FACTORS IN CROP PRODUCTION WITH SPECIAL REFERENCE TO PERMANENT AGRICULTURE IN ILLINOIS.*

By CYRIL G. HOPKINS, CHIEF IN AGRONOMY AND CHEMISTRY.

In order to emphasize the importance of producing and maintaining large crop yields on Illinois lands, I ask you to consider the data presented in Table 1, in which I have tried to illustrate in some detail the method of measuring land values by crop yields. You will understand, of course, that these data, at the best, represent only approximately average conditions. Thus the price of corn is placed at 35 cents a bushel, to represent approximately the average price over a series of years. The price of corn has been known to vary from less than 20 to more than 60 cents a bushel, and although 35 cents may be the average for the past ten years, it may not be the average for the next ten years. The expense of taking hay from the swath and delivering it in bales on the local market is placed at $2.50 a ton. This may fairly represent the expense in one section of the state where the cost of baling is $1.25 a ton and where labor is obtained at a corresponding price, but it would not be sufficient where the baling costs $2.00 a ton, with other expenses in proportion.

Remember I do not even suggest that you accept these data for your conditions, but only that you consider the principle of measuring land values by crop yields, on the basis of selling the crops at the local markets. Then if you have any further interest in the matter, I suggest that you change these data to fit your own average local conditions and then recalculate the land values, not only on the basis of

*An address read before the Illinois State Farmers' Institute at Joliet, February 23, 1905.
VALUE OF LAND MEASURED BY CROP YIELDS.

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<tr>
<th>Crop yield</th>
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<td>AN ACRE OF CLOVER AT $6.00 A TON.</td>
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*This would be $2.40 for the phosphorus and potassium alone, but 20 cents credit is given for the nitrogen stored in the roots and stubble for each ton of clover hay produced.*
selling the crops on the market, but also on the basis of feeding part or all of the crops grown and selling the animal products thus produced. In some sections or in some seasons, or under some systems of farming, there are several side products, or by-products, which might properly be considered, such, for example, as corn stover, straw and clover seed.

In the computations I have made, I have tried to avoid using data which would exaggerate the land values. It must be understood that the values given are for the year during which the particular crop is grown. The average value would depend upon the rotation of crops and would be the average of the different values found in the different years of the rotation.

For plant food, I have allowed 1 cent a pound for nitrogen (expecting it to be furnished by legumes and farm manure), 12 cents a pound for phosphorus and 6 cents a pound for potassium. (At these prices phosphorus can be bought in steamed bone meal and potassium in potassium chlorid). For taxes, I have allowed one-half percent on the value of the land.

By referring to the table, it will be seen that 20 bushels of corn at 35 cents a bushel gives a gross return of $7.00 an acre. Deducting from this $5.91 the total annual expense, including 80 cents for plant food removed in the crop, $4.00 for growing the crop (plowing, planting, cultivating, etc.), $1.00 (5 cents a bushel) for harvesting and marketing, and 11 cents for taxes, we have left $1.09 as the net value of the crop. This is equal to 5 percent interest per annum on a valuation of $21.81 per acre.

With 40 bushels of corn per acre, the value of the land becomes $116.36. In other words, by doubling the crop yield, we multiply the land value more than five times. With 60 bushels of corn per acre, the land becomes worth $210.91; with 80 bushels, $305.45; and, if we could raise 100 bushels of corn per acre, we could pay the annual expense of $4.00 for plant food, $4.00 for raising the crop, $5.00 for harvesting and marketing, and $2.00 an acre for taxes, and still have left $20.00 an acre, as the net value of the crop. This would pay 5 percent interest on exactly $400.00, which would represent the value of the land for that year.

If land costs $100 an acre, the interest and taxes would be $5.50. If we raise 40 bushels of corn per acre, the profit from the business would be 90 cents an acre; whereas if we raise 60 bushels per acre, the profit for the year becomes $6.00 an acre. In other words, by increasing the yield only 50 percent, we have increased the profit more than 600 percent.
If we increase the cost of growing the crop from $4.00 to $6.00 an acre, the value of the land, if only 20 bushels of corn are produced, is $16.00 below zero, although with 40 bushels, the land becomes worth $80.00 an acre, and rises to $363.64 with a 100-bushel crop.

By similar methods of computation we find that with wheat at 70 cents a bushel, crops ranging from 10 to 50 bushels produce land values ranging from $45.45 to $445.45 an acre; and that with oats at 25 cents a bushel, crops ranging from 20 to 100 bushels per acre produce land values from $9.09 to $263.64.

It is perhaps worthy of special consideration that with timothy hay worth $8.00 a ton, the land value rises to only $140.91 with 2½ tons of baled hay from an acre; but still more significant is the fact that if we are to sell clover hay at $6.00 a ton, 2½ tons of baled hay per acre would produce a land value of only $40.91, notwithstanding that the clover is credited with the nitrogen which it adds to the soil.

These data certainly emphasize the fact that there is great loss in selling hay at $6.00 or $8.00 a ton if we are to maintain the fertility of the land.

On land worth $150.00 an acre there is an actual loss of $1.00 a year in selling timothy hay at $10.00 a ton, if we are to maintain the fertility of the soil and raise 1½ tons to the acre. If we can afford to do this, it is because we have in our soils such an abundant stock of the element potassium that we are willing to sell it for 3 cents a pound when it is worth 6 cents in the Chicago markets in the cheapest commercial form.

Essential Factors in Crop Production.

While I shall dwell mainly upon the subject of plant food in this paper, no one should understand therefrom that I do not consider of great importance the other five essential factors of crop production; namely, the heat, light, moisture, the physical condition of the soil, and the seed; indeed these six factors are of equal importance, because they are all absolutely essential to growing crops.

It is certainly important that we improve our seed corn, and our seed oats, and seed wheat, and all other seed, so far as practicable and profitable.

And let us improve the home of the plant—by better drainage, by increasing and maintaining humus in the soil, and by better plowing and more frequent and thorough cultivation. This is an exceedingly important matter in crop production, for by it we may to some extent control both heat and moisture. Drainage not only removes the surplus water from a "water-logged" soil, making plant growth possi-
ble, but it decreases the amount of water to be evaporated from the surface and permits the sun’s heat, which would be required to evaporate that water, to be utilized in warming the soil; it also allows the air to enter the soil, increasing the activity of soil organisms at greater depths, encouraging the plant roots to penetrate the soil more deeply, thus adding to the organic matter of the subsoil and increasing its porosity and giving the soil greater power to absorb and retain moisture and to resist drought. And let us bear in mind that this applies not only to the flat level lands, but also to the rolling lands—and sometimes with even greater force; for thorough tile-drainage is one of the best means of reducing the surface washing of rolling lands. We may also conserve the moisture to a considerable extent by maintaining dust mulches produced by proper cultivation; and, by increasing the organic matter in the soil, we are able to increase the temperature of the soil, for the dark color of a soil is largely due to its organic matter content, and dark soils are warmer than light-colored ones. Recent investigations by Professor Mosier at the Illinois Station have shown that the temperature of a light-colored soil was raised five or six degrees when it was covered with a thin layer of dark soil, and this difference was maintained from 10 or 11 o’clock in the morning till nearly sunset. This is a point of some importance during the early part of the season. Actual tests by Professor Mosier showed that seeds germinate more quickly and the young plants grow more rapidly in the darker soils.

Of the six essential factors, light is the only one over which we have almost no control, but fortunately it is also the factor which rarely, if ever, limits the yield of crops.

**Elements of Plant Food.**

But I am to speak with special reference to the subject of plant food, which I believe is truly the least understood and the most neglected of all the factors essential to crop production.

I scarcely need to remind you that there are ten essential elements of plant food. Of these, carbon is the only one obtained directly from the air by most agricultural plants. The fixation of carbon occurs in the leaves, the carbon dioxide of the air reacting with the elements hydrogen and oxygen from the water (which is absorbed by the roots and carried to the leaves), forming organic compounds which finally condense to sugar, starch, cellulose, or wood fiber, and other carbohydrates. Many who are familiar with the fixation of atmospheric nitrogen by means of nitrogen-gathering bacteria living in tubercles on the roots of legume plants, are not aware of the fact that more than 90 per-
cent of the total dry weight of most agricultural plants results from the fixation of carbon and the consequent formation of carbohydrates and other organic bodies. While this very large percentage of the plant consists of the three plant food elements, carbon, hydrogen and oxygen, these three elements are no more essential to the life of the plant than the seven other elements of fertility, as calcium, magnesium, iron and sulfur, all of which are present in most soils in quantities far beyond the needs of crops for ages to come; or as nitrogen, phosphorus, and potassium, of which one or more may be so deficient in a soil as to limit the yield of the crop.

It is to the consideration of these three well known elements of plant food, nitrogen, phosphorus, and potassium, which are sometimes called the "golden tripod" of agriculture, that we may well devote more of our time.

**Crop Yields in Soil Experiments.**

In order to emphasize the possible tremendous importance of each of these elements of soil fertility, I beg to ask your attention to Table 2, which gives some of the most striking yet absolutely truthful results which we have thus far obtained in our investigation of Illinois soils.

From the information obtainable from American and European research, it is estimated that a normal fertile soil of ordinary physical composition should contain the amounts of plant food shown in column 1, as commonly determined; namely, about 5800 pounds of nitrogen, 2000 pounds of phosphorus, and 5300 pounds of potassium per acre in the surface soil to a depth of seven inches, which is considered a good depth for plowing. Column 2 shows the plant food contained in the richest soil of large area in Illinois, commonly called "gumbo," while column 3 represents the most common soil of the Corn Belt in Illinois, this soil being a brown silt loam. In this column are also given results obtained from two different soil experiment fields located on this type of soil, the first located near Sibley, in Ford County, and the second near Bloomington, in McLean County. Nitrogen and potassium applied to this soil either singly or together have produced injury rather than benefit to the corn crop; while phosphorus, applied in steamed bone meal at a cost equal to the present value of six bushels of corn, produced 8 bushels gain on the one field and 13 on the other. After nitrogen had been applied (which can be furnished by clover in rotations), the gains due to phosphorus are 15 bushels on the Sibley field and 18 bushels on the Bloomington field. More phosphorus was applied than was removed by the largest crop.
Table 2—Plant Food in Some Illinois Surface Soils.
Founds per Acre.

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<td>Nitrogen</td>
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<td>5,320</td>
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<td>1,000</td>
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Crop Yields in Soil Experiments.

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<td>3</td>
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<td>Nitrogen, phosphorus, potassium</td>
<td>64</td>
<td>81</td>
<td>34</td>
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To the old worn unglaciated hill soil of southern Illinois (red silt loam, the principal type in seven counties), whose chemical composition shows it to be markedly deficient in nitrogen, we added both phosphorus and potassium and obtained practically the same yield as where no plant food was applied, but when nitrogen was added the yield of wheat in pot cultures was increased from only 3 grams to from 26 to 34 grams per pot.

To the principal type of soil in the Lower Illinois Glaciation (covering more than 20 counties), whose analysis shows that its phosphorus content is less than one-third of a normal fertile soil, phosphorus was added and the yield of wheat was increased, from 7 to 25 bushels per acre. The marked effect of potassium on this soil when used alone or with nitrogen only, whereby the yield of wheat was increased 9 bushels per acre in each case, was probably produced, in part at least, by the corrosive or destructive action of the soluble potassium salt. Even common salt (sodium chlorid) and landplaster (calcium sulfate) were added to the soil, but the yield was no greater than before. The marked effect of potassium on the old worn unglaciated hill soil of southern Illinois suggests the advisability of using potassium on this soil for the further increase of yields of wheat and corn, and the use of phosphorus on the principal type of soil in the Lower Illinois Glaciation for the increase of yields of wheat and corn. The marked effect of potassium and phosphorus on the old worn unglaciated hill soil of southern Illinois suggests the advisability of using these elements on this soil for the further increase of yields of wheat and corn.
produce similar effects on some soils, especially with wheat. Possibly this caustic action tends to liberate phosphorus from the soil. This effect is also indicated where potassium was added with nitrogen on the unglaciated hill land).

To the peaty swamp soil, representing some hundred thousand acres in north central Illinois, whose composition shows that it contains less than one-third as much potassium as a normal fertile soil and only one-sixth as much potassium as the best soils in the Corn Belt, we added both nitrogen and phosphorus and obtained practically the same crop as where no plant food was added, the total yield per acre amounting to less than a ton of corn fodder with practically no ear corn; and, yet where we applied potassium to that soil we obtained about two tons of corn stover and 45 to 59 bushels per acre of good sound corn. (Applied nitrogen produced an appreciable effect only because of insufficient nitrification of the soil nitrogen, due to imperfect drainage).

Most of these results were obtained after two or three years' treatment, and in all cases, abundance of the deficient element was applied to meet the needs of large crops.

**Maintaining Soil Fertility.**

One of the problems which probably is, and which surely ought to be, uppermost in our minds is how to restore the fertility of our poorer soils and how to profitably and permanently maintain all our lands in a state of high productive capacity.

You will pardon me if I emphasize the fact that the Illinois Standard for the investigation of Illinois soils is set to bring about a system of agriculture in Illinois which shall at least permanently maintain the high crop yields of our best soils and which shall increase the fertility of our poorer soils to their maximum profitable productive capacity.

But to grow large crops requires large quantities of these valuable elements of plant food, and this brings us to the subject of the "Circulation of Plant Food." This I believe is the most important process connected with any possible system of permanent agriculture. The farmer of greatest temporary success is as a rule the farmer who takes the largest amounts of plant food from the soil; but the system of farming of greatest permanent success must be a system which will not only take large amounts of plant food from the soil, but which brings about such a circulation of plant food that so far as necessary equivalent amounts are returned, again to be used by growing crops, and again to be returned.
HISTORIC SYSTEMS OF LAND RUIN.

The almost universal practice of the civilized world up to date has been to ruin land and then cry, "Westward Ho!" and he who undertakes to say that the rich soils of the great central states can never be reduced in fertility knows not whereof he speaks.

What has been the system? And what is the common practice today? First, beginning with virgin soil, we crop continuously with corn and small grains till the practice becomes unprofitable. Second, when these crop yields become much reduced, we introduce clover into the rotation and thus maintain, to some extent at least, the nitrogen. But the fixation of nitrogen is not the only function of clover, nor indeed its most effective function on many soils. Clover is a gross feeder on phosphorus. Considerable quantities of the elements taken from the soil and subsoil by the deep rooting biennial clover plant remain in the roots and stubble and, as these residues decompose, the products of fermentation and decay liberate still other quantities of phosphorus from the soil itself, thus furnishing a good supply of available phosphorus to succeeding crops of corn or other grain. (Potassium may be effected in a similar way.) On soils where this is the principal effect of growing clover in rotation, applications of phosphorus produce about the same increase in crop yields as are produced by the use of clover; whereas, applications of nitrogen itself, even in the best forms, produce little or no increase in the crop. Furthermore, on such soils, about the same effects are produced by the use of non-leguminous green manures, such as rye, buckwheat, or rape, as are produced by clover or by applications of phosphorus.

Usually this process continues until the clover system fails, until the clover crop is unable to obtain sufficient phosphorus for its own growth.

Landplaster and caustic lime are next brought into use to force the soil to give up plant food which could not otherwise be obtained by crops. This system is effective but short-lived, for after a score of years the soil commonly refuses to yield up the required quantities of its remaining stock of fertility even under the destructive action of these powerful stimulants. It is this use of lime that is referred to by the well known German proverb which says: "Lime may make the fathers rich, but it makes the children poor."

Then comes the common commercial fertilizer system, in which we apply to the soil not sufficient plant food to grow good crops and maintain the productive capacity of the soil, but only enough to sup-
plement that which can still be forced from the land. The most common application is 200 pounds per acre of so-called 2-8-2 goods applied once or twice in a four-year or five-year rotation. This means 2 percent of ammonia, 8 percent of so-called phosphoric acid, and 2 percent of potash. A 200-pound application of such a "complete" commercial fertilizer would supply 4 pounds of ammonia, 16 pounds of so-called phosphoric acid, and 4 pounds of potash; or, in the language of Illinois, about 3½ pounds of actual nitrogen, 7 pounds of actual phosphorus, and 3½ pounds of actual potassium, whereas a 100-bushel crop of corn would remove from the soil in one season about 148 pounds of nitrogen, 23 pounds of phosphorus, and 71 pounds of potassium; or 40 times as much nitrogen, 3 times as much phosphorus and 20 times as much potassium as is commonly applied for two or three years' crops. Sometimes acid phosphate alone is used and this is certainly less absurd than to continue to buy potassium when it is not needed, and to pay 15 cents a pound for nitrogen when it can be obtained from the air at a cost not to exceed one cent a pound, or at no cost whatever if the legume crops and catch crops are properly fed or pastured.

But even where acid phosphate alone is used the applications are usually too small to supply the needs of maximum crops and maintain the supply of phosphorus in the soil. The common practice is to remove all that can be extracted from the soil even by the aid of the 60 percent of manufactured landplaster, contained in the acid phosphate, and then depend upon the added phosphorus to make up the balance required by the crop. Even in the rotation experiments at the Ohio Station, where a system better than commonly followed has been practiced, the total phosphorus applied in acid phosphate during a five-year rotation is less than is contained in a single 100-bushel crop of corn.

Most farmers use more or less farm manure, and this is well, for it helps to maintain the supply of nitrogen and potassium even though it does not return much phosphorus to the land. It should be remembered that about three-fourths of the potassium in a crop of corn, wheat, or oats is contained in the stalks or straw, while only one-fourth is contained in the grain; also that when the crop is fed to animals, practically all of the potassium is returned in the solid and liquid manure; whereas, about three-fourths of the phosphorus in the crop is contained in the grain, and, even if the grain is all fed, a considerable part of the phosphorus remains in the bones of the animals and is thus sold from the farm.
THE SUPPLY OF PHOSPHORUS IN ILLINOIS SOILS.

Please bear in mind that the average soil of the Corn Belt in Illinois contains about 1000 pounds of acid-soluble phosphorus in the plowed soil of an acre, to a depth of 7 inches; while the total phosphorus in the same soil, including both acid-soluble and insoluble, is only about 1500 pounds. A 100-bushel crop of corn contains 17 pounds of phosphorus in the grain alone. Thus the acid-soluble phosphorus is sufficient for 59 such crops, if only the grain is removed from the land; while the total supply of phosphorus would be sufficient for only 88 such crops. The sub-soil is more deficient than the face, in phosphorus. These figures are not given as tentative; they are based upon sufficient accurate analytical data from large numbers of representative soil samples collected with the greatest possible care from all of the great soil areas in the state to justify us in saying that they are, in round numbers, exact and final. The chemical analyses have not been made by one chemist alone, but seven different soil analysts, than whom there are, today, none more experienced or more accurate, have had part in this analytical work. L. H. Smith, J. H. Pettit, E. M. East, W. F. Pate, I. O. Schaub, C. A. Schroeder and Andrew Ystgard are these analysts. They represent the training of Johns Hopkins and Cornell Universities, of the well known Chemical Department of the North Carolina Agricultural College, of the scientific schools of Norway, of the Chemical Department of the University of Illinois, and the experience and practice received in the Illinois Experiment Station.

In addition to the chemical analyses there are the University Soil Experiment fields in all parts of the state, all in charge of our Superintendent, J. E. Readhimer, to whose faithfulness and accuracy twenty progressive farmers can testify,—farmers upon whose lands these soil experiment fields are located and to whom great credit is due for their watchful care of the fields, for their assistance to the Experiment Station, and for the valuable service which they thus render to the state.

Hundreds of farmers are also watching these experiment fields as the work goes on from year to year.

Furthermore, your own committee upon soil investigations, frequently accompanied by Director Davenport and by agricultural editors, annually visits nearly all of these soil experiment fields, giving of their own time that they may watch the progress of the investigations and inspect the actual work in the field, not only on the soil experiment fields, but also on the soil survey, which is being prosecuted with a degree of accuracy and industry which commands the respect of
visitors who have the time and energy to follow such men as J. G. Mosier, Clifford Willis, R. C. Lloyd, and E. L. Worthen, through the fields and over the hedges, criss-cross, and forward and back, from seven in the morning till six at night, everywhere examining the soil to a depth of 40 inches or more.

The fact was clearly determined and definitely established more than two years ago that the supply of phosphorus in most Illinois soils is limited; indeed, most farmers who read the bulletins from the Experiment Station or any of the leading agricultural papers of Illinois, or who attend farmers' institutes, are not only well informed as to the need of phosphorus in Illinois soils, but many of them are already using on their own farms liberal amounts of phosphorus in connection with legumes and farm manure.

THE STATE'S INTEREST IN SOIL INVESTIGATIONS.

Gentlemen of the Illinois Farmers' Institute, the thing of first importance to Illinois is not that we have grown larger crops with greater profits. The fact of greatest moment to Illinois is not that the Experiment Station has grown 73 bushels of corn per acre on the peaty swamp land of Kankakee county by the addition of potassium, while only 4 bushels were grown without potassium on similar adjoining land. The work of highest interest to Illinois is not that we have increased the yield of corn 13 bushels per acre on the most valuable land in McLean county by the addition of phosphorus and that half of this increase was net profit. The result of chief significance to Illinois is not that we have increased the yield of wheat in Washington county by the addition of phosphorus from 9 to 31 bushels and, on a duplicate field, from 11 to 33 bushels per acre, the 33 bushels being worth 15 cents more per bushel than the 11 bushels. The accomplishment of maximum value to Illinois is not that we have produced two tons to the acre of red clover hay by means of limestone and phosphorus and proper inoculation on the ordinary prairie soils of Effingham county, where red clover was never grown before. No, not these. But the thing of first importance, the fact of greatest moment, the work of highest interest, the result of chief significance, the accomplishment of maximum value, and the only achievement of permanent benefit to Illinois is that the soils which are producing these increased crop yields are being made richer and not poorer.

When we apply phosphorus sufficient for a hundred-bushel crop of corn and thereby increase the yield from 60 to 73 bushels, it is of only temporary interest to the farmer that one-half of this 13-bushel
increase is net profit, but the fact which interests the State is that the field which produced the 73 bushels is still richer than it was by an amount of phosphorus equal to 27 bushels of corn, while the untreated field is poorer by the phosphorus removed in 60 bushels.

Most Illinois soils are still rich and highly productive. The average yield of corn in the Corn Belt is I think more than 40 bushels per acre, and the average yield for the entire state is 33 bushels. Much of our richest land has been drained out and put under cultivation during the past 20 years. We are still growing large crops and there is no need for any sensation, but there is need for sense, and the time is now here when we should stop depleting our soils of plant food elements which already limit our crop yields and begin returning in liberal quantities the plant food needed to grow still larger crops. If we fail to do this while we are raising 40 to 60 bushels of corn per acre, how can we hope to be able to do it if our yields shall become reduced to 20 or 30 bushels? But if we can adopt a permanent system and by so doing make our farming more profitable in building up the soil than it would be in running it down, then how much greater is our sin, if in our prosperity we neglect our opportunity and our duty, and afterward turn over to our children an impoverished soil!

**FORMS OF PHOSPHORUS FOR ILLINOIS SOILS.**

The annual corn crop of Illinois is more than three hundred million bushels. More than fifty million pounds of the element phosphorus is removed from the soil in this crop, even though all of the stalks are left on the land. The phosphorus in all other crops will surely exceed the amount returned in manure; so that there are at least fifty million pounds of phosphorus annually removed from Illinois soils. At 12 cents a pound for phosphorus, the present price in acid phosphate, this would cost six million dollars annually. At 3 cents a pound for phosphorus, the present price in raw rock phosphate, it would cost Illinois one and one-half million dollars annually to replace this amount of phosphorus, and this is the lowest priced form of phosphorus in the world today. I do not know which form of phosphorus will prove the most economical and the most profitable to use under the varying conditions and the different lengths of time involved in its use; but I do know this: that one of the greatest, if not the greatest, problem which is to confront the people of Illinois is the phosphorus problem; and I believe that the time is now here when every Illinois land owner should adopt a system of farming which shall tend to increase rather than diminish the supply of phosphorus in his soil. I say LANDOWNER
because I have no right to expect tenant farmers to pay out their money to build up my soil. If the land owner furnishes phosphorus, or lime, or other materials at the nearest railway station, then the man who farms the land, should haul such materials to the farm and properly apply them to the soil.

I firmly believe that the supply of phosphorus in Illinois soils can be profitably maintained by the use of sufficiently large quantities of acid phosphate; and if the continued use of acid phosphate finally produces such acid conditions in the soil as to prevent the growth of clover as appears to have been a common occurrence where it has long been used, then the acidity can be corrected from time to time by applications of some form of lime.

At present prices we can profitably substitute for acid phosphate steamed bone meal, which is known to be a satisfactory form of phosphorus, and thus avoid the possible injurious effect of acid phosphate, but this suggestion could not be adopted by any large proportion of the farmers of this country because of the limited supply of bone meal.

The only very extensive supply of phosphorus is the natural rock phosphate, from which acid phosphate is made by mixing a ton of rock phosphate, with about a ton of sulfuric acid (oil of vitriol), the resulting acid phosphate being sold for about $15 a ton, or $30 for the two tons of material which contain no more phosphorus than the original one ton of raw rock phosphate, which we get for about $8 delivered in Illinois.

As to the value of non-acidulated, finely ground natural rock phosphate, I consider this as a material which gives great promise of extensive use in the economic and profitable improvement of poor soils and in the maintenance of large crop yields on good soils, especially in the states throughout the great central West. It should be distinctly understood, however, that repeated experiments have shown that this material gives practically no immediate returns if used in the absence of decaying organic matter. On the other hand, when used in intimate connection with liberal amounts of farm manure or green manures or both, we have conclusive evidence that it is one of the most economic and profitable forms of phosphorus, especially where the crop returns for a series of years are to be taken into account.

In exact pot-culture experiments carried on under controlled conditions at the University of Illinois, ground rock phosphate used in connection with clover and manure has produced some marked results. Extensive field experiments in operation in our state and in other
states also point in the same direction, although the Illinois experiments have not been carried on for a sufficient length of time to justify final conclusions. In 1904, on the University fields at Urbana where we had applied rock phosphate without manure, it produced 4.1 bushels increase in the corn crop, as an average of 16 separate tests. Where we had applied both rock phosphate and farm manure, the rock phosphate produced an increase of 8.1 bushels of corn per acre, as compared with the manure alone, this also being the average of 16 separate tests. The rock phosphate was applied in amounts from 1000 to 2000 pounds per acre and 1000 pounds per acre of ground limestone was applied with it for the special benefit of legume crops which are to follow in the rotation. The eight bushels increase would more than pay for one-fourth of the expense for both phosphate and limestone, even with the 2000 pounds of phosphate applied every four years. In both cases the results were more marked than we had expected.

I have received only two letters from Illinois farmers giving the results from their trials with rock phosphate in 1904. One of these is from Mr. James A. Dewey, a graduate of the Illinois Agricultural College, who is operating a farm in Vermilion County, and the other from a gentleman with whom I am not acquainted, Mr. J. O. Winship, of Putnam County. I feel sure that it will be of interest to you if I quote these two letters in full.

Mr. Dewey writes as follows under date of December 30, 1904:

PROF. C. G. HOPKINS,

University of Illinois, Urbana.

My Dear Mr. Hopkins: I enclose with this a plat of the field upon which the 30 tons of phosphate rock was sowed last spring. The portion of the plots, their treatment and area and the yield per acre of each is indicated. I send this as partial payment for the bone meal (1000-lb.) the Experiment Station sent me to check against the rock. For the rest of the payment please accept my gratitude for your kindness.

In determining the yields a certain number of rows, generally 16 or a day’s husking was taken from as near the center of the plot as possible. In plots VI and IX the tests were made of rows adjacent to the plots to be compared. Rows of corn upon the dividing lines of two plots were not included.

The returns from all the plots I am sure are reliable, save in plot I. My man here, perhaps accidentally, I fear, maliciously, mixed things up and no reliance can be placed on his record. The yield indicated by his work was 55.6 bu. Of course he was eliminated immediately from the experiment but the true yield of plot I is lost. Plots II, III, V and VI (west end) must rely on plot IV for their check.
On this basis, plot II shows an increase of 5.1 bu. from the application of 1 ton rock per acre—an increase of 9.8 percent over the area not treated (plot IV) while plot III, where one-half ton of rock per acre was applied, shows an increase of 3.2 bu. or 6.1 percent over the control (plot IV). On the east of the control plot is an area of 2 acres upon which 200 lbs. per acre of bone meal was spread. Its yield is nearly that of plot II being 5.7 bu. increase or 10.9 percent.

In plot VI (west end) we meet a surprise in that the half ton of rock makes a better showing than the bone meal. There is a gain of 6.6 bushel or 12.6 percent. There is a very gentle slope as we proceed from the west side of the field to the center of plot VI so that the difference in yield between plots III and VI (west side) of 3.4 bu. is explicable as plot VI (west side) lies a trifle lower and this season this was an advantage. Upon all these plots about 8 tons of manure was scattered by means of a manure spreader, the fall previous and turned under in the fall. Would not this experiment indicate that for such a season as 1904 that manure and rock one-half ton per acre is as valuable as manure and 200 pounds bone meal?

The eastern plots were upon fall plowed ground that had received no application of manure the year previous. It lay generally higher too, which was unfavorable for large yields last year. The control made a yield of 39.7 bu. while the areas receiving one-half ton of phosphate rock [plot VI (east end) and IX (west end)] made an average yield of 44.6 bu. These two plots vary very little from this average. This average is an increase of 4.9 bu. over the control or 12.3 percent. When 200 pounds bone meal was applied our increase is 8.5 bu. or 21.4 percent over the plot receiving no treatment. Bone meal in soil deficient in humus seems to be quite superior to the rock. During the growing season there seemed to be no difference in the plots so that the results of the husking come as a surprise to me. The only visible difference was in the amount of down corn, plots IV and VIII suffering much worse than the treated areas,—so much so that the man shucking out plot VIII suggested I give him an extra one-half cent per bu. for the work. As the area was small I didn’t take kindly to the suggestion.

You sent me 1000 pounds of bone as I intended to apply 250 pounds per acre of it which is about equivalent in price to one-half ton of rock. But as the sacks containing the bone were delivered in bad condition, I received a little less than 900 pounds and so applied but 200 pounds per acre to the four acres tested.

I cannot but think the results quite remarkable as I expected no returns the first year from the rock. Especially am
I surprised that we should get results during such a season. The spring opened very late so that the application was made immediately before the disking before the planter. After the season once opened it was very dry throughout the summer and fall—a feature generally unfavorable for a good showing for fertilizers. I shall put this field in corn again next season and then we will expect great things indeed.

A sample of soil taken from plot VI at the point indicated by the star was analyzed in the soil fertility laboratory last year with the following result:

<table>
<thead>
<tr>
<th>Depth Range</th>
<th>Nitrogen</th>
<th>Phosphorus</th>
<th>Potassium</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&quot; to 7&quot;</td>
<td>.2757%</td>
<td>.046%</td>
<td>.539%</td>
</tr>
<tr>
<td>7&quot; to 16&quot;</td>
<td>.1604%</td>
<td>.023%</td>
<td></td>
</tr>
<tr>
<td>20&quot; to 26&quot;</td>
<td>.0647%</td>
<td>.020%</td>
<td></td>
</tr>
</tbody>
</table>

It will be seen that while the nitrogen content is nearly up to standard and with potassium far above, the phosphorus percent is not half what it should be.

Pot cultures were also run from soil taken from this point. I have not as yet received the data from these pot cultures, but Mr. Eckhardt has it at hand and can furnish it to you if you would like it. With these field tests reported here, the chemical analyses, and the pot cultures I feel that I know this soil quite thoroughly.

I wish to thank you again for your assistance and to express to you my entire willingness to undertake the solution of any problem in soil fertility, etc., that I am able to do. I will be glad to hear from you at any time.

Yours truly,

JAMES A. DEWEY.

Mr. Winship writes as follows:

"PUTNAM, PUTNAM CO., ILL.
JAN. 16TH, 1905.

Dear Sir: Last winter I wrote you concerning soil fertility and fertilizers and thought it might interest you to hear the result. In all I applied 10 tons of ground limestone on old clay soil and 22 tons of phosphate (Tenn. rock) on both clay and prairie soils 600 to 800 pounds per acre on both oats and corn land. My experiments agree very closely with the published results of your Ex. On oat land in corn stalks I applied 600 lbs. per acre without the aid of legumes or manure and sowed clover seed at same time all at oat seeding time. The increase in oat yield was 6 bu. per acre or about one bu. increase for each 100 pounds rock phosphate. The growth of clover was great and was the admiration of all my neighbors. On corn land I applied 600 to 800 pounds rock phosphate per acre, partly in connection with manure, partly with clover, partly without either and on the clay I also applied 1400 to 1800 lbs. ground limestone per acre. On one experiment plot I applied 10 loads cow yard manure largely mixed with dirt and fine the fall before, and in spring following
applied 1400 lbs. rock phosphate and 1800 lbs. lime per acre and on this plot of old worn clay I raised 90 bu. corn per acre of first quality and there was scarcely a barren stalk on the plot. 10 loads of manure and 800 lbs. phosphate, 1800 lbs. lime produced 80 bu. corn; and the same lime and manure, 600 lbs. phosphate, (gave) 70 to 75 bushels of corn per acre; phosphate and clover and lime, 80 bu. per acre; phosphate alone gave an increase of one bushel of corn to each 100 lbs. rock phosphate. The phosphate and lime were sown on fall plowing and disked in. I sowed clover in the corn at last plowing and got a good stand. The above all on worn clay land. The oats were sown on prairie soil. I applied 600 lbs. rock phosphate per acre to 10 acres prairie corn land but did not apply manure and the field had been cropped in corn and oats for several years, the increase in yield was however the same as on the clay, one bushel for each 100 lbs. of rock phosphate. Therefore, I conclude that 500 lbs. rock phosphate is not enough for the first application. 10 loads of manure and 1000 lbs. of phosphate make a nice application but I think more phosphate is better. One thing surprised me and that was, the more natural fertility the soil contained the more marked was the increase where the phosphate was applied. I should have stated that the above clay fields would have produced 40 bu. per acre this year without fertilizers as it was a very favorable year for corn and that was the yield on the fields not fertilized. I am so well pleased that I shall apply 25 tons more rock phosphate this year. Yours respectfully,

J. O. WINSHIP.

Probably the most reliable and valuable experiments ever conducted with raw rock phosphate are those in progress at the Ohio Experiment Station, where careful field experiments with the use of this material in connection with farm manure and clover have been carried on during the past eight years, duplicate experiments having been made each year with each of the different crops included in a three-year rotation of corn, wheat and clover. Based upon the increased crop yields produced where ground rock phosphate was mixed with the manure previous to the application of the manure to the clover sod to be plowed under for corn, as compared with the use of the same manure without rock phosphate, these soil experiments have shown that the addition of the ground rock phosphate increased the value of the manure more than 60 percent. In other words, as an average of 42 different tests extending over a period of seven years (I have not yet seen the results for 1904), the average value of farm manure was found to be $1.99 per ton, measured in increased crop yields produced; but, when forty pounds of finely ground rock phos-
phate were added to the ton of manure, its average value was found to be $3.23 per ton, making an increased value due to the addition of the phosphorus of $1.24 per ton of manure.

At the present price of ground raw rock phosphate delivered in Illinois, namely $8 per ton, the forty pounds of raw rock phosphate would cost 16 cents, which would leave an added net profit of $1.08 for every ton of manure with which the phosphate is mixed. It is worthy of special note that in this same series of Ohio experiments 16 cents' worth of raw rock phosphate has produced almost as large an increase in the crop yields as 30 cents' worth of ordinary acid phosphate, the use of which gave an added net return of $1.18 for each ton of manure with which the acid phosphate was mixed. As an average of 42 tests with each material, $1.00 invested in raw rock phosphate made a net profit of $6.75, and $1.00 invested in acid phosphate made a net profit of $3.93. Furthermore the forty pounds of untreated rock phosphate is enriching the soil in phosphorus twice as much as the forty pounds of acid phosphate; consequently, in the long run, the untreated rock phosphate must produce the more lasting results.

METHODS OF USING ROCK PHOSPHATE.

In my opinion somewhat larger quantities of the raw rock phosphate should be mixed with the manure to insure the maximum profitable crop yields on soils deficient in phosphorus. I am practicing and advising the addition of 100 pounds of finely ground rock phosphate to be mixed with each ton of manure. The phosphate may be scattered over the manure from day to day as the manure is being made in the stable or in the feed lot; indeed, this appears to be the ideal method of using it; or, when loading the manure onto the manure spreader from the yard or stall, the spreader box may be loaded half full, then 100 pounds of rock phosphate scattered over the manure as uniformly as possible, and after completing the load of manure it may be hauled to the field and spread.

If farm manure is not available, then I advise applying from 1000 to 2000 pounds of finely ground rock phosphate per acre every three to six years, depending upon the length of the rotation. In this case the phosphate should be applied to clover sod or to a catch crop of cowpeas, soy beans, etc., and plowed under with as much organic matter as practicable. With a three-year rotation of corn, wheat, and clover, or corn, oats and clover, 1000 pounds of rock phosphate may be applied to the clover sod and turned under, preferably in connection with the second crop of clover, which often is worth more to turn under than it
is to cut for seed. With a six-year rotation of corn, oats, wheat, clover, timothy, and pasture, one ton per acre of rock phosphate may be applied to the pasture-ground in connection with farm manure and plowed under for corn, preferably with a considerable growth of grass and clover.

In considering the purchase and use of finely ground rock phosphate, attention is called to the fact that this is a form of phosphorus originally provided in the soil by nature. Virgin soils do not contain bone meal or acid phosphate.

It is fast becoming evident that we can profitably use raw rock phosphate in sufficient quantities for more than maximum crop yields and thus gradually actually enrich the soil in that element, but we still have to provide for the permanent maintenance of a sufficient supply of nitrogen and potassium.

THE SUPPLY OF POTASSIUM IN ILLINOIS SOILS.

It should always be borne in mind that our ordinary soils are exceedingly rich in potassium soluble in strong acid, as determined in the ordinary chemical analysis. Thus, the common prairie soils of the Corn Belt in Illinois contain more than 8000 pounds of acid-soluble potassium per acre to a depth of 7 inches, and even larger amounts in the clayey subsoils. In addition to this it should also be kept in mind that only one-fourth of the total potassium in the soil is soluble in this acid solution, although it is by no means sure that much of the so-called insoluble potassium will not be made available by the same system of farming which seems necessary to make raw rock phosphate available namely, by a liberal use of decaying organic matter, as farm manure, legume crops and catch crops, and other green manures. Please note these figures: One hundred bushels of corn contain 19 pounds of the element potassium. If the corn stover is kept on the farm, either by burning in the field, or by cutting and plowing under, which is a much better practice as a rule or by feeding and returning the manure to the land, which is probably the best practice, in either case if only the grain is sold from the farm the total loss of potassium is but 19 pounds for a hundred-bushel crop of corn. The 8000 pounds of acid-soluble potassium contained in the plowed soil of one acre is sufficient for 420 hundred-bushel crops of corn; while the total potassium in the plowed soil of the average land of the Corn Belt is sufficient for a 100-bushel crop of corn every year for 1700 years. Considering this enormous supply of potassium and the additional fact that applications of potassium to this soil commonly produce an injurious effect on the corn crop, we
are not yet ready to use any so-called "complete" fertilizer containing two pounds of potassium to the hundred, not even if we do sell 19 pounds of potassium in 100 bushels of corn.

It should be understood that if all crops grown on the farm are fed, plenty of bedding being used, and all solid and liquid manure returned to the land, the original supply of potassium will be indefinitely maintained; and even if some of the most valuable grains are sold from the farm, the loss of potassium is insignificant compared with the enormous store in our soils.

Of course on soils already deficient in potassium, as peaty swamp soils, potassium should be applied in some form, preferably, and most cheaply, as potassium chloride or potassium sulfate, unless one has abundance of farm manure not needed on other land.

THE SUPPLY OF NITROGEN FOR ILLINOIS AGRICULTURE.

Regarding nitrogen it may be said that no agricultural fact is better established than this: That the atmosphere is the only inexhaustible, and the most economical, source of nitrogen for plant food for all general farming. With good drainage and good physical conditions and with abundance of phosphorus and potassium provided, about the only possible difficulty in the way of successful crops of clover or other legumes in normal seasons is the present or future acidity of the soil. All soils tend to become acid with long cultivation. Many reactions going on naturally in all good soils tend to destroy the limestone and other basic or alkaline materials in the soil; thus there is already a need for some form of lime on some Illinois soils of great area, and there will be a continuous need for such material on still larger areas as time goes on. Consequently it seems that some mention of the lime question must be made in connection with nitrogen and legumes, for both the nitrogen-gathering bacteria and the nitrifying bacteria are not active and effective in acid soils.

THE USE OF LIME ON SOILS AND THE KINDS OF LIME TO USE.

There are two distinctly different forms of lime: One is known as caustic lime, or burned lime; and the other as carbonate of lime or the natural form, such as limestone or marble.

There are two principal effects produced by using lime on soils: One of these is to correct the acidity of the soil, and the other is to decompose the soil itself. To correct the acidity of sour soils is certainly a very desirable and profitable use of lime. Clover, alfalfa, alsike, cowpeas, soy beans, and many other legumes will not thrive on soils which are strongly acid. To be sure such crops can be made to grow on acid
soils by liberal applications of farm manure or other complete fertilizers, but the nitrogen-gathering bacteria of the legume plants do not properly develop and multiply in acid soils and consequently the legumes do not have the power which they should have to accumulate large quantities of atmospheric nitrogen by means of the bacteria which inhabit, or should inhabit, their roots. Furthermore, the process which is termed nitrification by which the nitrifying bacteria transform the insoluble organic nitrogen, in farm manure and plant residues, into soluble nitrate nitrogen, the form in which it becomes available as plant food, is greatly promoted by the presence of lime and retarded by acid conditions.

It will thus be seen that the use of some form of lime for correcting the acidity of soils and thus encouraging the growth of clover and other legumes with their wonderful power to enrich the soil is certainly good farm practice.

Any form of lime which is finely divided and can be thoroughly mixed with the soil will serve to correct the soil acidity, whether it be ground limestone, marl, or chalk, or fresh burned lime, water-slacked lime, or air-slacked lime.

The other effect produced by lime, the effect for which it has been most used in past ages, is the decomposition of the soil itself. In this decomposition the organic matter of the soil is destroyed with the liberation of nitrogen and phosphorus held in organic form and the mineral particles of the soil are disintegrated with the liberation of some plant food elements, as potassium and phosphorus held in inorganic form. This effect is produced only by fresh burned lime or fresh slacked lime. It is not produced by ground limestone or by old air-slacked lime.

Thus it will be seen that the first effect of lime, the correction of soil acidity, results in a building-up process through the increased growth of legumes and nitrogen-gathering bacteria; while the second effect, the decomposition of the soil, is in all respects a destructive process, serving only to liberate and reduce the stock of plant food stored in the soil. Whether this second effect is desirable will depend upon the nature of the soil itself. On soils which are exceedingly rich in organic matter, such as peaty soils and other swamp soils, it would seem altogether rational to make use of caustic lime to hasten the decomposition of the soil and consequent liberation of nitrogen, if such treatment is necessary.

There may possibly be conditions under which soils contain large
amounts of phosphorus and potassium, which are too slowly available for profitable crop production, and in such cases it might be good farm practice for a time to make use of caustic lime to hasten the liberation of these mineral elements of plant food. We should bear in mind, however, that this use of lime on a soil which is already deficient in nitrogen, phosphorus, or potassium only serves to still further exhaust the soil of its meager supply of those elements. Without a doubt this is the most common condition and the most common effect of the use of caustic lime (fresh burned lime or water-slacked lime). Probably no method of treatment will exhaust such lands more rapidly than heavy or frequent applications of caustic lime. It is true that the immediate effect is usually somewhat increased crops, but it should be borne in mind that when a farmer pays out money for caustic lime to be used for this purpose he is purchasing only a stimulant which will ultimately leave his land in worse condition than before, especially in the loss of nitrogen and organic matter, and in the exhaustion of phosphorus and potassium from the soil. In other words, this use of lime if continued tends rapidly to exhaust the soil and ultimately to leave it practically ruined. In this connection it may be stated that gypsum or land plaster produces a similar effect as far as the mineral elements are concerned, although it does not effect the destruction of the organic matter as the caustic lime does.

As a general rule, the farmer should use lime only to correct the acidity of the soil, and this is only necessary where there is difficulty in obtaining a good stand and luxuriant growth of a leguminous crop, such as red clover. Probably one ton to the acre will be sufficient on any soil which has in past years grown red clover successfully. Heavier applications may be required on soils where red clover has never been successfully grown. As to the form of lime to use for this purpose, the farmer should be governed very largely by the cost of the material. Fine-ground limestone will be the most economical form of lime to use wherever it can easily be obtained.

It would be expected that burned lime would produce a greater increase in the crops for the first year or two than would be produced by the ground limestone, more especially where the mineral elements, phosphorus and potassium, are not applied; for the reason that ground limestone produces practically no effect except to correct the acidity of the soil and thus encourage the multiplication and activity of the nitrogen-gathering and nitrifying bacteria, whereas, the burned lime not only produces this same effect, but it also acts as a soil stimulant,
or soil destroyer, attacking and destroying the organic matter and de­
composing the mineral constituents and thus liberating plant food
from the soil. The use of ground limestone to correct acidity and in­
crease the fixation of atmospheric nitrogen is certainly altogether
legitimate and commendable, but to use burned lime to force the soil
to give up plant food more rapidly than it would otherwise furnish,
thus producing an increase in the first few crops, but ultimately leav­
ing the soil more impoverished than before the lime was applied, is
not thought to be advisable or profitable in the long run, unless the
soil contains comparatively large stores of unavailable plant food and
abundant organic matter, which is certainly not the case with most
soils.

In this connection it seems very appropriate to call attention to a
series of experiments which have been carried on by the Pennsylvania
Experiment Station, probably the most extended investigation ever
conducted relating to the use of burned lime and ground limestone in
comparative tests. Four plots were treated with burned lime (slacked
before being spread) at the rate of two tons per acre once in four years.
Four other plots were treated with ground limestone at the rate at
two tons per acre every two years. A four-year rotation was practiced con­
sisting of corn, oats, wheat and hay, the hay being mixed timothy and
clover, seeded on the wheat land in the spring. By having four sets of
plots, each crop was grown every year. Seven products were obtained
and weighed each year; namely, corn, corn stover, oats, oat straw,
wheat, wheat straw, and hay.

After twenty years' results had been obtained (1882 to 1901), the
Pennsylvania Station reports data showing that with every product a
greater total yield had been obtained from the plots treated with lime­
stone than from those treated with burned lime. This is certainly
significant. Furthermore, with every product whose total yield for
the last eight years was greater than the total yield of the first eight
years the limestone produced a greater increase than the burned lime;
and with every product whose total yield for the last eight years was
less than the total yield for the first eight years, the decrease was less
where limestone was used than where burned lime was applied (oat
straw alone excepted). This is even more significant, in that it dem­
onstrates the tendency of burned lime with continued use to exhaust
or destroy the fertility of the soil.

After these experiments had been in progress for sixteen years, the
soil of each of the four plots in each test was sampled for analysis. The
average nitrogen content of the four plots receiving ground limestone was found to be 2,979 pounds per acre to a depth of 9 inches, while only 2,604 pounds were found in the soil treated with burned lime. This difference of 375 pounds of nitrogen is equal to the nitrogen contained in 37½ tons of farm manure. In other words, the data indicate that the effect of burned lime as compared with limestone was equal to the destruction of 37½ tons of farm manure in 16 years, or more than two tons a year to the acre.

The estimation of humus in these soils, based upon the determination of organic carbon showed the soil receiving limestone to contain 38.9 tons of humus per acre to a depth of 9 inches (counting 300,000 pounds of soil to the acre-inch), while only 34.2 tons of humus remained in the soil treated with burned lime. If 4 tons of farm manure contain only 1 ton of dry matter (average fresh farm manure contains about 75 percent of water), and if two tons of such dry matter would be required to make 1 ton of humus (when exposed to the weather manure usually loses half of its dry matter content within one year or less), then this difference of 4.7 tons of humus would be equal to 37.6 tons of fresh farm manure, which represents the loss from the destructive action of burned lime as compared with ground limestone.

If it is true, as indicated by the Pennsylvania experiments, that 8 tons of burned lime, applied during 16 years, destroyed organic matter equivalent to 37 tons of farm manure, or more than 4½ tons of manure destroyed for each ton of burned lime used, as compared with ground limestone, and if larger crops were obtained where limestone was used, especially where the practice is extended over several years, and, if the ground limestone is sustaining the productive capacity of the soil much better than burned lime, then, as a very general rule, we should avoid applying burned lime to the land, but make liberal use of ground limestone where needed to correct the acidity of the soil. And may we not call attention to the fact that limestone is the form of lime originally provided in the soil by nature? Among the most valuable and durable soils in the world are the limestone soils. They do not contain burned lime.

**SUMMARY.**

In summarizing, I would say that while we do not have complete, definite, and final knowledge regarding all questions involved, we certainly do have sufficient information and data to justify a decision to discard any agricultural system which continually decreases the amount of any element of plant food which is already so deficient in
the soil as to limit the yield of crops, to discard any system which ultimately and inevitably must leave an impoverished land and an impoverished people, indeed, to discard any system under which the soil is made to produce smaller crops than when first the virgin sod was broken, to discard the use of gypsum and caustic lime as stimulants or soil-destroyers for the sole purpose of forcing the soil to give up even more of some deficient plant food element than it would otherwise furnish, and even to discard the use of acid phosphate when applied in such small quantities that a good crop is obtained only by the combined effect of the phosphorus added, together with that naturally liberated from the soil and that forced from the soil by the manufactured gypsum contained in the acid phosphate.

Can we not adopt a system of profitable farming which shall permanently insure a high productive capacity of the soil and which shall be of unlimited practical application? I firmly believe we can. For ordinary soils I believe such a system will include:

1. Thorough underdrainage wherever needed.
2. Applications of ground natural limestone whenever necessary to correct and prevent soil acidity.
3. Continued use of large quantities of fine ground natural rock phosphate (or some other form of phosphorus) in connection with decaying organic matter by which the phosphorus is made available, and by this means gradually increasing the total phosphorus content of the soil, even though maximum crops are removed.
4. Liberal use of clover and other legumes in rotation and as catch crops, by which nitrogen and organic matter will be added to the soil.
5. Feeding of all crops excepting some of the most valuable grains or other high-priced products and returning all manure to the land, by which means, the supply of potassium, the most abundant plant food element in our common soils, will be practically maintained. The manure together with the legume crop residues will effect an increase or permanent maintenance of the supply of nitrogen and organic matter in the soil.

With the use of sufficient limestone to keep the soil sweet and abundant use of legume crops and catch crops, and the addition to the soil of a ton of ground rock phosphate, or its equivalent, every six or eight years, in connection with all of the farm manure which can be made, the ordinary lands of the Central West can be made to grow large crops indefinitely.

This, I believe, will be the ILLINOIS SYSTEM, and the system for
general farming on the ordinary soils of all the states here in the great Agricultural West, the present and, may we say, the future granary of the world. Essentially by this system of soil improvement and soil maintenance, I believe the farmers and landowners of the Central United States will reject the world's historic verdict: "Westward the Course of Empire takes its way," and erect a new Standard which shall say: "Here a permanent Agriculture holds sway."

**THE PURCHASE AND APPLICATION OF MATERIALS.**

Ground limestone can be obtained for about $1.00 a ton (and freight) from the Crystal Carbonate Lime Company, Elsberry, Missouri, or from the Mitchell Lime Company, Mitchell, Indiana. So far as known to the writer, there is no place in Illinois where finely-ground limestone is offered for sale, although there is excellent limestone in many places in the state, especially along the Mississippi river, as at Quincy, and in the Ozark Hills, in the southern part of the state, as at Anna.

Steamed bone meal can be obtained for $25 to $30 a ton from local agents of Armour Fertilizer Works, Morris & Company, Swift & Company, and other packers of the Union Stock Yards, Chicago, Illinois.

Ground rock phosphate can be obtained in carload lots for about $8.00 a ton (including freight) from Robin Jones, Nashville, Tennessee, or from the N. Y. & St. L. Mining & Mfg. Company, St. Louis, Mo.

Steamed bone meal can be applied with any good force-feed seeder or with a fertilizer drill. Ground rock phosphate or ground limestone can be applied with an end-gate seeder or with an “agitator-feed” grain seeder, but neither of these is made of sufficient capacity or strength for very satisfactory use, and they are sometimes broken when used to sow these materials. The most satisfactory implement which we have tried for making heavy applications of limestone or rock phosphate is the Stevens Fertilizer Sower, which sows a strip 8 feet, 3 inches (4 rod) wide. This is manufactured by the Belcher & Taylor Agricultural Tool Company, Chicopee Falls, Mass. This machine costs about $40 and freight, while an “agitator-feed” seeder of the same width can be bought from local agents of Illinois manufacturers for $16 or $18.

The Ohio Experiment Station reports that a very satisfactory machine for sowing limestone, rock phosphate, etc., can be made for less than $20 by a blacksmith and a carpenter, using a pair of old mower wheels to start with. The axles are cut off a few inches from the wheels and a strong rod about 8½ feet long welded or bolted onto these axles, thus putting the wheels about 9 feet apart and retaining
the use of the ratchets in the wheels. A box or hopper is built with a
double bottom, the lower one being made to slide endwise and thus to
open or close the holes which are made through the double bottom.
The rod connecting the two wheels runs through the box near the
bottom and some sort of iron straps are attached to this axle rod,
about the same as in the "agitator feed" seeders, so that when a
tongue is attached to the box frame and the machine drawn forward,
the axle rod rotates with the wheels and forces out the material in the
box, thus distributing it broadcast on the land.

Wherever possible the rock phosphate should be mixed with the
manure as it is being made in the stall or covered feed lot.

Gentlemen of the Illinois State Farmers' Institute, I ask you to
pardon me if I make some personal remarks. The Illinois State
Farmers' Institute is the organization which first asked for an appro­
priation for the investigation of Illinois soils. For that reason this
organization stands as a guardian over the soils of this state, that their
fertility and productive capacity may be preserved for all future gen­
erations; and it seems to me entirely appropriate that what I am about
to say I should say to this organization.

After I had become convinced that the low-priced lands of the
Lower Illinois Glaciation, comprising about twenty-five counties in
Southern Illinois, could be profitably improved, and after the results
of investigation showing marked improvement in those soils had been
published and republished throughout the state, I bought a farm in
Southern Illinois, expecting to improve it. My object or purpose in
the investment was three-fold; first, personal financial gain from the
profits of the business; second, a closer personal touch with the practi­
cal business of improving a worn out farm; third, a desire to demon­
strate on a good sized farm, and with my own money, that such im­
provement by practical scientific methods is possible and profitable.

Again, after I had become convinced that the element phosphorus
is deficient in most Illinois soils, that this element must be applied to
many of our soils if they are to produce and to continue to produce
maximum profitable crop yields, and after these facts and the data
upon which they were based had been published and republished
throughout the state for two years, I bought phosphorus; I invested
in a phosphate company; I secured all the phosphate stock I could
obtain; and I have suggested to others, as I have had opportunity,
that they might well do the same. Here, again, my object or purpose
was three-fold: first, to secure a supply of phosphorus for my own farm;
second, personal financial gain from the phosphate stock obtained;
third, the desire to have Illinois farmers and land owners obtain con­
trol, if possible, of a supply of phosphorus sufficient for the needs of
Illinois soils.

Under the authority of the University of Illinois and the Director
of the Agricultural Experiment Station and the Advisory Committee from the State Farmers’ Institute, I am charged with the investigation of Illinois soils; but I have assumed that after the facts above referred to had been widely published throughout the state, then I had the same right as any other citizen of Illinois to invest in Southern Illinois land, to purchase phosphorus, to secure stock in a phosphate company, or to advise others to do the same.

I mention this matter because some are reported to have raised the question whether I ought to have taken any interest in a phosphate company or to have induced Illinois farmers or others interested in Illinois agriculture to invest in phosphate property.

Certainly I would have no right to keep secret any information relating to the investigation of Illinois soils until I should profit therefrom or thereby obtain some undue advantage, but I have assumed, and still assume, that after such information has been given wide publicity then I would have the same right to profit from those investigations as has any other citizen of this state. I believe this would be true even if the phosphate deposit were in Illinois and if it were the only source of phosphorus for this state; but, as a matter of fact, this phosphate property is only a part of the great phosphate deposit in Tennessee. It is not necessary that any Illinois farmer should ever purchase phosphorus from the company in which I am interested (there are others); neither is it necessary for the success of this company that it should ever sell a ton of rock phosphate in Illinois; the markets of the world are open and a million tons is the annual American export.

I believe it is due to this Association and to the Experiment Station, to myself and to my associates that I should present to you a brief chronological history of these transactions:

The first appropriation for the investigation of Illinois soils became available July 1, 1901.

In July, 1902, one year later, Bulletin No. 76, “Alfalfa on Illinois Soils,” was published, in which it was shown on the ordinary prairie soil of Illinois, as in Champaign County that “Applications of phosphorus to this soil were greatly to the advantage of the alfalfa crop.”

On September 29, 1902, I made a report of progress to the Board of Directors of the Illinois State Farmers’ Institute on the “Investigation of Illinois Soils,” which was soon afterward published and widely distributed by the Institute and by the Experiment Station. In this report it was pointed out that the soil analyses which had been made showed that the principal types of soil in several very large soil areas in the state were deficient in phosphorus.

Whenever I have suggested the advisability of using any material on the soils of Illinois, I have always tried to make it possible for any one to adopt the suggestion and for this reason I have constantly followed the practice of stating in reports and bulletins where such materials could be obtained, never for the purpose of advertising anybody’s goods, but always to give Illinois farmers necessary information,
which, if it were not given in the bulletins, would be called for by thousands of letters. Thus, in this report I stated that we had obtained pulverized lime from the Marble Head Lime Company, of Marble Head, Illinois, and from J. B. Speed & Company, of Milltown, Indiana; ground limestone from the Crystal Carbonate Lime Company, of Ellsberry Missouri; bone meal from the Armour Fertilizer Works, Union Stock Yards, Chicago, and potash salts from the German Kali Works, of New York.

On February 25, 1903, I gave an address before the Illinois State Farmers' Institute at Bloomington on the subject, "Methods of Maintaining the Productive Capacity of Illinois Soils," which was soon afterward published by the Experiment Station as Circular No. 68 and distributed to the Station's entire mailing list in Illinois. In that address I presented data from chemical analyses, from pot cultures, and from field experiments, all showing the great need of phosphorus for improving and permanently maintaining the productive capacity of most Illinois soils. Some of the statements which I made to this organization at Bloomington, two years ago this month are as follows:

1. "Nitrogen is free as air and potassium is abundant in nearly all of the soils of the state, and both nitrogen and potassium remain in the straw and corn stalks and in the farm manures to a considerable extent. Phosphorus, on the contrary, is present in nearly all soils in limited amounts and it is being continually removed from the land both by grain farming and live stock farming, although two or three times faster by grain farming than by the live stock system of farming."

2. "I believe that the purchase and intelligent use of phosphorus on many Illinois soils will ultimately pay a higher interest on the investment than the purchase of Illinois soils themselves."

3. "Phosphorus is the one element of fertility above all others which has a high absolute and permanent value to Illinois farmers."

4. "If there is any one factor more potent than others to finally ruin the agriculture of this state, to reduce all our lands to the level of the worn out lands of the Eastern States and of the countries of Europe, many of which cannot today produce their own supply of bread, I say if there is any one thing which shall ultimately bring this condition upon us or upon our children, I believe it is the loss of phosphorus."

I described, in that address, the three chief sources of phosphorus and mentioned that steamed bone meal could be bought "from fertilizer dealers in Chicago (as Nelson Morris & Company, Armour Fertilizer Works, or Swift & Company)" that ground rock phosphate could be bought "from Robin Jones, of Nashville, Tennessee," and that slag phosphate could be obtained "from Jacob Reese, Pottstown, Pa."

In August, 1903, I prepared Bulletin No. 88, "Soil Treatment for Wheat in Rotations, with Special Reference to Southern Illinois Soils," which was at once published and distributed to the Station's entire mailing list. In this I especially emphasized the need of phosphorus on southern Illinois soils. I suggested the two forms, steamed bone
meal and ground rock phosphate. I expressed the opinion that farmers who desired to try phosphorus on their land would have no difficulty in obtaining pure bone meal from such firms as “Nelson Morris & Company, Union Stock Yards, Chicago, Armour Fertilizer Works, Swift & Company, or from several other companies located at the Union Stock Yards.”

On November 17, 1903, I read an address before the Section of Agriculture and Chemistry of the Association of American Agricultural Colleges and Experiment Stations at Washington, D. C. which was soon afterward published by the Illinois Experiment Station as Circular No. 72, and distributed to the agricultural press of Illinois and to all others who asked for it.

Following are some of the statements which were made in that address:

“We have in Illinois an area of land whose principal type of soil contains only 600 pounds of phosphorus an acre in the plowed soil to a depth of 7 inches. A good crop of corn, such as we commonly produce on the best soils in the state, removes from the soil 23 pounds of phosphorus an acre. Twenty-five or thirty good crops would actually remove from the soil as much phosphorus as is contained in the plowed soil, and the plowed soil is considerably richer in phosphorus than the soil below it.

“It is mathematically impossible that the supply will be indefinitely maintained if good crops should be removed from this land for any considerable number of years. The question is asked if this is not a very small area of abnormal soil. It is true that this area is a fraction of the state of Illinois, but nevertheless it is large enough to make eleven states the size of Rhode Island. In former years this part of Illinois supplied sufficient corn to the rest of the state so that it was nicknamed Egypt; and it is still popularly known by that name.”

It was also in November, 1903, that I purchased my “Poorland” farm in Marion County, in the heart of Egypt, a farm which during the previous five years had not paid the owners 2 percent interest per annum on the price at which I purchased it.

Twenty-one months after Bulletin No. 76 was published, eighteen months after the general need of phosphorus had been given wide publicity, and fourteen months after I had made the most positive statements before this organization that the loss of phosphorus threatens ultimately to ruin the agriculture of Illinois, in April, 1904, I first learned of the phosphate company in which I afterward invested and in which I now own stock.

In securing an Illinois farm and in securing stock in a phosphate company, I am practicing what I preach, fully believing that the people who are interested in Illinois agriculture are not only willing that I should own stock in Illinois soil and in Tennessee phosphate, but that knowing these facts will increase your confidence in the work which we are doing in trying to discover, and in helping to establish,
a system of farming which shall insure a profitable and a permanent agriculture in the commonwealth of Illinois.

A PROFITABLE AND PERMANENT AGRICULTURE! Let this be our goal. Let this be the motto of every citizen of Illinois. And let us begin now, while we are rich and prosperous and powerful. Let us not repeat in Illinois the history of such lands as the great Mohawk Valley in New York and the James River Valley in Virginia, both of which were once famous for their fertility and productive capacity and both of which are now practically ruined.

I have knowledge at the present time of a large farm in the State of New York which more than half a century ago sold for $125 an acre and which today is offered for $23 an acre, which is less than the cost of the buildings now standing on the farm.

Professor Joseph Carter of Champaign, well known to the teachers and farmers of Illinois, recently stated in a public address, that within the past two years he had traveled through the Valley of the James River in Old Virginia. He found there that some of the beautiful farm lands which once grew the great crops of tobacco that made Virginia rich are now absolutely abandoned, and no man will own them.

I repeat what I said at your annual meeting two years ago:

"The fertility of Illinois soils ought not and need not be reduced; Illinois land ought never to be reduced below its original productive capacity."

"If he who makes two blades of grass grow where but one grew before is a public benefactor, then he who reduces the fertility of the soil so that but one ear of corn grows where two have been grown before is a public curse."