Ammonia	1450	680*	1980	167	255	86	139
9	None	1460	470	1060	162	220	51	75
10	Organic	1490	570	1530	192	260	126	122

*Lime applied.

Potatoes

Since potatoes were associated with the soy bean crops, their group will be discussed next.

The crop of 1900 followed a crop of mixed clover and grass, and consequently had a sod turned under as a preparation for it. The next two crops had only soy

bean stubble as residual organic matter. The fourth crop, in 1917, followed a heavy crop of Japanese millet which leaves a thick stubble and root mass, but presumably not as rich in nitrogen as the clover sod.

The crop of 1900 shows the value of a clover sod as a store of nitrogen. The plots without nitrogen, 4, 7, and 9, equal several of the plots which received those fertilizers, although the average yield is slightly lower than the other averages. The manure plot exceeds any of the averages.

The crop of 1902 was produced from two distinct varieties of seed; Plots 0, 1, 2, and part of 3 received a wholly different variety of seed from that used for the other plots. This may have caused the lower yields on these plots when compared with the rest of the field. Manure was noticeably superior to nitrate. Organic nitrogen was superior to ammonia, which at best was little better than no nitrogen.

In 1904, the manure plot again excelled all other plots. Ammonia again was little if any better than no nitrogen. Soy bean stubble is not equal to a clover sod as a supply of nitrogen for a following crop. Ammonium sulfate showed lack of accompanying lime. Plot 10 needs the following note, made in the report for 1904:

. . . the potatoes on this plot were covered by hand, while those on the other plots were covered by the use of the plow. The potatoes on this plot came up much more quickly and more vigorously than those on the others, and showed decided superiority in growth from the start.

The crop of 1917 was much superior to the crops of the earlier years, which may have been due to the abundant residual organic matter from the millet stubble. Brooks mentioned the value of organic matter in the soil for potatoes in his report on the crop of 1904, as follows:

Experiments in continuous potato culture . . . have shown in a striking manner the dependence of this crop upon the presence of a suitable proportion of organic matter in the soil.

Nitrate plots were definitely superior to the others, and organic nitrogen was not far behind.

These important results stand out with the potato crops here grouped: Nitrogen fertilizers were of comparatively little value following a clover sod; manure was superior to chemicals when the soil lacked organic matter; soy bean stubble was ineffective as a source of nitrogen.

TABLE 4—YIELD OF POTATOES
(Pounds per plot.)

Plot	Form of nitrogen	1900	1902	1904	1917
0	Manure	1399	1007	1669	1885
1	Nitrate	1198	861	1356	1899
2	Nitrate	1455	867	1326	2214
3	Organic	1153	1127	1062	1977
4	None	1387	1011	756	1890
5	Ammonia	1343	1002	1056	1599
6	Ammonia	1247	1218	696	1668
7	None	1268	1114	690	1458
8	Ammonia	1215	978	876	1644
9	None	1108	1013	1062	1464
10	Organic	1519	1369	1536	1914

Hay

Several crops of hay were produced in these experiments, but not in systematic rotation with other crops. Numerous efforts to secure a crop of clover are mentioned in the records of the field but repeatedly the stand was so reduced by winterkilling that the remaining plants were plowed under in the spring and an annual crop was substituted. The first hay crop reported was in 1899. Red clover had been sown after a crop of oats late in the previous August. The field had been limed before the oats were sown and the catch of clover was successful. The winter of 1898-99, however, injured it somewhat; April and May were unusually dry and the first crop was small. The season was favorable for the second cutting, which was made August 21. Considerable grass had appeared in all plots. Both crops are combined in the table.

Although limed the previous year, the ammonia plots were inferior to the other nitrogen plots. Manure produced the best crop.

The years 1907, 1908, 1909, and 1910 were devoted to attempts to grow clover. The field had been limed at the rate of one ton per acre in 1905. Peas and oats in that year and corn in 1906 had been the preceding crops. Alsike clover was sown in the corn. In April, 1907, additional alsike clover seed was sown. Two cuttings were made, July 17 and October 7, the second of which was small. The field was carried over to the next season, when in May, 1908, the records state that grasses were replacing clover and at the time of cutting, July 1, the plots contained mostly timothy and very little clover.

After the hay was removed, the field was plowed and harrowed. Alsike clover was sown on August 20. Late in November, there was a fairly uniform but thin stand of clover.

The crop of 1909 consisted principally of alsike clover, except on Plots 5, 6, and 8, where by actual weights the crops were half weeds, mainly sorrel. The field was plowed after the removal of the hay and on August 7 alsike clover was again sown. Previous to the seeding, an application of agricultural lime had been made to the east half of the field at the rate of 2500 pounds per acre.

In April, 1910, all plots had a good stand, but there was considerable grass mixed with the clover. As the season advanced timothy overtopped the clover. The hay was harvested on July 9.

These four seasons were notable for severe droughts during the growing season and a scanty rainfall for each year. The nitrate plots bore the heaviest crops in 1907; organic nitrogen gave a little the best yields in 1908; the two kinds were about equal in 1909; and in 1910, the ammonia plots responded to lime by practically equaling the other nitrogen plots in yields.

The crop of 1915 was seeded in the spring of 1914 with oats as a nurse crop. A mixture of timothy, red top, and red clover was used. After the removal of the oats, the clover predominated over the grasses, especially on the limed halves of the plots. The crop was not cut in the fall but permitted to remain as a protection to the roots. In the spring of 1915, the plots had passed the winter in excellent condition. Clover predominated except on the unlimed halves of ammonia Plots 5, 6, and 8, where red top constituted about half the crop.

The first cutting was made June 18, and the second on August 20. The season had been unusually dry in May, normal in June, and abundantly moist in July and August. Organic nitrogen and ammonia plots averaged nearly alike in productiveness and exceeded the average of the two nitrate plots.

TABLE 5—YIELD OF HAY
(Pounds per plot.)

Plot	Form of nitrogen	1899	1907	1908	1909*	1910	1915	1920	1921
0	Manure	508	375	430	415	695	805	351	500
1	Nitrate	443	445	630	565	767	850	542	524
2	Nitrate	422	450	570	440	700	775	538	534
3	Organic	345	355	590	415	660	830	449	535
4	None	336	405	340	395	640	845	343	590
5	Ammonia	342	325	358	437	722	770	539	468
6	Ammonia	375	272	215	420	700	835	457	431
7	None	343	385	463	315	675	783	305	561
8	Ammonia	407	300	505	450	680	820	670	590
9	None	421	325	465	375	705	700	296	524
10	Organic	456	504	635	590	715	835	582	505

*Lime applied.

The two successive crops of 1920 and 1921 represent a new arrangement of fertilizers and lime, described fully in connection with the corn crops. It is sufficient here to state that in 1919 the application of lime was made at the rate of 2000 pounds ground limestone per acre on the north half of each plot, except 6 which was left unlimed, and 8 which was limed throughout. Also the organic nitrogen fertilizers were changed at that time to cyanamid on Plot 3 and dry ground fish on Plot 10, because dried blood was no longer a common fertilizer but was in great demand as food for animals.

The crop of 1920 was seeded in the corn the summer before, and the crop of 1921 was the second from the same seeding. The crop consisted of mixed timothy, red top, and clover. Clover was the least of the three in proportion. Red top prevailed on the unlimed areas. The fertilizers had been applied as a spring top-dressing in each year.

There are two striking results in these two crops. The limed ammonia plots 5 and 8 are much superior to the other nitrogen plots in 1920 and equal to the best in 1921. Plots without nitrogen in 1921 excel all those with nitrogen and are much heavier than in 1920.

Corn

The corn crops were produced under varying soil conditions. That of 1906 followed oats and peas of the year before, but an attempt was made to seed the field with clover, after plowing under the stubble of the oats and peas. The clover was so much winterkilled that it, too, was plowed under in the spring of 1906, and corn was planted. The largest proportion of clover was on Plot 0 and the least on Plots 5 and 6. The manure plot is best this year, which may be due in part to the clover that was on this plot when plowed.

In 1911, the corn was grown upon a clover and timothy sod from the previous hay crop. In this year, the maximum yield was on the plots without nitrogen, and the ammonia plots were second. The crops of 1912, 1918, and 1919 followed tilled crops of the previous year. Plots without nitrogen were noticeably inferior. Nitrate plots and organic plots shared first and second places between them, alternating in standing with the years.

Some minor changes were made in the applications of fertilizers and lime in 1919. Up to this time, dissolved boneblack had been used continuously as the phosphoric acid fertilizer and dried blood as the organic nitrogen fertilizer. Both were no longer in common use. Acid phosphate, or plain superphosphate as dissolved rock phosphate was called, was now the standard source of phosphoric acid and was substituted for the boneblack. Dried blood was now in demand as a food for calves and pigs. A new synthetic nitrogen fertilizer, cyanamid, was introduced on Plot 3; and a standard organic substance, ground fish, was substituted on Plot 10. The application of fish carried with the nitrogen a small addition of phosphoric acid, which was ignored because there had always appeared to be a surplus of that plant food and the phosphoric acid in fish was less soluble than that yielded by superphosphate.

Lime had been liberally applied on the east half of every plot, and with most crops there was a sharp demarcation between the unlimed and limed areas. But a comparison of yield between the two halves was unfair because the east side of the field was definitely, though slightly, moister than the west half. In 1919, one ton per acre of ground limestone was applied to the north half of each plot except Plot 6 and Plot 8. These were duplicate plots with ammonium sulfate and it was deemed to be a better comparison of the value of lime as an accompaniment to ammonium sulfate with Plot 8 limed throughout and Plot 6 left without any addition.

The change in sources of phosphoric acid and organic nitrogen did not appear to alter the relative standing of the different fertilizers.

The proportions of weights of ears to weights of stover in the different corn crops indicate that the addition of nitrogen promoted the development of ears.

In 1883, the first year of these experiments, Longfellow flint corn was grown without fertilizer; the yields were fairly uniform on all the plots and the ratio of ears to stover averaged 1 : 1.8.

In 1889, the first year of the comparison of nitrogen fertilizers, Plots 7 and 9 without nitrogen bore small quantities of ears, while the weights of stover were equal to those on the nitrogen plots. The proportions of ears to stover on 7 and 9 were respectively 1 : 12 and 1 : 7, while the crops on the nitrogen plots had an average ratio of 1 : 2.3. Plot 4, also without nitrogen, differed somewhat from Plots 7 and 9. Its crop was somewhat heavier in weight of ears, but much less in stover, and the ratio was 1 : 3.

Plot 4 had been without fertilizer of any kind until 1889, while Plot 7 had received phosphoric acid and potash, and Plot 9 had received potash. Plot 4 had borne about one-third as much fodder as had been produced on 7 and 9, due to the lack of available potash. In 1889, the latter plots had exhausted their soil nitrogen more than Plot 4, while accumulating available potash. The failure to produce ears when nitrogen is lacking was noticeable. The need of potash to produce growth was also apparent.

Subsequent corn crops corroborated the relation of nitrogen to ear production. Rustler dent corn was grown in 1906, 1911, and 1912. The crop of 1911 was grown upon a clover sod, which supplied all the nitrogen that the different plots needed, and the proportions of ears to stover were nearly uniform around 1 : 0.9. The following year, 1912, the ratios separated a little and averaged 1 : 0.85 with the nitrogen plots and 1 : 1.05 for the plots without nitrogen. The crop of 1906 had wider differences between the two groups of plots, with an average ratio 1 : 1.1 for the nitrogen plots and 1 : 1.7 for the other group.

Longfellow flint corn was planted in 1918 and 1919. In the former year, ratios of ears to stover were transposed. The average for the nitrogen plots was 1 : 1.6 and for the plots without nitrogen the ratio was 1 : 1.4. Plots 7 and 9 in 1919 returned to the usual form. The average ratio of all nitrogen plots was 1 : 1, while the ratio was 1 : 1.2 for those two plots. Plot 4 was quite out of line, with a larger weight of ears than of stover. The weather conditions in 1918 were unusually hot and dry in July and August with the latter month slightly hotter than the former. Lack of water lessened growth on plots without nitrogen and produced an abnormal proportion of ears and stover.

TABLE 6—YIELD OF CORN
(Pounds per plot.)

Plot	Form of nitrogen	1906		1911		1912		1918		1919	
		Ears	Stover	Ears	Stover	Ears	Stover	Ears	Stover	Ears	Stover
0	Manure	721	650	497	475	650	500	454	685	473	430
1	Nitrate	525	630	500	485	690	640	479	905	530	615
2	Nitrate	588	610	472	465	637	500	525	330	530	600
3	Organic	504	600	590	480	610	545	551	990	452	480
4	None	336	620	580	535	485	465	406	530	448	375
5	Ammonia	504	540	575	470	571	485	450	595	516	425
6	Ammonia	504	535	576	470	533	510	442	680	423	415
7	None	315	535	531	490	484	550	425	630	333	410
8	Ammonia	518	593	510	460	573	545	501	790	484	530
9	None	315	560	576	515	490	520	428	590	347	430
10	Organic	490	580	506	485	602	545	534	855	606	500

Miscellaneous Crops

Five different crops are grouped as miscellaneous crops because none of them fitted well into the other groups.

The only crop of rye grown during these fertilizer experiments was in 1891. Winter rye was sown the fall before, after a crop of oats was harvested and the stubble plowed under. The latter part of the winter was unfavorable to winter crops. Plot 8 was badly injured by insects and was omitted from the records for the year. Nitrate was the outstanding fertilizer for yield of both grain and straw.

Oats and Canada peas formed the crop in 1905, one of the years in which the entire field was limed. This time there was applied one ton per acre of freshly slaked lime. The growth on all the plots that received nitrogen was very rank, and heavy rains caused lodging of the crop and without doubt decreased their yields. Liming improved the relative standing of the best two ammonia plots, 6 and 8, and they were but a little inferior to the nitrate plots. The introduction of the peas as a legume did not raise the standing of the plots without nitrogen.

Oats grown in 1914 as a nurse crop for clover and grasses were cut early for hay, as was the crop of oats and peas just discussed. Nitrate was again the leading nitrogen fertilizer, and ammonia was a little superior to organic nitrogen. One-half of every plot had been limed the previous year, so that conditions were similar to those of 1905.

Japanese millet was seeded in 1913 and cut for hay. The liming of one-half of each plot brought the ammonia plots to the front in yield, with organic nitrogen a good second. This kind of millet was grown in 1916 and was matured and separated into seed and straw. The conditions were somewhat unlike those of 1913, when the millet followed two successive crops of corn. This year, the millet had been preceded in 1915 by an exceptionally good clover crop, the sod of which had been plowed under and on which potatoes had been planted before sowing the millet. Defective seed caused a very uneven stand of potatoes, which were plowed under and the millet substituted.

Estimation of the efficiency of the different nitrogen fertilizers was puzzling. Manure produced the highest yield of seed, while ammonia plots 6 and 8 bore the smallest quantity. But total crop of seed and straw were practically equal. Nitrate plots and organic nitrogen plots bore a similar relation to one another. Plots without nitrogen were nearly as good in yield as those with nitrogen. There may be noted in this crop the influence of the previous clover crop on the nitrogen supply by the narrow gap between the plots without nitrogen and those with it.

TABLE 7—YIELD OF MISCELLANEOUS CROPS
(Pounds per plot.)

Plot	Form of nitrogen	1891		1905*	1913*	1914	1916	
		Rye		Oats and Peas	Japanese Millet	Oats	Japanese Millet	
		Grain	Straw	Hay	Hay	Hay	Seed	Straw
0	Manure	142	328	495	900	265	152	498
1	Nitrate	154	416	690	985	400	121	488
2	Nitrate	134	391	700	915	305	112	458
3	Organic	130	345	670	1005	320	94	550
4	None	107	283	435	730	190	115	470
5	Ammonia	145	385	565	1020	230	103	477
6	Ammonia	102	298	660	1120	290	87	588
7	None	109	341	480	670	205	83	562
8	Ammonia	.....	.....	690	1220	335	88	586
9	None	109	316	390	870	200	102	538
10	Organic	125	300	650	1020	285	87	547

*Lime applied.

AN ECONOMIC VIEW OF THE EXPERIMENT

A fertilizer experiment, of the kind on Field A, is made to ascertain the effects of definite forms of fertilizers from which may be deduced plans for cropping and manuring that will be economical.

Did the crops grown on Field A use all the fertilizer that was applied each year? The question can be partially answered by calculating the amounts of fertility removed year by year in the harvested crops. Some of the crops grown on these plots were analyzed and numerous analyses have been made of the same kinds of crops grown on other fields of the experiment station. The data have been used to calculate the amounts of nitrogen, phosphoric acid, and potash contained in the crops during the years from 1889 to 1921, including 33 harvests.

The crops are estimated to have removed from each of the plots receiving sodium nitrate, 228 pounds of nitrogen, while they had each received a total of 148.5 pounds of that element, or 79.5 pounds less than the crops removed. The amount of nitrogen carried away from each of the plots that did not receive any was 174 pounds, which is double the deficit of nitrogen on the sodium nitrate plots; therefore it appears that the latter plots received at least as much nitrogen as the crops could use. The crops on other forms of nitrogen fertilizers as a whole did not remove as much nitrogen as those grown on sodium nitrate.

The amounts of phosphoric acid and potash that were applied to these plots were assumed to be more than enough to supply the crops that could be grown with the nitrogen used. The amounts of these elements removed in the different crops have been calculated in order to learn whether there was any shortage of either at any time.

It was found that the heaviest yield of hay in 1910 removed 13.5 pounds potash and 3.7 pounds phosphoric acid; Japanese millet in 1913 carried away 19.3 pounds potash and 2.9 pounds phosphoric acid; clover in 1915 contained 20.5 pounds potash and 4 pounds phosphoric acid.

The yearly application of chemicals contained 12.5 pounds potash and 8 pounds phosphoric acid for each plot. There is no doubt that the latter was supplied in plenty. With regard to potash, the majority of harvests removed much less than was applied; for example, the largest crop of oats contained 7.5 pounds potash, corn removed 9 pounds potash, four successive crops of hay, 1907, 1908, 1909, and 1910, removed 43 pounds potash and 50 pounds were applied. Since potash is not leached readily from the soil, as a rule there was a surplus of it present for the occasional heavy demand.

Measured by crop yields, manure was the superior source of nitrogen in seven of the years and shared first place with ammonium sulfate in one. The crops were hay, potatoes, soy beans, corn and Japanese millet. One condition affected these crops in common. They were growing throughout the summer season and could utilize the manure nitrogen as it became available. The hay crop may not usually be regarded as a summer crop, but in this instance Brooks, in his report for 1899, stated:

It is perhaps questionable whether much weight should be attached to the yields at the first cutting, since full development was not reached on account of drought. The rowen gives a better basis for comparison.

Sodium nitrate was superior with eleven crops and shared with organic nitrogen once. Its superiority was shown with all the different kinds of crops except Japanese millet, and it may be regarded as the generally efficient nitrogen fertilizer.

Ammonium sulfate was superior in seven harvests, while it shared superiority once with organic nitrogen and once with manure. In five of these seasons, lime had been recently applied.

Organic nitrogen led the other forms in only three harvests, while it shared the lead once with nitrate and once with ammonia. In four of these seasons the rainfall was below normal; while in that in which it shared first place with ammonium sulfate, a dry spring was followed by drenching summer rains, which apparently washed all sodium nitrate down beyond the root level.

Plots without nitrogen produced in 1911 larger yields of corn, both ears and stover, than any of the plots with nitrogen fertilizers. The corn followed a crop

of clover and timothy, the roots and stubble of which had accumulated so much nitrogen that additional nitrogen in fertilizers had no effect. The summer was exceptionally hot and normally moist, which was especially favorable for corn.

In 1921 the plots without nitrogen were again superior in the production of clover hay, the second year from seeding. This unusual result is explained as follows: The new seeding in 1920 consisted of clover, timothy, and red top. In that season the active nitrogen of sodium nitrate and ammonium sulfate pushed forward the grasses which smothered the clover. Grasses were not encouraged in the absence of nitrogen, and the clover gained its foothold, so that its second year's growth on the plots without nitrogen outstripped the grasses on the plots with nitrogen.

The economic possibilities of the application of nitrogen are shown by comparing the average harvest from all plots with nitrogen against the average harvest of all plots without nitrogen. The crops chosen for this comparison were shelled corn, seed oats, potatoes, and hay. These products are standard money crops and have definite market values. The various other crops grown on these plots are important, but are usually consumed on the farm and therefore are difficult to evaluate.

The average gain per plot as the result of applying nitrogen to oats was small, and ranged from only 5 pounds in 1893 to 50 pounds in 1897. During this period oats alternated with soy beans. The first rotation appeared to make additions of nitrogen of little value, but continuous repetition made it necessary. The average result of five harvests was a gain of barely one bushel of oats to pay for applying 4.5 pounds nitrogen. Since the nitrate was, as a rule, the most effective form and at the present time one of the lowest in price, the added nitrogen for oats may be worth while. It should be mentioned that climatic conditions at this experiment station are not favorable to maximum yields of oats.

The application of nitrogen to the corn crop in 1911 gave no gain in shelled corn. This corn crop followed clover and grass. The accumulation of nitrogen in the turf was all that the crop required. The largest gain from nitrogen was in 1906 when corn followed several successive annual crops, which tended to exhaust rather than increase organic matter in the soil. The gain in this year was 177 pounds, or a little more than 3 bushels. Other gains ranged from one bushel to barely two per plot. Corn needs nitrogen when following tilled crops.

Potatoes in 1900, planted on a clover sod, showed an average gain per plot of 62 pounds or about one bushel. Following soy beans in 1904 and Japanese millet in 1917, there were gains respectively of 361 pounds and 243 pounds. These gains would more than pay for 4.5 pounds of nitrogen. Eight crops of hay showed gains from the use of nitrogen which ranged from nothing when the crop was all clover to 201 pounds when grasses constituted most of the harvest.

Keeping up the nitrogen of the soil in this field appeared to depend on the choice of crops and rotations, when the records of Plots 4, 7, and 9 are considered. In 1883, the soil was that of a "run out" hay field. Corn was grown without fertilizer of any kind. These three plots gave an average yield at the rate of 29 bushels of shelled corn and 3700 pounds of stover. Cropped with corn year after year, these three plots without any nitrogen had dwindled in 1889 to 9.3 bushels per acre. Soil nitrogen appeared to be exhausted. These plots in 1899, after ten more crops of various kinds had been grown on them without nitrogen, bore a crop of clover hay averaging 3660 pounds per acre. The next year they produced potatoes at the rate of 209 bushels per acre. After ten more years,

in 1910, these plots bore a crop of mixed clover and timothy hay at the rate of 6730 pounds per acre, followed in 1911 by a crop of corn at the rate of 83 bushels of shelled corn and 5130 pounds stover per acre, which was slightly more than was produced on the plots which had been receiving 45 pounds of nitrogen in fertilizers every year.

The practical aspect of these experiments may be more clearly perceived by expressing the amounts of the fertilizers in pounds per acre. On this basis the rate per acre for each plot was 45 pounds nitrogen, 80 pounds available phosphoric acid, and 125 pounds potash, which is equivalent to 1200 pounds mixed fertilizer containing 3.75 per cent nitrogen, 6.5 per cent available phosphoric acid and 10 per cent potash. This is a heavy application to be made yearly to some of the crops grown on these plots.

Farm manure was used at the rate of 8000 pounds per acre, or about four loads, and was supplemented by 500 pounds per acre of chemicals containing 6 per cent phosphoric acid and 16 per cent potash. The records of this plot show that manure may be advantageously spread thin when reinforced by superphosphate and potash.

The records indicate that for corn, oats, and hay in a suitable rotation, it would be economical to make a reduction in the amounts of fertilizer to be used, and this would necessitate re-arrangement of the experiment.

EFFECT OF LIME WITH NITROGEN FERTILIZERS

Rearrangement of the application of lime in 1919, by dividing each plot lengthwise, permitted a fair comparison of lime with no lime in relation to the different forms of nitrogen.

Two years, 1919 and 1920, supplied the data, with crops of corn and hay. The different nitrogen fertilizers are compared by averaging the crops from the separate plots. The crop from the manure plot is averaged with those from the organic nitrogen plots.

Liming the nitrate plots was ineffective with corn and barely helpful with hay. It notably increased the yield of ears with the corn crops on the organic plots and on those without nitrogen. The hay crop was also improved.

Liming the ammonium sulfate plots increased the yields of both ears and stover with corn, while the hay crop actually exceeded that on the nitrate plots. Red top was the prevailing grass on the unlimed areas, but timothy and clover grew freely on the limed areas and displaced it.

TABLE 8—COMPARISON OF LIMED AND UNLIMED AREAS
(Yields in pounds per half-plot.)

Form of nitrogen	Corn—1919				Hay—1920	
	Ears		Stover		Limed	Unlimed
	Limed	Unlimed	Limed	Unlimed		
Nitrate	255	274	297	310	276	264
Organic	281	232	238	232	262	198
Ammonia	251	223	255	202	324	231
None	201	175	203	202	177	138

These results of the application of lime are due primarily to the chemical reaction between the lime and the acids of the soil. Lessening the acidity favors the growth of the bacteria that change the nitrogen of organic matter and ammonia into nitrates, which are the most available of nitrogen fertilizers.

Another important effect is produced by the reaction of lime with the ammonium sulfate, which forms calcium sulfate, a substance sometimes found to be beneficial and always harmless; while if lime is absent, ammonium sulfate forms other sulfates with the soil minerals, that are often injurious, particularly to clover, timothy, and corn. Several bulletins of this experiment station describe this behavior of ammonium sulfate.

Lime was not applied in uniform quantities every year like the superphosphate and potash but at infrequent intervals in amounts of 2000 pounds or more per acre. Calcium carbonate dissolves very slowly in the soil water, yet the rainfall will gradually carry it down below the surface soil. Calcium sulfate is more soluble than the carbonate, from which it is formed by ammonium sulfate; therefore plots fertilized with ammonium sulfate will lose the benefits of liming most quickly. To show how the effects of liming wore away, a comparison is made year by year between the average yields of the sodium nitrate plots, 1 and 2, and the averages of the ammonium sulfate plots, 5, 6, and 8.

The comparison is graphical in form, with the yields on the nitrate plots set always at 100, while the ammonium sulfate yields are proportional. It is begun with the crop of 1897, though Plot 8 had been limed in 1894. The effect on this had nearly disappeared but its results led to the application of lime to all plots in 1898, and in subsequent applications all plots were treated alike.

The use of different kinds of crops in the experiment was partly responsible for the fluctuations in production on the two sets of plots; but it should be noted that the deepest depressions occurred from three to five years after an application of lime. A positive rise from the depression took place with the application of lime, except in 1919, when it occurred in the following year.

Because agricultural lime in its different forms is a low-priced commodity in comparison with nitrogen fertilizers, it has been customary to apply it at the rate of one ton or more per acre at intervals of several years. The graph indicates that greater efficiency of ammonium sulfate as a nitrogen fertilizer may be secured by more frequent applications of a smaller quantity of lime at a time.

SUMMARY AND CONCLUSIONS

Field A was laid out in 1883 on "run out" hay land and included eleven plots of one-tenth acre each.

Seven successive crops of corn were grown from 1883 to 1889, to study the effects of different forms and kinds of plant food. The earlier harvests showed potash to be the most needed fertilizer; the later ones indicated that a complete fertilizer had become necessary.

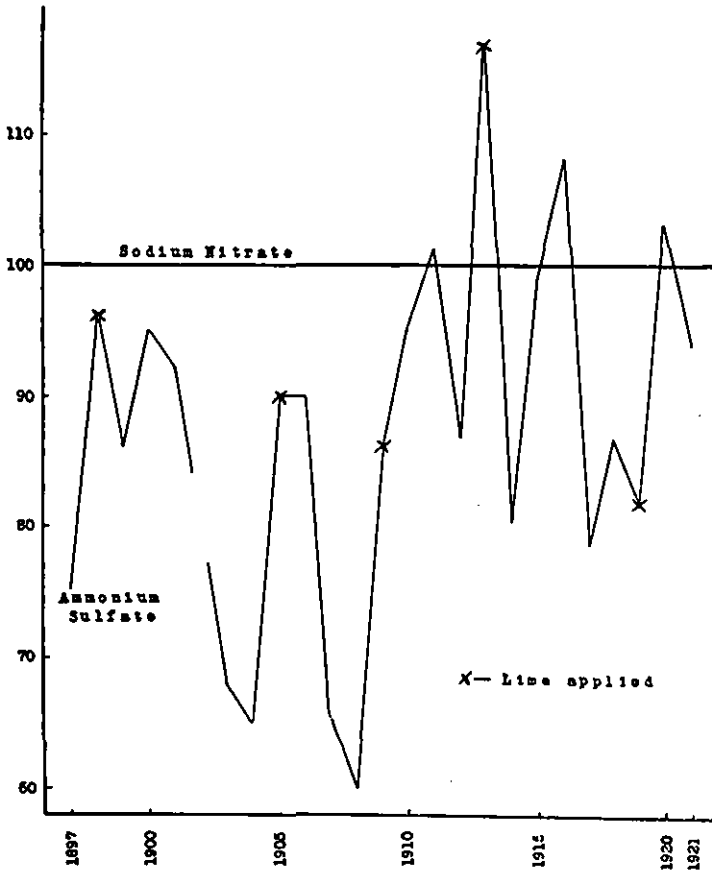
Four standard types of nitrogen fertilizers—nitrate of soda, sulfate of ammonia, dried blood or fish or cyanamid, and stable manure—were compared in 1889, and the comparison was continued with minor changes until 1921.

A variety of crops was grown, and tables show results obtained with oats, soy beans, potatoes, hay, corn, and miscellaneous crops.

When Field A was planned, the use of nitrogen from the air by plants was considered to be doubtful. By 1889, it had been shown that leguminous plants

Effect of Lime as an Accompaniment to Ammonium Sulfate

The yearly ratios between yields of dry matter on sodium nitrate (rated at 100) and on ammonium sulfate are presented graphically.



were using it with the aid of specific bacteria. Early in the present century it was established that nitrogen compounds were formed from air by certain bacteria in the soil, without the presence of leguminous plants.

The early corn crops indicated that "run out" hay land contained a stock of nitrogen which had been accumulated without nitrogen fertilizers.

In 1911, following four successive years of clover and grass, the plots without nitrogen fertilizers led all others in their average yields of corn and stover. In the last year of the experiment, clover hay was heaviest on these plots.

Nitrogen fertilizers were most effective when a tilled crop followed a tilled crop.

Measured by crop yields, sodium nitrate was most frequently in the lead. Ammonium sulfate required the presence of calcium carbonate in the soil to be most effective. When recently limed, the ammonium sulfate plots were virtually equal to the sodium nitrate plots. Farm manure, supplemented with phosphate and potash, excelled several times with crops which made their growth in summer. Organic nitrogen was superior in three seasons.

When this comparison of nitrogen fertilizers was begun, the manufacture of nitrogen compounds from nitrogen in air was impractical because of high cost. At the close of the comparison, such compounds were being made in enormous quantities. At the present time, synthetic fertilizers are being produced from atmospheric nitrogen at such low cost that those used in these experiments may become obsolete in practical agriculture.

The value of Field A to agriculture is its history of the diversity of results. Back of any subsequent work upon it are authentic records of each plot, of which no similar records were to be had when the field was laid out.

There is now nearly ended a comparison of a succession of graminaceous crops with rotations in which such crops alternate with legumes. The experiment is directly dependent upon the records of the plots without nitrogen, from which more nitrogen has been removed in crops than adjoining plots have received in fertilizers.

Field experiments should be planned primarily to afford the investigator an opportunity to test under practical conditions, on a small inexpensive scale, those theories, principles, and processes which have been developed under controlled conditions in the laboratory and vegetation house. To depend upon such experiments to furnish the information and data upon which practices and theories may be based and developed is not justified and is sure to prove disappointing. Where such work has been continued for a long period of years without change, it has resulted in the accumulation of a large mass of records which could not be interpreted in terms of much agronomic value. An intelligent program requires variation in the details of treatment and management in conformity with the changes in economic conditions operating in those relationships.

(The main redeeming feature in the plan for field investigation as developed at Massachusetts State College is the evidence of sufficient courage on the part of those in authority to be willing to change the program from time to time to keep pace with new developments in farm and industrial practice. Had it not been for such courage, the few conclusions possible after this fifty-year period of detailed and accurate work would, no doubt, have proved more limited. F. J. S.)