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SOIL TREATMENT FOR WHEAT ON THE POORER LANDS OF THE ILLINOIS WHEAT BELT

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An average yield of wheat of **29 bushels on treated soil** and of **9 bushels on untreated soil** is the record of the Illinois Experiment Station for 1905 on four soil experiment fields located in three different counties in southern Illinois.

Expense and Profit

This wheat was grown in regular rotation in the Illinois Wheat Belt, on land valued at less than $40 an acre. The rotations include only one crop of wheat during three or four years, and at least one legume crop is also grown in the rotation; and yet, with this rotation and on a soil naturally well adapted to wheat growing and once famous for its wheat producing power, only 9 bushels of wheat were produced in a good wheat year; but where proper soil treatment was applied the average yield was increased to 29 bushels per acre. The increase of 20 bushels at 70 cents a bushel is worth $14.00 an acre. The total annual expense for materials used in the soil improvement is not over $3.00 an acre, so that the increase from soil treatment in this one wheat crop is sufficient to more than pay the total expense for materials for four years, which is a sufficient length of time for a good crop rotation. It is believed, moreover, that this expense for materials can be reduced to $1.70 a year, and still maintain a system of soil treatment under which the land will grow richer year by year.

Methods Employed

The methods by which these results have been obtained consist of crop rotation, including a liberal use of legumes, such as clover, cow peas, or soy beans, both as catch crops and as regular rotation crops, by which the soil is enriched in nitrogen and humus; also the addition of sufficient lime or ground limestone to correct the acidity of the soil in order to encourage the development and activity of the nitrifying and nitrogen-fixing bacteria; and the application of sufficient steamed bone meal to supply the phosphorus required for large crops.

Crop Rotations

The following four-year or five-year rotation is found to be one of the most satisfactory crop rotations for southern Illinois.

First year, Corn, with cow peas, soy beans, or clover seeded as a catch crop when the corn is "laid by."

Second year, Cow peas or soy beans, to be followed by wheat seeded in the fall.

Third year, Wheat, with clover seeded in the spring.

Fourth year, Clover, the first crop to be cut for hay and the second crop to be cut for hay or for seed or to be pastured or plowed under as green manure. (The catch crops may be pastured with hogs or other stock if practicable.)

In practicing a four-year rotation the farm should be divided into four nearly equal fields so that every crop may be grown every year. Thus, on an 80-acre farm there would be 20 acres of corn, 20 acres of cow peas or soy beans, 20 acres of wheat, and 20 acres of clover, and every year there should be 20 acres of clover ground to be plowed for corn, and 20 acres of cow pea or soy bean ground to be seeded to wheat.

If any crop fails some other similar crop should be substituted which will not seriously interfere with the rotation. Thus, if wheat winter kills, oats may be seeded in the spring and the clover seeded with the oats, and if the clover fails, cow peas or soy beans may be substituted for clover that season.

If there is no permanent pasture land on the farm, timothy may be seeded with the clover and the rotation extended to five years, the land being pastured the fifth year.

The Use of the Crops

The wheat may be sold and also some clover seed, and some cow peas or soy beans, and if necessary some corn; but all hay and forage and most of the corn and sometimes the cow peas or soy beans should be fed on the farm, plenty of bedding being used and all manure being carefully returned to the land, preferably as soon as possible after it is made. It may well be spread on the meadow or pasture land which is to be plowed for corn. (Attention is called to the fact that two-thirds corn and one-third soy bean meal has been found by the Indiana Station to be a very satisfactory and profitable ration for hogs. Some Illinois feeders have obtained very good results by substituting soy bean meal for bran and oil meal in beef production.)

The Use of Limestone

On the ordinary upland soil between the Wabash and Kaskaskia rivers and south of the Shelbyville moraine (which marks the boundary line between the black soil of the corn belt and the gray soil of the Illinois wheat belt), at least two tons to the acre of ground limestone should be applied as the initial application. Afterward one ton to the acre every four to six years will probably be sufficient to keep the soil sweet.

It is thought best to apply the limestone between the time of plowing for corn and the time of plowing for cow peas or soy beans. Any other form of lime may be used in place of ground limestone if it can be obtained more cheaply, provided ample provision is made to maintain the supply of organic matter in the soil.

The Use of Phosphorus

For quick results, steamed bone meal may be used. This applies especially to drilling in bone meal with the wheat in the fall on land which has received no phosphorus in previous years. It is now believed, however, that it is even more profitable to apply the phosphorus in the form of raw rock phosphate, using liberal quantities and either spreading it with the manure or scattering it over the meadow or pasture land to be plowed under for corn together with as much organic matter as possible. The decaying organic matter helps to liberate the phosphorus and thus make it available for the corn and other crops. On the other hand if lime and phosphate are applied together in intimate mixture, the lime tends to retard the availability of the phosphorus by holding it in an insoluble form. Because of this, it is advisable to apply the limestone some time after the phosphate has been plowed under.

As a rule, either 600 to 800 pounds of steamed bone meal or 1200 to 1500 pounds of raw rock phosphate should be applied once every four or five years. These materials are about equally rich in phosphorus, but the raw rock phosphate is much less readily available than the steamed bone meal; consequently it should be applied in larger amounts, at least for some time, and special care should be taken to thoroughly mix it with the soil and to plow it under with decaying organic matter, preferably several months or a year before marked effects from it are expected.

These amounts of raw rock phosphate are more than sufficient to meet the needs of maximum crop yields, so that under this system the soil grows richer and richer, not only in nitrogen and humus, furnished by the legumes, but also in phosphorus, this element being more deficient than any other in this soil, especially for the wheat crop, as a careful study of the following tables will show.

Cost of Soil Treatment

If we allow 50 cents an acre a year for ground limestone, after the heavy initial application has been made (the cost of which should be added to the value of the land), one ton costing about $2.20 to $2.50 delivered in carload lots at most railroad stations in southern Illinois, and $2.50 an acre a year for the cost of 200 pounds of steamed bone meal (assuming 800 pounds of this material, costing $25 a ton, are to be used every four or five years), we have an annual expense of $3.00 an acre for the cost of materials. It is assumed that the seed for legume catch crops will be raised on the farm, and the pasturing of such crops should pay for seed and seeding. Thus we have an annual expense per acre of $3.00 for materials if the phosphorus is applied in steamed bone meal.

If, however, instead of using 800 pounds of steamed bone meal, we finally substitute 1200 or (in a five-year rotation) 1500 pounds of raw rock phosphate, to be applied once in the rotation, assuming the rock phosphate can be procured at $8.00 a ton, the present price at most points, the annual expense for phosphorus will be reduced to $1.20, thus reducing the total annual expense for materials to $1.70 an acre.

Unprofitable Methods

As a rule the greatest difficulty to be overcome in the introduction of a more intensive system of agriculture by which larger crops and greater profits are to be made with practically no increase in labor, is for the farmer to persuade himself to hold fast to a good rotation of crops and to continue to make good use of all obtainable farm manure, by which means alone can we hope to maintain sufficient nitrogen and humus in the soil. Too frequently it happens, that as soon as the farmer discovers that he can double his wheat yield by a liberal use of phosphorus, he immediately discards his rotation of crops and the use of farm manure and tries to grow wheat almost continuously, year after year, with the inevitable result that in his greed and ignorance he soon reduces his land to such a condition that even the wheat crop again becomes a failure.

Neither ground limestone, nor steamed bone meal, nor raw natural rock phosphate will ever injure the land, but the benefit to be derived from the use of those materials alone is temporary in continuous wheat growing, and no profitable and permanent system of agriculture can be adopted for Southern Illinois which does not include a rotation of crops with a liberal use of legumes, and it is exceedingly good practice to make and use as much farm manure as possible.

Four Years' Results in Wheat Growing

The following tables will give all of the wheat yields which have been obtained during the past four years on four soil experiment fields in southern Illinois, under the different systems of soil treatment indicated. It will be noted that no farm manure has been used in any of these systems of soil treatment (although it is being used on certain other plots), and it should also be borne in mind that if southern Illinois soils are ever to be made as rich and as productive (for the crops to which they are adapted) and as valuable as the black soils of the corn belt in central Illinois (and this is not impossible), it must be done without any large initial supply of farm manure, for the simple reason that no such supply exists, nor can it be made from the crops now being grown in southern Illinois, especially under the present ruinous practice of raising timothy as the principal hay crop and even shipping that out of the state.

It is sometimes more popular than practicable to talk about the possibilities of soil improvement with farm manure, when there is no manure.

The Odin Soil Experiment Field

The Odin soil experiment field is located on the west side of the Illinois Central Railroad, about one mile southwest of Odin, Marion County, on the farm of Col. N. B. Morrison. The original field contains 40 fifth-acre plots, arranged in four series (100 to 400), of 10 plots each, one-half of each series (plots 1 to 5) is not drained, while the other half (plots 6 to 10) is tile-drained. Plots 1 and 2, especially in series 300 and 400, are better land than the average, being on the lower side of the field. All the remaining plots are believed to be fairly uniform. A four-year rotation is being practiced on this field. The four series of plots make it possible to have every crop growing every year. During the first four years the rotation has been corn, oats, wheat, and cow peas, with catch crops of cow peas in the corn and after the wheat and oats, on all plots receiving legume treatment. Furthermore, the full crop of cow peas has been plowed under during the first four years on all plots receiving legume treatment, but as yet the only wheat crop which has been grown where a regular rotation crop of cow peas has been turned under was in 1905 on the 400 series where a full crop of cow peas was plowed under in 1902 (excepting of course on plots 401 and 406 where the crop was harvested and removed.) After the first four years, all regular legume crops are to be harvested. On the untreated plots, Nos. 1 and 6 in each series, no legume catch crops are grown and the regular cow pea crops have been harvested and removed from those plots.

TABLE 1. WHEAT YIELDS FROM ODIN SOIL EXPERIMENT FIELD

Soil plot Nos.	Gray silt loam prairie of the Lower Illinois Glaciation.	Wheat, bushels per acre.					
		1903, Series 200.		1904, Series 300.		1905, Series 400.	
	Soil treatment.	Total yield.	Bu. increase.	Total yield.	Bu. increase.	Total yield.	Bu. increase.
	Land not tile-drained.						
1	None	**.4**	.0	**7.9**	.0	**15.2**	.0
2	Legume	.6	.2	5.4	−2.5	16.6	1.4
3	Legume, lime	.7	.3	10.7	2.8	24.8	9.6
4	**Legume, lime, phosphorus**	5.8	**5.4**	21.6	**13.7**	36.5	**21.3**
5	Legm., lime, phos., potassium	14.0	13.6	24.4	16.5	35.8	20.6
	Land tile-drained.						
6	None	**.6**	.0	**6.7**	.0	**10.8**	.0
7	Legume	.6	.0	8.5	1.8	18.7	7.9
8	Legume, lime	2.1	1.5	9.6	2.9	23.9	13.1
9	**Legume, lime, phosphorus**	13.4	**12.8**	21.5	**14.8**	35.3	**24.5**
10	Legm., lime, phos., potassium	15.2	14.6	25.4	18.7	28.4	17.6

After this season, cow peas are to be substituted for oats, and red clover for the cow peas in the rotation at Odin, thus making the four-year rotation as follows:

First year, Corn (with cow peas or clover as catch crop).

Second year, Cow peas (with wheat to be seeded in the fall).

Third year, Wheat (with clover to be seeded in the spring).

Fourth year, Clover.

Table 1 gives all of the wheat yields which have been obtained from the Odin soil experiment field.

The figures in **bold face** type show the yields produced by the untreated land and also the **increase** in yield produced by legume-lime-phosphorus treatment, which is the treatment recommended for general use on this soil. It will be observed, for example, that on the undrained series in 1904, plot 304, with legume-lime-phosphorus treatment, produced 21.6 bushels of wheat per acre, of which 7.9 bushels are to be credited to the land and 13.7 bushels to the treatment. On the corresponding tile-drained plot (No. 309), 21.5 bushels per acre were produced, of which 6.7 bushels are to be credited to the untreated land and 14.8 bushels to the treatment. Of this 14.8 bushels increase, 1.8 bushels are due to the legumes, 1.1 bushels to the lime, and 11.9 bushels to the phosphorus.

It should be borne in mind that plots 301 and 401 are naturally somewhat better soil than the other plots in the field, as will be seen by comparing the yields from those plots with the yields from the corresponding plots (306 and 406) on tile-drained land.

The Cutler Soil Experiment Field

The Cutler soil experiment field is located about five miles northwest of Cutler, Perry County, on the farm of Mr. W. E. Braden. The original field contains 40 fifth-acre plots. Thirty of these are in three divisions of ten plots each, for a three-year rotation of wheat, corn, and cow peas. On certain plots a catch crop of cow peas is also grown after the wheat and with the corn. The other 10-plot series is used for a "complete fertility test," some nitrogen having been purchased for use on this field. A four-year rotation of corn, oats, wheat, and clover is followed on this series. None of the Cutler field is tile-drained. The soil treatment and wheat yields for the individual plots are shown in Tables 2 and 3.

TABLE 2. WHEAT YIELDS FROM CUTLER SOIL EXPERIMENT FIELD
(Land not tile-drained)

Soil plot Nos.	Gray silt loam prairie of the Lower Illinois Glaciation.	Wheat, bushels per acre.			
	Soil treatment.	1902, Series 221–230. Total yield.*	1903, Series 201–210. Total yield.	1904, Series 211–220. Total yield.	1905, Series 221–230 Total yield.
1	None	**12.8**	**6.0**	**9.0**	**8.7**
2	Legume, lime	12.4	9.2	8.5	12.8
4	Legume, lime	13.3	13.5	8.8	13.8
6	**Legume, lime, phos.**	**16.9**	**20.3**	**14.3**	**18.2**
8	Legm., lime, phos., potassium	20.8	26.8	16.4	23.5
		Bu. increase.*	Bu. increase.	Bu. increase.	Bu. increase.
1	None	.0	.0	.0	.0
2	Legume	—	3.2	−.5	4.1
4	Legume, lime	—	7.5	−.2	5.1
6	**Legume, lime, phos.**	**4.1**	**14.3**	**5.3**	**9.5**
8	Legume, lime, phos., potassium	8.0	20.8	7.4	14.8

* Legume and lime treatments were not begun until after wheat harvest in 1902.

Legume-lime-phosphorus treatment has increased the yield of wheat from 7.9 bushels to 17.6 bushels, as an average of the three years, 1903, 1904, and 1905. The addition of potassium has still further increased the average by 4.6 bushels, which is a more marked effect than has been produced by potassium on the other fields.

In Table 3 are given for comparison the wheat yields which have been obtained from three series of plots (one on the Cutler field and two on the DuBois field) corresponding almost exactly to the regular legume series, excepting that commercial nitrogen, costing 15 cents a pound or

$15.00 an acre, has been used in place of the legume treatment, in order to determine whether nitrogen is the element most needed in this soil and whether the effect of legumes is due largely to the nitrogen which they gather from the air. (Nitrogen has been applied at the rate of 100 pounds of nitrogen per acre, in 700 pounds of dried blood, which is only two-thirds as much nitrogen as is removed from the soil by a 100-bushel crop of corn.)

TABLE 3. WHEAT YIELDS IN 1904 FROM CUTLER AND DUBOIS EXPERIMENT FIELDS WHERE COMMERCIAL NITROGEN WAS USED IN PLACE OF LEGUMES.

Soil plot Nos.	Gray silt loam prairie of the Lower Illinois Glaciation.	Wheat, bushels per acre.						
		Cutler, not drained.		DuBois, not drained.		DuBois, tile-drained.		Av. of 3 fields, total yield.
	Treatment applied.	Total yield.	Bu. increase.	Total yield.	Bu. increase.	Total yield.	Bu. increase.	
1	None	**9.0**	.0	**6.3**	.0	**3.3**	.0	**6.2**
2	Lime	10.5	1.5	6.5	.2	11.5	8.2	9.5
3	Lime, nitrogen..	9.8	.8	11.0	4.7	9.2	5.9	10.0
6	**Lime, nitrogen, phosphor.**	15.8	**6.8**	32.7	**26.4**	31.2	**27.9**	**26.6**
9	Lime, nit., phos., potassium	17.7	8.7	33.3	27.0	30.5	27.2	27.2

It will be seen that as an average of three tests a yield of 27.2 bushel of wheat per acre was produced, the credit for which may be distributed as follows among five different factors:

(1) The untreated land produced .... 6.2 bu.
(2) Lime increased the yield .... 3.3 "
(3) Nitrogen increased the yield .... .5 "
(4) Phosphorus increased the yield ....16.6 "
(5) Potassium increased the yield .... .6 "

Total average yield ....27.2 "

Thus we see that the effect of nitrogen upon the yield of wheat was very slight. It might be argued that the large increase made by phosphorus was produced in the presence of applied nitrogen and possibly by the combined influence of the nitrogen and phosphorus. This might well be expected, but, as a matter of fact these "complete fertility tests" contain plots with lime-phosphorus-potassium treatment to which no nitrogen is applied, and the average of the three tests with this treatment was 27.4 bushels of wheat per acre, or .2 bushel more than where nitrogen was included in the treatment.

The conclusion seems justified that the first beneficial effect of legumes on this soil is not due solely or even largely to the fixation of nitrogen, but rather to the chemical action of the decaying organic matter in liberating phosphorus from the meager supply in the soil and to the improved physical condition of the soil.

The Vienna Soil Experiment Field

The Vienna soil experiment field is located near the Big Four Railroad about one mile southeast of Vienna, Johnson County, on the farm of Mr. J. M. Price. The soil on which this field is located is representative of the red silt loam hill land of the unglaciated area, comprising most of the seven southernmost counties in the state. The soil is yellowish red in color and is sometimes called "red clay." It is most deficient in the element nitrogen and as a rule is too acid to grow clover successfully in normal seasons. It is somewhat poor in phosphorus, but its total supply of potassium is very large, although the soil is so deficient in decaying organic matter that as a rule the potassium is not made available as rapidly as needed by growing crops.

This soil can be very markedly improved by lime and legumes; although where the soil is protected from destructive surface washing, phosphorus may be used in connection with legumes and lime and thus add profit and permanency to the soil improvement.

A three-year rotation of corn, wheat, and clover is to be followed on the Vienna field, although thus far cow peas have been grown in place of clover. Three crops of wheat have been grown since the work was begun in 1902. The results are given in Table 4.

TABLE 4. WHEAT YIELDS FROM VIENNA SOIL EXPERIMENT FIELD
(Land not tile-drained)

Soil plot Nos.	Red silt loam hill land of the unglaciated area.	Wheat, bushels per acre.						
		1903, Series 300.		1904, Series 200.		1905, Series 100.		Total wheat from 3 crops
	Treatment applied.	Total yield.	Bu. increase.	Total yield.	Bu. increase.	Total yield.	Bu. increase.	
1	None	**.4**	.0	**6.7**	.0	**1.3**	.0	**8.4**
2	Legume ..	.6	.2	7.1	.4	10.8	9.5	18.5
3	Legume, lime	.7	.3	10.0	3.3	18.2	16.9	28.9
4	**Legume, lime, phos.** ...	8.0	**7.6**	14.8	**8.1**	25.6	**24.3**	**48.4**
5	Legume, lime, phos., potassium	11.0	10.6	17.5	10.8	30.0	28.7	58.5

The 1903 wheat crop was almost a failure in this section of the state. It will be seen that each of the first three plots in the series produced less than one bushel per acre. Plot 4, with legume-lime-phosphorus treatment produced 8 bushels, and this was increased 3 bushels by the addition of readily available potassium.

In 1904 the yield is increased from 6.7 bushels on the untreated plot to 10 bushels with legume-lime treatment, but a larger gain is still produced by the addition of phosphorus.

In 1905, however, where lime had been applied to correct soil acidity and legumes had then been grown to add nitrogen and decaying organic matter to the soil, the yield was increased from 1.3 bushels on untreated soil to 18.2 bushels per acre with legume-lime treatment, a gain of 16.9 bushels. Phosphorus gave a further increase of 7.4 bushels, thus producing a total yield of 25.6 bushels with legume-lime-phosphorus treatment.

By adding together the wheat yields for three years we get the following significant results:

(1) The untreated land produced .... 8.4 bushels.
(2) Legume treatment increased the yield...........10.1 "
(3) Lime treatment increased the yield ....10.4 "
(4) Phosphorus treatment increased the yield.......19.5 "

Land with legume-lime-phosphorus treatment produced. 48.4 bushels.

Pot Culture Experiments on Unglaciated Hill Land

Some very satisfactory and valuable results have been obtained from a series of pot culture experiments which have been in progress since 1902 in the pot culture greenhouse, and in which this red silt loam of the unglaciated hill land has been used. The first year's work with these pot cultures was performed by Mr. W. O. Farrin as a thesis for graduation from the University of Illinois in 1902.

The soil used in these experiments was collected by Mr. Farrin in the fall of 1901 and represents the old worn hill soil. It is much poorer in nitrogen and humus than the average of the type, although large areas are to be found as badly worn as the field from which this soil was collected. This field has been under cultivation for about seventy-five years and was still being cropped when the soil was collected. During the earlier period of its cultivation this soil had not infrequently produced 25 bushels of wheat per acre, but during the later years about 5 bushels has been the average crop in normal seasons.

Table 5 gives the results of four years' experiments with pot cultures on this type of soil.

A study of this table will show clearly that no appreciable increase in yield has been made except when nitrgoen has been supplied, either directly in commercial form or indirectly by means of legume treatment. It should be borne in mind, of course, that no legume treatment preceded the 1902 wheat crop. The catch crop of cow peas which followed the 1902 wheat crop produced a marked effect upon the 1903 wheat crop. This effect became more marked in 1904 and 1905 when every pot receiving legume treatment outyielded the pot receiving lime-nitrogen treatment. If we disregard the exceptional yield from legume-lime treatment in 1905, the addition of phosphorus to nitrogen or legume treatment has always increased the yield, and the addition of potassium has still further increased the yield after the first year, but the effect of potassium has been less where decaying organic matter has been provided in the legume treatment than where the nitrogen has been supplied in commercial form carrying but little organic matter.

TABLE 5. WHEAT YIELDS FROM PULASKI COUNTY SOIL

Red silt loam hill land of the unglaciated area. / Soil treatment applied.	1902 wheat, grams.	1903 wheat, grams.	1904 wheat, grams.	1905 wheat, grams.
None	3	5	4	4
Legume, lime	4	10	17	26
Legume, lime, phosphorus	3	14	19	20
Legume, lime, phosphorus, potassium	2	16	20	21
Lime, nitrogen	26	17	14	15
Lime, phosphorus	3	6	4	6
Lime, potassium	3	3	3	5
Lime, nitrogen, phosphorus	34	26	20	18
Lime, nitrogen, potassium	33	14	21	21
Lime, phosphorus, potassium	2	3	3	5
Lime, nitrogen, phosphorus, potassium	34	31	34	21
Virgin soil (no treatment)	24	17	15	17

The last line in the table gives the yields from a pot of virgin soil collected from a piece of unbroken virgin sod-land adjoining the cultivated field from which the soil in all other pots was taken.

PROFIT IN WHEAT GROWING

In Table 6 is given a summarized statement showing the yields and value (at 70 cents a bushel) of the wheat produced (1) from the untreated land, (2) from the land receiving legume-lime-phosphorus treatment, and (3) the difference between these two, or the increase produced by the treatment. In the last column is given the ratio of increase from treatment above the produce of the untreated land, and in the last line of the table are the averages of twelve separate and comparable tests, covering three years' work in three different counties. Attention is called to the fact that on none of these experiment fields has the same land been used for wheat more than once during the three years, a different series of plots being used for each year in the rotation, as may be seen by referring to Tables 1, 2 and 4. Furthermore, where there has been any perceptible difference in the natural fertility of the soil the untreated check plots have been located on the best soil, so as to avoid any possible exaggeration.

It will be seen that the average yield of wheat in 1903 was 1.9 bushels per acre on the untreated land and 11.9 on the treated land, making a gain of 10 bushels for the treatment or 5.26 times the average yield of the untreated land. In 1904 the land is to be credited with 7.6 bushels and the treatment with 10.5 bushels, making the total yield 18.1 bushels on the treated land. In 1905 an average yield of 28.9 bushels was produced on the treated land and only 9 bushels on the untreated land, making a gain of 19.9 bushels, which is 2.21 times the average yield of the untreated land.

As an average of twelve tests, covering three years' work, the untreated land produced 6.1 bushels, and the treated land 19.6 bushels, 13.5 bushels being produced by the legume-lime-phosphorus treatment above that produced by the untreated rotated land.

If we consider $3.00 as the annual expense for materials and add to this the extra expense for binding twine and threshing required for the increased crop, we find that we have an annual profit of about 200 percent on the investment for 1903 and 1904, and more than 300 percent for 1905, besides leaving our land richer each year.

Effect of Soil Treatment on Corn, Oats, and Clover

The question naturally arises as to what effect the legume-lime-phosphorus treatment will produce on crops other than wheat. For the ordinary high-priced land of the Illinois Corn Belt, this question has already been answered tentatively in Circular No. 96. For the poorer lands of the Wheat Belt, which are not so well adapted to corn or oats as they are to wheat, we can only give the results thus far obtained. As an average of the first three years' tests on these soil experiment fields, during 1903, 1904, and 1905, the legume-lime-phosphorus treatment increased the yield of oats 13.2 bushels per acre.

In 1903, owing to the drouth, the corn crop in southern Illinois was almost a total failure, less than 10 bushels per acre having been produced on untreated land as an average result from four experiment fields. The 1905 corn crop is not yet harvested. Consequently we are limited to the results of 1904 for data on corn. As an average of six tests made in 1904, the untreated land produced 32.1 bushels of corn, and the treated land

TABLE 6. VALUE OF LEGUME-LIME-PHOSPHORUS TREATMENT FOR WHEAT

Soil experiment field.	Wheat from untr'ted land.		Wheat from treated land.		Increase from treatment.		
	Bus.	Dolls.	Bus.	Dolls.	Bus.	Dolls.	Ratio
Results in 1903.							
Odin (not drained)	.4	$ .28	5.8	$ 4.06	5.4	$ 3.78	13.50
Odin (tile-drained)	.6	.42	13.4	9.38	12.8	8.96	21.33
Cutler (not dr'ned)	6.0	4.20	20.3	14.21	14.3	10.01	2.38
Vienna (not dr'ned)	.4	.28	8.0	5.60	7.6	5.32	19.00
Average for 1903..	1.9	**$ 1.33**	11.9	**$ 8.33**	10.0	**$ 7.00**	5.26
Results in 1904.							
Odin (not drained)	7.9	$ 5.53	21.6	$15.12	13.7	$ 9.59	1.73
Odin (tile-drained)	6.7	4.69	21.5	15.05	14.8	10.36	2.21
Cutler (not dr'ned)	9.0	6.30	14.3	10.01	5.3	3.71	.59
Vienna (not dr'ned)	6.7	4.69	14.8	10.36	8.1	5.67	1.21
Average for 1904..	7.6	**$ 5.32**	18.1	**$12.67**	10.5	**$ 7.35**	1.38
Results in 1905.							
Odin (not drained)	15.2	$10.64	36.5	$25.55	21.3	$14.91	1.40
Odin (tile-drained)	10.8	7.56	35.3	24.71	24.5	17.15	2.27
Cutler not(dr'ned)	8.7	6.09	18.2	12.74	9.5	6.65	1.09
Vienna (not dr'ned)	1.3	.91	25.6	17.92	24.3	17.01	18.69
Average for 1905..	9.0	**$ 6.30**	28.9	**$20.23**	19.9	**$13.93**	2.21
Av. for three years	6.1	$ 4.27	19.6	$13.72	13.5	$ 9.45	2.21

produced 45.4 bushels, making an average increase of 13.3 bushels of corn from legume-lime-phosphorus treatment. A further increase in the yield of corn was produced by including potassium in the soil treatment, but the effect of potassium on wheat and oats is so slight that its general use cannot be recommended from the data thus far obtained. Furthermore, these soils actually contain a very large total supply of potassium and by further addition of decaying organic matter it is believed that potassium can be liberated from this immense stock more economically than it can be imported from Germany in commercial form.

At 25 cents a bushel for oats and 35 cents for corn the increase produced in each of these crops by legume-lime-phosphorus treatment has been more than enough to pay for the annual cost of the materials.

As a result of five trials with clover harvested in 1905 (one at Cutler, two at DuBois, and two at Edgewood), the lime-phosphorus treatment increased the yield of field-cured clover hay by 1.14 tons per acre, and the quality of hay was also markedly improved by the treatment. In fact, the hay on the untreated land was estimated to be fully one-half weeds,while on the treated land it was very clean clover. The hay was sold at $4.50 to $5.00 a ton as drawn from the field, so that the treatment has more than paid for itself in the increased yield of clover, even without considering the quality of the hay or the value of the second crop for pasture, hay, or seed.

Practically no data have been secured from the cow pea crop, because as a rule this crop has been plowed under on the treated land during the first course of the rotations. The indications are, however, that cow peas respond best to about the same treatment as is required for corn. Legume-lime-phosphorus treatment has generally noticeably benefited the cow pea crop, but the further addition of potassium has produced a much more marked effect.

Comparative Value of Steamed Bone Meal and finely ground Raw Rock Phosphate

The phosphorus used in all the experiments described above was applied in the form of steamed bone meal, and there is no doubt that at present prices phosphorus can be purchased in that form and used with market profit on this type of soil with proper crop rotations. On the other hand the fact that steamed bone meal costs $25 to $30 a ton, while raw rock phosphate, equally rich in phosphorus, can be bought for one-third as much, has led several experiment stations to investigate the practicability of using raw rock phosphate. Some of the results obtained by the experiment stations of Ohio, Maryland, and Illinois are reported in Circulars 68 and 87.

A series of pot culture experiments recently harvested at the Illinois Station furnishes some additional data on the relative values of steamed bone meal and raw rock phosphate. The soil used was from the gray silt loam prairie of the Lower Illinois Glaciation, and wheat was the crop grown in the pots. The phosphate used is known as the "blue rock phosphate", which is thought to be somewhat more readily available than the "brown rock phosphate." In certain pots the phosphorus was turned under with a good growth of clover; in other pots with farm manure, and in others with both clover and manure. In all cases equal money values of bone meal and rock phosphate were applied, that is, the quantity of rock phosphate applied was three times the application of bone meal.

Table 7 shows the soil treatment, the actual yields of wheat in grams per pot, the rate of yield in bushels per acre, and the gains from treatment.

It will be seen that the untreated soil (pot 101) yielded at the rate of 27 bushels of wheat per acre (28 bushels on the duplicate pot No. 125). Where clover was turned under (102) the yield was increased by 16 bushels; that is, from 27 to 43; and where bone meal was turned under with clover (105) the rate of yield was 59 bushels per acre, the increase of 32 bushels being just double that produced by clover without bone meal.

Where raw rock phosphate was turned under with clover (106) the wheat yielded at the rate of 62 bushels per acre, making a total increase of 35 bushels over the yield of the untreated soil. Of this 35-bushel increase, 16 bushels should be credited to the clover and 19 bushels to the rock phosphate.

It will be observed that rock phosphate used alone produced an increase of only 11 bushels, which added to the increase of 16 bushels due to clover alone makes only 27 bushels. In other words the sum of the gains which they make when used separately was 8 bushels less than the increase produced when the rock phosphate and clover were turned under together. Somewhat similar results are produced with clover and bone meal when used separately and together; also with bone meal and potassium, and with rock phosphate and potassium, one of the chief functions of the potassium apparently being to increase the availability of the phosphorus in the bone meal and in the rock phosphate. Such extraordinary combined action does not appear, however, from other combinations.

TABLE 7. COMPARATIVE EFFECT OF STEAMED BONE MEAL AND RAW ROCK PHOSPHATE, IN CONNECTION WITH CLOVER AND MANURE

Soil pot No.	Treatment applied.	Wheat yields.		Increase bushels per acre.
		Grams per pot.	Bushels* per acre.	
101	None	10.0	27	......
102	Clover	16.3	43	16
103	Bone meal	14.7	39	12
104	Rock phosphate	14.2	38	11
105	Clover, bone meal	22.2	59	32
106	Clover, rock phosphate	23.3	62	35
107	Manure	16.5	44	17
108	Clover, manure	22.7	60	33
109	Manure, bone meal	19.4	52	25
110	Manure, rock phosphate	19.5	52	25
111	Clover, manure, bone meal	23.1	62	35
112	Clover, manure, rock phosphate	23.3	62	35

* The pots used in these investigations are 10½ inches in diameter, consequently 1 gram per pot corresponds to 1 pound per square rod or to 160 pounds per acre. The actual yields in grams per pot are given but the results are also computed to bushels per acre. It should be remembered that pot cultures constitute an intensive form of agriculture. They are carried on under almost complete control and the yields obtained are usually two or three times as much as can be expected in the field under ordinary weather conditions. They are not, however, larger than could be obtained in the field under perfect weather conditions. The largest yield reported in Table 4 is 25.3 grams per pot, or 67 bushels per acre. A yield of 54 bushels of wheat per acre has actually been produced on the University farm under field conditions.

As a general average the rock phosphate has made slightly better gains than the steamed bone meal. A detailed study of Table 7 is worth while. It offers some other valuable comparisons and reveals several interesting results, some of which are readily understood while others will require further investigation.

TABLE 7—Continued

Soil pot No.	Treatment applied.	Wheat yields.		Increase bushels per acre.
		Grams per pot.	Bushels per acre.	
113	Potassium	11.3	30	3
114	Clover, potassium	18.4	49	22
115	Potassium, bone meal	18.4	49	22
116	Potassium, rock phosphate	18.2	49	22
117	Clover, potassium, bone meal	21.9	58	31
118	Clover, potassium, rock phosphate	21.9	58	31
119	Manure, potassium	18.1	48	21
120	Clover, manure, potassium	19.1	51	24
121	Manure, potassium, bone meal	19.3	51	24
122	Manure, potassium, rock phosphate	19.0	51	24
123	Clover, manure, potassium, bone meal	25.3	67	40
124	Clover, manure, potassium, rock phosphate	25.3	67	40
125	None	10.6	28	

SOURCE AND SUPPLY OF PHOSPHORUS

It is estimated that the total rock phosphate deposits of the world thus far discovered will furnish between 150 million and 200 million tons. The present annual consumption is about 3 million tons. Thus the total supply so far as now known will be exhausted in about fifty years, or in much less time if the rate of consumption increases in the future as it has in the past. The most extensive deposits known are in southern United States. About 1,600,000 tons are being mined annually from these deposits and more than a million tons of this is exported to European countries.

Phosphorus is the plant food element which already limits the crop yields on at least 80 percent of the soils of Illinois, and liberal applications of this element must be made to Illinois soils if their productive capacity is to be increased and maintained.

Steamed bone meal and raw rock phosphate are the two most economical commercial forms of phosphorus. They are natural products and they have absolutely no injurious effect on the land, either immediate or subsequent. A good grade of either of these materials contains about 12½ percent of phosphorus. They may be applied in any amount and will remain in the soil until removed by cropping. As much as five tons to the acre of ground rock phosphate containing 12½ percent phosphorus has been applied by way of experiment without deleterious effects. This excessive quantity contains as much phosphorus as would be removed from the soil by fifty crops of corn of 100 bushels each, which is double the amount of phosphorus contained in the plowed soil of an acre of the commonest type of soil in the Illinois Wheat Belt.

The use of acid phosphates, acidulated bone meal, or acidulated manufactured so-called "complete" fertilizers is not advised for general farming on any Illinois soil, not only because they are exceedingly expensive for the relatively small amount of phosphorus which they contain, but also because of their ultimate injurious effect upon the soil.

A Personal Statement

This general information relating to phosphorus and Illinois soils has been given the widest possible publicity in Illinois during the past three years by means of Experiment Station bulletins and circulars, articles in the agricultural press, and addresses at farmers' institutes. Considerable quantities of steamed bone meal and hundreds of carloads of raw rock phosphate are already being used in this state, and with very gratifying increase in crop yields and satisfactory profits.

During the past four years the writer has been responsible for the investigation of Illinois soils. It was hoped that methods might be discovered whereby agriculture in this state might be made not only more profitable but also permanent. The only obstacle which has seemed insurmountable to the accomplishment of this most desirable end has been the limited supply of phosphorus.

Some phosphorus can be saved in the manure made from the coarser farm products, and if all grains are also fed and some concentrated feeds purchased, such as bran and oil meal, the phosphorus content of the soil can be maintained and even increased without the purchase of any commercial phosphorus. Steamed bone meal also furnishes phosphorus in an available and harmless form, and the fact that this comes originally from the farm is perhaps an additional reason why it should be returned to the farm.

The slag produced by the Illinois steel works has been investigated, but it has been found that the iron ore used in these works contains so little phosphorus that the slag produced in the process of converting the iron into steel has no value as a source of phosphorus.

Every possible source of this element of which I could conceive has been investigated, with the result that the only present adequate supply is found to be in the natural rock phosphate deposits and even these appear to be exceedingly limited when measured by the probable needs of future generations.

In the spring of 1904 I was rejoiced to learn of a large tract of phosphate land in western Tennessee, less than two-hundred miles from Cairo, which possibly could be secured for Illinois. I made this fact known to large numbers of Illinois farmers and land owners, annoucements being published in the agricultural press that an effort was being made to obtain control of this phosphate property. Largely to induce others to assist in the enterprise, I invested, myself, as heavily as possible.

The effort was finally successful and this large supply of phosphorus is now controlled by people whose greatest interest is in Illinois agriculture. My only regret is that every Illinois farmer does not have absolute control of an unlimited supply of phosphorus for his own farm, as he already has of nitrogen and (in most soils) of potassium.

While it seemed necessary and wise for me to invest in the enterprise personally in order to encourage others to do so, it is not now necessary for me to retain my financial connection with it, although surely entitled to do so by any legal or moral standard of justice.

It has seemed best, however, to sacrifice this right and the future possibility of personal profit from the investment in order to avoid even unfair and unreasonable suggestions that might place any discount upon the advice which I gave two years before I knew of the possibility of this investment, and which I must continue to give, regarding the use of phosphorus on Illinois soils. Consequently I have severed my connection with this phosphate company and have absolutely no financial interest direct or indirect in any phosphate enterprise, except in the use of rock phosphate on my own Illinois farm.

NOTES.—Ground limestone can be obtained from the Crystal Carbonate Lime Company, Ellsberry, Mo., or from the Mitchell Lime Company, Mitchell, Ind., for about $2.20 a ton, delivered in Illinois in carload lots, on direct east and west lines running into East St. Louis; on north and south lines it may cost 20 to 30 cents more. Illinois has abundance of good limestone, especially along the Mississippi and in the Ozark hills in the southern part of the state, and it is hoped that grinding plants will soon be established in Illinois so that ground limestone can be obtained more cheaply. It ought to be furnished at any point delivered in carload lots at a total cost of $2.00 a ton or less.

Finely ground raw rock phosphate (12½ percent phosphorus) can be obtained from Robin Jones, Nashville, Tenn., or from the N. Y. & St. L. Mining & Mfg. Co., St. Louis, Mo., for about $8.00 a ton delivered in Southern Illinois in carload lots.

A good grade of steamed bone meal (about 12½ percent phosphorus) can be obtained delivered in southern Illinois for about $25.00 a ton, from the local agents of Armour & Company, Morris & Company, Swift & Company, or others, of the Union Stock Yards, Chicago, Ill.; and potassium chlorid (42 percent potassium) can also be obtained from Armour & Company, for about $50.00 a ton, f. o. b. cars Chicago.

For general information regarding methods of soil improvement, and the uses and application of lime, ground limestone, and plant food materials, see Illinois Circular No. 87.

For more detailed information regarding the history of the fields previous to 1905 and the individual yields of all crops grown on every plot on the four soil experiment fields in the lower Illinois Glaciation, see Bulletin No. 99. Each of these publications has already been sent to the Station's entire mailing list in Illinois, and they will be sent to anyone, free of charge, upon request to the Illinois Experiment Station Urbana, Illinois.