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PRESENT STATUS

OF

SOIL INVESTIGATION

BY CYRIL G. HOPKINS.

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EXPLANATORY STATEMENT.

This address was written for the purpose of calling attention to certain discrepancies in the work of the different prominent investigators in the subject of soil fertility, especially such as have a bearing upon investigations and conclusions touching soil conditions in Illinois. The paper deals particularly with the recently issued and much advertised Bulletin No. 22, from the Bureau of Soils, United States Department of Agriculture, on "The Chemistry of the Soil as Related to Crop Production," which says that "practically all soils contain sufficient plant food for good crop yields," and that "this supply will be indefinitely maintained." This is commonly understood and is certainly intended to mean that the use of farm manure, the growing of clover and other leguminous crops, as a source of nitrogen, or the application of bone meal or other fertilizers has little or no tendency toward permanent soil improvement, and that even the effect which they do produce is due very largely, if not entirely, to improved physical condition of the soil, which effect, the Bureau of Soils believes, can be better obtained by "a simple rotation and change of cultural methods," and the statement is added that "the effect due to cultivation is also more permanent than the effect due to fertilizers."

This sudden and radical departure from the established lines of agricultural science struck at the very basis of soil investigations in progress in this state, and notice of these remarkable statements could not be avoided. The bulletin has been widely read and unfavorably received by all who are capable of judging of its merits. It has been welcomed by land agents with poor lands for sale, and these are making the most of this opportunity.

After the publication of this bulletin the offices of this Experiment Station were at once flooded with letters from the agricultural press and farmers alike asking if these things could possibly be true, and if all their ideas of soil fertility are erroneous. This address is therefore published in order to answer a mass of inquiries impossible to answer by letter, and in order to prevent as much as possible the evil consequences to Illinois soils that would certainly follow a literal acceptance of the teachings of that bulletin.

It may be added that other papers on the same subject were read at the same meeting and that the tenor of the whole discussion was to the effect that a serious mistake had been made by the Bureau of Soils both in methods and conclusions.

It is not a pleasant task to publish matter aiming to set aside the conclusions of any branch of government research, but the circumstances surrounding this Station and the process of our work in soil investigations makes some general and public statement imperative. Unpleasant though it is, it may yet be as well for Americans to anticipate the criticism* that is certain to come in due time from foreign investigators.

This Experiment Station entertains the hope that Illinois farmers will not permit their ideas of the importance of soil fertility to be disturbed by this unfortunate incident, but that they will go on treasuring the fertility in their soils for economic use and not ignore or waste the plant food required to make crops.

E. DAVENPORT, Director.

*** Since the above was written a criticism from Director Hall of the Rothamsted Experiment Station has appeared in "Nature," Nov. 19, 1903, page 58.**

THE PRESENT STATUS OF SOIL INVESTIGATION*

BY CYRIL G. HOPKINS.

The permanent maintenance of the productive capacity of the soil is a subject which transcends all other subjects in its importance to American agriculture, if not, indeed, in its importance to the American people.

Does not the ultimate position or final destiny of America rest upon the question whether the crop producing power of our soils shall continue gradually to be reduced or whether it shall be increased or at least maintained? We need not ask whether the fertility of the soil can be absolutely and completely exhausted. The fundamental question is, will the system of farming which we practice or advise ultimately reduce the productive capacity of the soil?

Because of the present very general interest in soils and soil investigations, it seems especially appropriate to discuss this general subject at the present time. Surely there is no subject pertaining to agricultural science and practice regarding which there is such a diversity of opinion as the subject of soil improvement for increased crop production. Both practical farmers and even eminent scientific authorities disagree almost absolutely on some fundamental principles. Indeed these differences of opinion are so marked and so frequent that I feel compelled to ask, in language which has recently been declared grammatical, "Where are we at?"

To illustrate:

There is a large class of fruit farmers who practice and advocate clean cultivation of orchard soils, sometimes with a cover crop during the latter part of the season; while another class of succesful fruit growers maintain and strongly advocate a continuous grass cover kept under suitable control. Some of the important details of this practice are included in what is sometimes called the "Hitching system" of orchard cultivation. So far as can be learned the advocates of each system are equally positive that their practice is vastly superior to the other. It is extremely doubtful if an absolutely fair and complete test has been made of the comparative value of

*Chairman's address, read before the Section of Agriculture and Chemistry of the Association of American Agricultural Colleges and Experiment Stations at Washington, D. C., November 17, 1903.

the two methods. It seems difficult, for example, for the advocates of clean cultivation to understand that a permanent grass cover can mean anything else but an ordinary hay field or an unrestrained growth of grass and weeds.

Again, there are about seventy-five million pounds of nitrogen resting upon every acre of the earth's surface, and the investigations of several American experiment stations, especially those of Deleware, Illinois, and Canada, have furnished abundant evidence that under proper conditions nitrogen can be obtained from the atmosphere for the use of farm crops at a cost of about one cent a pound. On the other hand, several other experiment stations, as New Jersey and Ohio, advocate the purchase to a greater or less extent of commercial nitrogen at a cost of 15 cents a pound for use on ordinary farm crops, such as corn, oats, wheat, or timothy.

Doctor Bernard Dyer, one of the eminent English authorities on scientific agriculture, even advocates the purchase and use of sodium nitrate for growing leguminous crops, especially for alfalfa.* From our own investigations in Illinois we have conclusive proof that at 15 cents a pound we have obtained at least $45 worth of nitrogen from the atmosphere per acre per annum by means of alfalfa properly infected with the alfalfa bacteria and provided with suitable soil conditions, free from acidity and well supplied with the mineral elements of plant food; and the evidence strongly indicates that even much more nitrogen than that was obtained from the air† (See Plate I). Dyer does not state, so far as I can learn, whether his alfalfa was well infected with the proper bacteria. If not, of course, the application of sodium nitrate would be expected to produce a marked effect.

In America we commonly harvest from 5 to 8 tons of alfalfa per acre during the season, and a total yield of 10 tons of well cured hay is not infrequent; and no nitrogenous fertilizer is used. Dyer does not give his yield of cured hay, but he reports the average annual yield of green, or freshly cut, alfalfa forage as shown in Table 1.

TABLE 1. ALFALFA YIELDS IN FERTILIZER EXPERIMENTS. (*Benard Dyer*).

Plant food applied.	Green alfalfa per acre.
Phosphates and potash only	11.4 tons
Phosphates, potash, 1 cwt. nitrate	14.2 tons
Phosphates, potash, 2 cwt. nitrate	15.9 tons
Phosphates, potash, 4 cwt. nitrate	14.8 tons

*Reprint from Transactions from the Highland and Agricultural Society of Scotland, Fifth Series Vol. 14 (1902); also Reprint from Journal of the Royal Horticultural Society, Vol. 27, part 4.

†University of Illinois Agricultural Experiment Station Bulletin No. 76, "Alfalfa on Illinois Soil."

PLATE I.—TRIPLICATE TESTS OF THE EFFECT OF ALFALFA BACTERIA IN GROWING ALFALFA IN ORDINARY FARM SOILS WITHOUT FERTILIZERS—JARS MARKED "BAC." CONTAIN ALFALFA BACTERIA.

Dyer estimates the value of the green forage at $2.50 a ton; and, as the cured hay would certainly be worth at least $10.00 a ton in England, it seems safe to conclude that the highest yield which he obtained, even with the use of sodium nitrate did not exceed 4 tons per acre. This is less than the increase only which has been obtained by proper inoculation. It should also be stated that the annual application of potassium in Dyer's experiments was less than would be contained in two tons of ordinary alfalfa hay and the question arises whether the effect of the sodium nitrate in increasing the yield of alfalfa may not have been due in part at least to the liberation of potassium from the soil by the addition of sodium or even to the partial substitution of sodium for potassium by the alfalfa plant. Results* obtained at Woburn by the Agricultural Experiment Station of the Royal Agricultural Society of England tend to confirm the suspicion that the benefit of the sodium nitrate was indirect to some extent at least, as will be seen by referring to Table 2.

TABLE 2. ALFALFA YIELDS IN FERTILIZER EXPERIMENTS AT WOBURN.

Plot No.	Annual fertilizer per acre.	Green alfalfa per acre.	
		1897.	1898.
1	None	15.0 tons	8.9 tons
2	8 cwt. Phosphates †	16.0 tons	8.5 tons
3	4 cwt. Potassium sulfate	17.3 tons	12.1 tons
4	2 cwt. Ammonium sulfate	12.1 tons	8.0 tons
5	2 cwt. Sodium nitrate	17.2 tons	11.1 tons
6	Phosphates †, potash, and ammonium sulfate	22.1 tons	16.6 tons
7	Phosphates †, potash, and sodium nitrate	23.9 tons	16.4 tons

It will be observed that potassium sulfate produced a higher yield than sodium nitrate, the difference being greater the second year than the first. Dyer makes no comment on this fact, but in referring to the effect of nitrogen he says: "The bad effect of sulfate of ammonia used alone, on plot 4, is probably due to the scarcity of lime in the soil, which is unsuitable for the continuous use of this fertilizer unless lime be occassionally applied, either as lime or in some such form as basic slag or bone meal. In conjunction, however, with bone dust, superphosphate and sulphate of potash, sulfate of ammonia has produced a substantial increase. Nitrate of soda, even without the use of mineral fertilizers, has produced a very remunerative return in these two years, but it has done far better in conjunction with mineral fertilizers."

*Journal Royal Agricultural Society, December 1899 (through reprint of Dyer's report).

† 4 cwt. superphosphate and 4 cwt. bone dust.

These conclusions are not justified by the data given because of the fact that there was no plot fertilized with phosphorus and potassium without nitrogen. Each of the elements phosphorus and potassium when used singly proved beneficial (except in 1898 the acid phosphate appears to have produced an injurious effect upon the alfalfa, probably due to its increasing the acidity of the soil) and, if both mineral elements had been applied to one plot, no doubt the yield would have been larger than where either one was used alone.

The fact that reprints of Dyer's reports advocating the use of sodium nitrate for leguminous crops, are being very widely circulated in America, presumably by parties interested in selling nitrates, certainly justifies calling special attention to this marked disagreement among scientists as to the wisdom or economy of purchasing nitrogen for the use of legumes.

The agricultural experiment stations are becoming more and more responsible for the methods of soil management which are being practiced in this country. We stand as the guardian of the fertility of American soils. If leguminous crops do not obtain sufficient atmospheric nitrogen, is it not our business to discover why they do not and then to advocate a system of soil treatment or soil management which shall enable legumes to obtain from the free and absolutely inexhaustible supply of the atmosphere all of the nitrogen which they need for maximum yields? By proper inoculation we have grown a crop of alfalfa which contained as high as seventeen times the quantity of nitrogen which was contained in a crop grown without inoculation, but otherwise under exactly the same conditions and in soil which last year produced more than 60 bushels of corn an acre (See Plate 2).

Director Thorne of the Ohio Experiment Station, unquestionably one of our most careful and exact agricultural investigators, has fully demonstrated during the past dozen years that a five-year rotation of corn, oats, wheat, clover, and timothy, when grown on certain Ohio soils, does not secure sufficient atmospheric nitrogen for maximum crops. He has also obtained abundant proof that the purchase and use of commercial nitrogen in that rotation, either alone or in combination with other elements, is attended with financial loss, as will be seen from the following data taken from the recently issued Ohio Bulletin No. 141. (See Table 3).

It will be observed that on these Ohio soils, commercial nitrogen used alone, or with potassium only, has produced an increased yield sufficient to pay less than 50 percent. of the cost of the nitrogen used. When used in connection with phosphorus, or with

PLATE 2. ALFALFA POT CULTURES, SHOWING EFFECT OF APPLICATIONS OF DIFFERENT ELEMENTS OF PLANT FOOD AND OF ALFALFA BACTERIA ON ORDINARY ILLINOIS BLACK PRAIRIE SOIL. (COMPARE 32 AND 44).

both phosphorus and potassium, it has not increased the yield above that produced by the phosphorus alone, or by the phosphorus and potassium together, sufficient to pay for the cost of the nitrogen used. As a matter of fact no other treatment has produced a net profit equal to that resulting from the use of phosphorus alone. To be sure we have larger yields from other applications, but we must bear in mind that it is not large yields that we desire, but large profits. (Large yields remove large quantities of plant food from the soil.)

TABLE 3. FERTILIZERS FOR CROPS GROWN IN FIVE-YEAR ROTATION IN OHIO

Soil Plot No.	Plant food applied	Cost of plant food in 5 years	Wooster Field		Strongsville Field	
			Value of increase	Profit (+) or loss (−)	Value of increase	Profit (+) or loss (−)
5	Nitrogen	$12.00	$ 5.64	−$ 6.36	$ 0.57	−$11.43
2	Phosphorus........	2.40	11.40	+ 9.00	14.56	+ 12.16
3	Potassium	6.50	4.44	− 2.06	0.53	− 5.97
6	Nitrogen, Phos.,....	14.40	22.05	+ 7.65	16.76	+ 2.36
9	Nitrogen, Pot.,.....	18.50	6.24	− 12.26	2.50	− 16.00
8	Phosphorus, Pot.,..	8.90	16.57	+ 7.67	14.35	+ 5.45
11	Nitrogen, Phos., Pot.	20.90	27.83	+ 6.93	19.98	− 0.92
12	Nitrogen, Phos., Pot.	26.90	28.97	+ 2.07	20.33	− 6.57
14	Nitrogen, Phos., Pot.	14.30	22.70	+ 8.40	17.02	+ 2.72
15	Nitrogen, Phos., Pot.	7.70	15.57	+ 7.87	10.22	+ 2.52

What shall we say then? Shall we advise farmers to buy commercial nitrogen for use in this rotation? Or shall we rather advise them to grow a catch crop of stock peas or soy beans with the corn or a crop of clover with the o ats, or, if necessary to add an other full leguminous crop to their rotation?

A recent contribution* from the United States Department of Agriculture, Bureau of Chemistry, suggests, and offers some experimental data in support of the suggestion, that a chemical analysis of the soil might be made each year in order to ascertain the amount of available plant food contained in the soil and the consequent kinds and quantities of fertilizers to be added for the more certain production of the crop desired.

The opinion is advanced† "that the mineral plant food which a plant does take up is that which existed in the soil in an assimilable form at the time of planting." The cost of determining the assimilable, or available, plant food and the necessary laboratory equipment is described and the statement‡ is made "that samples

*Journal American Chemical Society **24**, 79 (1903).
†Ibid. page 106.
‡Ibid. page 98.

(of soil) could be brought to such a laboratory, and four days later the results could be received as to the immediately available phosphate and potash." It is even asserted* that "on lines similar to those followed in this paper (from the Bureau of Chemistry), it would be possible to establish solvent conditions as representing the feeding ability of any plant, whereupon the desired crop would be specified when the soil sample is forwarded for analysis."

Following this contribution, and in almost absolute disagreement with it, has appeared Bulletin No. 22 of the United States Department of Agriculture, Bureau of Soils, on the "Chemistry of the Soil as Related to Crop Production," in which it is asserted† with confidence, "that practically all soils contain sufficient plant food for good crop yields, that this supply will be indefinitely maintained and that the actual yield of plants adapted to the soil depends mainly, under favorable climatic conditions, upon the cultural methods and suitable crop rotation."

It is further asserted‡ that this is, "a conclusion strictly in accord with the experience of good farm practice in all countries, and that a chemical analysis of a soil, even by these extremely delicate and sensitive methods, will in itself give no indication of the fertility of this soil or of the probable yield of a crop, and it seems probable that this can only be determined, if at all, by physical methods, as it lies in the domain of soil physics."

Again, I feel compelled to ask, "Where are we at?" Shall we analyze our soils chemically every spring before seeding time? or shall we analyze them not at all? Shall we continue to use commercial fertilizers and farm manure for any other purpose than physical effect? Shall we continue our efforts to encourage the nitrogen-gathering bacteria to gather nitrogen? or shall we simply rotate and cultivate.

It may assist us in solving some of these soil problems if we keep in mind the fact that the soil serves the plant in two different ways,—or, we may say, the soil has two distinct offices or functions, in connection with crop production: First, the soil furnishes a home for the plant—a mere lodging place, in which the seed germinates and the plant "lives and has its being;" second the soil furnishes food, or nourishment, for the growth, development, and maturing of the plant.

Is the soil hard and compact and almost impenetrable to plant roots, or is it loose and porous? Is its texture fine and plastic,

*Journal American Chemical Society **24**, 113 (1903).

†United States Department of Agriculture, Bureau of Soils, Bul. **22**, 64 (1903).

‡Ibid. page 64.

medium and friable, or coarse and granular? Does it readily absorb and retain moisture, resist drouth, and permit the free movement of water through it and thus facilitate drainage? or is it almost impervious to water, non-absorbent and non-retentive of moisture? These questions deal with the first function of the soil, that is, with its physical properties, which determine whether the soil is a suitable home for the plant.

The second function of the soil is to feed the plant, to supply nourishment absolutely required for the growth and maturity of the crop. Does the soil contain a sufficient store of nitrogen, phosphorus, potassium and other required elements of plant food, and will a sufficient quantity of these be made available during the progress of the season to meet the needs of the growing crop? Can we add to the store of nitrogen in the soil or furnish it direct to the growing plant, from the uncombined nitrogen contained in the air, by biochemical means? Can we supply, or supplement the soil's supply, of plant food by applications of farm manure or other fertilizers? Can we hasten the disintegration of soil particles and the consequent liberation of plant food from the soil by increasing the amount of decaying organic matter in the soil or by applications of lime or other materials? These questions deal with the feeding or nourishing of plants. This is soil chemistry; the other is soil physics; and neither can truthfully say to the other, "I have no need of thee."

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 this 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.

We have another area comprising seven counties whose principal type of soil, after 80 years of cultivation, does not contain as much nitrogen to a depth of three feet, as would be contained in 20 good crops of corn.

Another large area, evidently comprising several hundred thousand acres, does not contain sufficient potassium in the plowed soil to make twenty good crops of corn, and the subsoil is still more deficient in potassium than the top soil.

By chemical analyses we have found that one of these extensive soil types contains more than six times as much phosphorus as another; one contains five times as much potassium in the top soil as another, with a still greater difference in the subsoils; one type contains from ten to sixty times as much nitrogen, as another. *The principal types of soil in central and northern Illinois contain from two to three times as much plant food, and produce two to three times as much corn, as the principal types in southern Illinois.* These are not mere theories; they are absolute facts, based upon chemical analysis of the soil, upon pot cultures carried on under controlled conditions, upon actual field experiments, and upon regular crop yields in ordinary farm practice. (See Table 4.)

TABLE 4. PLANT FOOD IN SOME ILLINOIS SURFACE SOILS.
(Pounds per acre.)

Elements of plant food	Black prairie (Wis. Glaciation)	"Red Clay" hills (unglaciated)	Gray prairie (Lower Ill. Glaciation)	Peaty swamps (Recently drained)
Nitrogen	6,200	1,000	2,800	67,000
Phosphorus	1,600	1,000	600	2,000
Potassium	8,800	5,600	4,200	1,200

Crop Yields in Soil Experiments.

Plant food applied	Corn bushels	Wheat grams	Wheat grams	Corn bu.	Corn fodder lb.
None	*75	3	10	0	1,000
Nitrogen	....	26	9	0	1,200
Phosphorus	....	3	14	0	2,000
Potassium	....	3	10	36	3,600
Nit., Phos	....	34	21	0	1,400
Nit., Pot	....	33	7	40	3,500
Phos., Pot	....	2	14	38	3,100
Nit., Phos., Pot	....	34	27	60	4,400

*A very common yield. No experiments on this type.

To the old worn unglaciated hill soil of southern Illinois, 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 was increased from only 3 grams to from 26 to 34 grams per pot. (See Plate 3.)

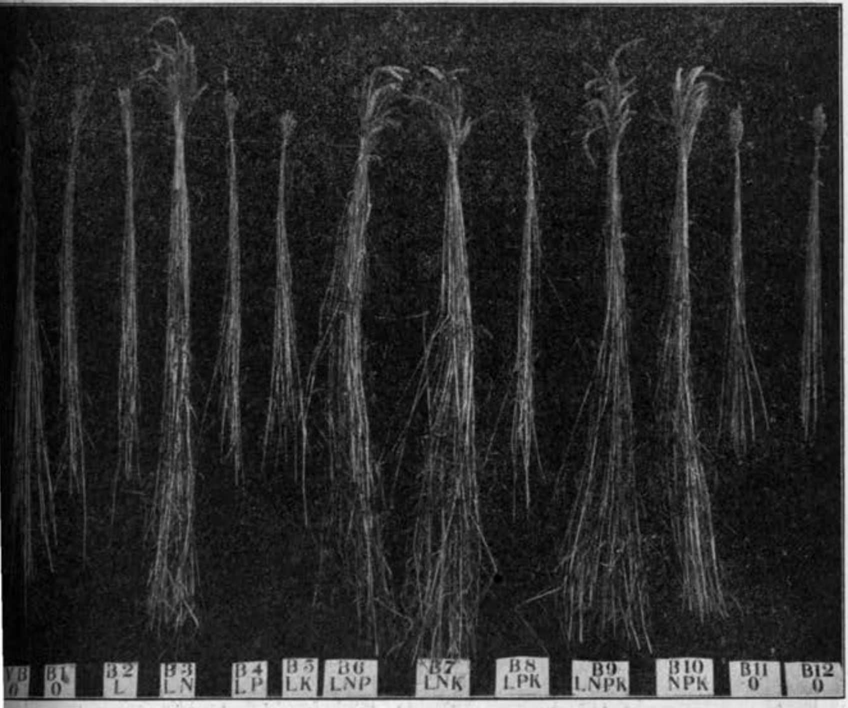

PLATE 3. WHEAT ON UNGLACIATED SOIL (PULASKI COUNTY HILLS) EFEECT OF NITROGEN.

To the principal type of soil in the Lower Illinoisan Glaciation, whose analysis shows that its phosphorus content is less than one-third of a normal fertile soil, we added both nitrogen and potassium and produced no increase whatever; but when phosphorus was added the yield of wheat was increased from 10 grams to from 14 to 27 grams per pot. (See also Plates 4 and 5, Odin field experiments.)

To the peaty swamp soil representing some hundred thousand acres in north central Illinois, whose composition shows that it contains less than one-fifth as much potassium as the best soils in the Corn Belt, we added both nitrogen and phosphorus and obtained practically the same yield of corn as where no plant food was added, the total yield per acre amounting to only a ton or less 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

PLATE 4.—WHEAT CROP WITH LEGUME AND LIME TREATMENT: ODIN SOIL EXPERIMENT FIELD.

PLATE 5.—WHEAT CROP WITH LEGUME, LIME, AND PHOSPHORUS TREATMENT: ODIN SOIL EXPERIMENT FIELD.

from 36 to 60 bushels per acre of good corn; and, following upon these results, the farmers who own and manage those lands are already profitably using carloads of potassium salts upon those soils,—not highly manufactured so called complete commercial fertilizers, but crude potassium salts direct from the German mines, and in quantities sufficient for a good crop of corn. (See Plate 6.) It will be observed that, after the most needed element has been applied, the other elements added may produce more or less increase in the crop.

Are all these results produced by the physical effect of these materials? Does nitrogenous material produce this physical effect in one soil, phosphatic in another, and potassic in a third? We have tried potassium chlorid and sodium chlorid, side by side. Potassium increases the yield three-fold and sodium not at all. To be sure we have been studying Illinois soils for only two years, and we have made only a mere beginning in that great state; but we are making use of soil chemistry, soil physics, soil bacteriology, pot cultures, field experiments, and in fact every method or agency which promises to aid us, and we hope to rapidly obtain much more complete knowledge of Illinois soils than we now have.

Bulletin No. 68 just received from the Florida Experiment Station contains 40 chemical analyses of the ordinary very sandy loams upon which nearly all of the pineapples produced in that state are grown. In commenting upon these soils, the authors say:* "Few of the soils would be able to produce more than two or three crops of pineapples if all the plant food present were available." Probably these sandy loams should be considered as abnormal soils, but there are actually all gradations between these sandy soils and the heaviest clays of the most peaty swamps. Where shall we draw the line between the soil whose fertility can be reduced so as to effect the crop yield and the soil whose supply of fertility "will be indefinitely maintained?"

The conclusions of the Bureau of Soils were based in part upon the fact that no special correlation was found between ordinary crop yields and the chemical composition of an aqueous extract of the soil, and in part upon a cursory examination of the literature bearing upon the subject. I say a *cursory* examination, because of the large amount of existing data which appear to have been overlooked.

For example, in the Bulletin from the Bureau of Soils it is suggested that the application of plant food is of little or no value, provided a proper rotation is practiced, and the results obtained from wheat grown continuously and from the four-year rotation of

*Florida Agricultural Experiment Station Bulletin No. 68, 691 (1903).

Plate 6.—Corn on Peaty Swamp Soil (Kankakee County) Effect of Potassium.

wheat, roots, barley and fallow, which have been carried on at Rothamsted during 50 years, are cited as proof. The statement* is made that "the yield of wheat grown continuously without manure for fifty years has been reduced from 33½ bushels, the average maintained on the best fertilized plot, to 15 bushels."

One would at first suppose this statement was a misprint. We might almost in truth make the opposite statement; namely, that by the use of farm manure the yield of wheat grown continuously has been increased from 13½ bushels, the average maintained on the unfertilized plot, to 33½ bushels. It is not the reduced yield from cropping without manuring that is noteworthy, but it is the increased yield due to the application of plant food. The unmanured plot never produced 33½ bushels. (See Table 5).

TABLE 5. WAEAT GROWN CONTINUOUSLY AT ROTHAMSTED†
(bushels per acre)

Harvest year.	Without manure.	With farm manure.	Difference.
1843	18‡	18‡	0
1844	15	21	6
1845	23	32	9
1846	18	27	9
1847	17	30	13
1848	15	26	11
1849	19	31	12
1850	16	28	12
1851	16	30	14
8 years average	17	28	11
1884	13	32	19
1885	15	40	25
1886	9	36	27
1887	15	35	20
1888	10	38	28
1889	12	40	28
1890	14	43	29
1891	14	48	34
8 years average	13	39	26
50 years average	13½	33½	20

The first recorded yield from the unmanured plot, in 1844, was only 15 bushels, and the average of the first eight years (1844 to 1851) was only 17⅜ bushels.

*United States Department of Agriculture, Bureau of Soils, Bulletin No. 22, 55 (1903).

† "Agricultural Investigations at Rothamsted," United States Department of Agriculture, Office of Experiment Stations, Bulletin No. 22, Plate 1 between pp. 146 and 147 (1895).

‡ Supposed yields for 1843.

It is also stated by the Bureau of Soils* that, "by a simple rotation and change of cultural methods from year to year with the change of the crop, the yield of wheat has been maintained practically constant for forty-four years," and the yields from a few selected years are cited as proof. The statement† is made, for example, that "the yield of wheat has not been sensibly reduced; the yield, even when the roots were carted off and the land left in fallow, being 33½ bushels in 1883, as against 30½ bushels in 1851, 37⅜ bushels in 1855, and 35 bushels in 1859." (See Table 6.)

While it is true that 33½ bushels was the yield in 1883 and that some other very satisfactory yields have since been obtained, nevertheless, the original data show that, during the four courses covering sixteen years (1852 to 1867) the average yield of wheat was 36 bushels per acre, while during the next four courses covering a second period of sixteen years (1868 to 1883) the average yield was 20 bushels, although in 1883 the yield was 33½ bushels, and during the sixteen year period (1884 to 1899) the average yield has been 29 bushels.

It is true that the average crop of wheat in the four-year rotation has been larger than where wheat was grown continuously, but is the difference due primarily to physical conditions of the soil? All students of agriculture practical and scientific, not only admit, but have always advocated, that the physical condition of the soil is a highly important factor, and in my judgment the statement‡ by the Bureau of Soils "that fertilizers rarely take the place of efficient methods of cultivation and of cropping in increasing or maintaining crop yields" is at fault in so far as it intimates that fertilizers may sometimes be substituted for good farming. Applications of plant food are not expected to retard, but to encourage, the growth of weeds. Fertilizers do not take the place of cultivation, their value is usually enhanced by cultivation, by means of which they are more thoroughly distributed and incorporated with the soil.

The fact is that in this four-year rotation the wheat crop followed a year of fallow cultivation, and we might expect the one crop to utilize the total amount of plant food made available during the two years' time. That this is probably true is indicated by a further study of this rotation. (See Tables 6 and 7.)

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*United States Department of Agriculture, Bureou of Soils, Bulletin No. 22, 56, (190).

†Ibid, page 55.

‡Ibid, page 60.

TABLE 6. YIELD OF CROPS GROWN IN FOUR-YEAR ROTATION AT ROTHAMSTED*
(Roots, barley, fallow, and wheat)
Root crop removed from land.

Number of Course	Roots, tons. Applied. No plant food.	Roots, tons. Applied. Nit., phos., pot.	Barley, bush. Applied. No plant food.	Barley, bush. Applied. Nit., phos., pot.	Wheat, bush. Applied. No plant food.	Wheat, bush. Applied. Nit., phos., pot.
1st†	8.8	19.7	34	37	30	30
2nd	1.9	20.4	32	38	37	38
3rd	2.3	16.4	44	48	36	42
4th	.1	4.4	35	61	45	53
5th	.4	9.1	34	45	27	22
Average 2 to 5	1.2	12.6	36	48	36	39
6th	.0	.0	21	40	11	17
7th	2.6	16.6	21	32	24	29
8th	1.6	15.5	23	31	10	12
9th	1.6	22.5	29	34	34	37
Average 6 to 9	1.5	13.7	24	34	20	24
10th	.9	14.9	16	19	35	39
11th	.8	21.6	16	20	32	41
12th	.5	26.2	20	19	22	33
13th	.8	17.3	11	21	27	33
Average 10 to 13	.8	20.0	16	20	29	37
Average 2 to 13	1.2	15.4	25	34	28	33

It is approximately correct, as stated by the Bureau of Soils,‡ that "the yield of wheat in this same experiment, where mixed mineral and nitrogenous manures had been used in some part of the rotation, had not been sensibly larger (than where no manure was used)," but the fact appears to have been overlooked that the root crop immediately following wheat has produced, during the forty-eight years, an average annual yield of 1.2 tons without fertilizing, and an average yield of 15.4 tons where mixed mineral and nitrogenous manures were used. If it were the physical condition which so markedly affected the yield of wheat, it certainly failed utterly in benefiting the root crop.

In addition to this, we have the simple fact reported by Lawes and Gilbert§ that during the forty years from 1852 to 1891 where mixed mineral and nitrogenous fertilizers were used the yield of

* Memoranda of the Origin, Plan, and Results of the Field and other Experiments at Rothamsted (1900) pages 110, 111.

† Clover instead of fallow in 1st rotation.

‡ United States Department of Agriculture, Bureau of Soils, Bulletin No. 22, 56 (1903).

§ "Agricultural Investigations at Rothamsted," United States Department of Agriculture, Office of Experiment Station Bulletin, No. 22, pp. 151 and 189 (1895).

wheat averaged 33¼ bushels when grown in this rotation and 36½ bushels when grown continuously. We might presume from these data that the higher yield produced where wheat was grown continuously is due to the improved physical condition of the soil, but more probably it is due to the fact that the crops grown continuously received somewhat heavier applications of plant food than the rotation crops. Table 7 shows for comparison of the results obtained in the four-year rotation at Rothamsted when the roots were either fed off by sheep or cut and spread upon the land.

TABLE 7. YIELD OF CROPS GROWN IN FOUR-YEAR ROTATION AT ROTHAMSTED*
(Roots, barley, fallow and wheat)
Roots not removed (fed or spread on land.)

Number of Course	Roots, tons		Barley, bush.		Wheat, bush.	
	Applied		Applied		Applied	
	No plant food	Nit., phos., pot.	No plant food	Nit., phos pot.	No plant food	Nit., phos., pot.
1st†	8 9	21.4	45	44	31	27
2nd	1.4	19.5	33	37	37	37
3rd	1.7	17.0	44	67	35	40
4th	.1	4.4	33	58	42	49
5th	.4	9.3	35	47	23	20
Average 2 to 5	1.0	12.6	36	52	34	37
6th	.0	.0	21	38	14	17
7th	2.5	16.6	21	47	24	30
8th	1.6	18.9	22	45	12	10
9th	1.9	22.8	31	48	34	39
Average 6 to 9	1.5	14.6	24	45	21	24
10th	1.0	14.8	23	32	33	41
11th	1.2	21.2	17	23	31	45
12th	.6	25.0	19	26	23	32
13th	1.2	16.6	13	35	27	39
Average 10 to 13	1.0	19.4	18	29	29	39
Average 2 to 13	1.2	15.5	26	42	28	33

In connection with the very extensive and truly valuable data furnished by the Bureau of Soils in this bulletin and the conclusion‡ drawn that, "all types of soil furnish about the same amount of plant food when treated with the same proportion of water, other conditions as time, temperature, etc.—being also the same,"

* Memoranda of the Origin, Plan, and Results of the Field and other Experiments at Rothamsted (1900) pp. 114, 115.

† Clover instead of fallow in 1st course.

‡ United States Department of Agriculture, Bureau of Soils, Bulletin No. 22, 46 (1903).

it may be remembered that Lawes and Gilbert,* by a careful examination of soils to considerable depths, by methods which were also exceedingly sensitive and accurate, found 17 pounds an acre of soluble nitrogen in soil supporting a crop of alfalfa, and 103 pounds, or more than six times as much, in soil where white clover was growing. To explain such discrepancies will require further and more comprehensive investigations.

Agriculture demands and deserves all the investigation which is being given to it—it is in need of, and is worthy of, all the investigators whose services are being devoted to this greatest of all our industries; but let us remember that it is only a genius who can draw correct conclusions from incomplete data or insufficient premises; that we are to use all obtainable information to guide us, and that we are to work together as a unit for the betterment of American agriculture. The work is greater than any man or any office. Let every man develop and magnify the line of work which he is called upon to perform, but let us neither decry nor ignore nor underestimate the value of any other good work.

And God speed the time when we shall agree on some fundamental principles; and when we shall discover and demonstrate the best and most economic methods for the permanent maintenance or increase of the productive capacity of our soils, not only by maintaining the most suitable physical conditions of the soil and by effecting the utmost possible control of soil water and by the most economic utilization of the virgin fertility already stored in the soil, but also, wherever necessary and profitable, by liberal additions to the soil of valuable plant food,—not by the purchase and use of sodium nitrate, almost certainly not, but undoubtedly by the assimilation and utilization of unlimited quantities of atmospheric nitrogen,—probably not by the use of acid phosphates, containing six percent of phosphorus and sixty percent of manufactured land plaster, usually supplying, as commonly practiced, less than one-half of the phosphorus actually removed by the crops and stimulating the soil to give up a greater quantity of the stock of plant food it contains, thus leaving it in a still more impoverished condition, but much more likely by returning to the land in pure form the bone meal produced on the farm and by using, together with farm manures and leguminous green fertilizers, large quantities of fine ground rock phosphate direct from the almost inexhaustible natural phosphate deposits in our Southern States, as

* "Investigations at Rothamsted Experimental Station," United States Department of Agriculture, Office of Experiment Stations, Bulletin No. 8, 82 (1892); also "Agricultural Investigations at Rothamsted," United States Department of Agriculture, Office of Experiment Stations, Bulletin No. 22, 115 (1895).

has already been done with marked profit, and greater promise, by the Ohio* and Maryland† Experiment Stations,—and possibly not by using mixed manufactured fertilizers containing from 2 to 4 percent of potassium, but by making the most complete use of the comparatively large amounts of potassium contained in the straw and stover and other coarser parts of our farm crops and in farm manures, by making much greater use than we now do of the immense store of potassium contained in our heavy clay subsoils, or, if necessary, by using concentrated potassium salts direct from the German mines, or, what may ultimately prove to be more economical, and certainly more unlimited, by recovering on our arid coasts, as they are now doing in Southern France, potassium salts from the inexhastible supply of the sea.

In closing, I beg to assure you that no spirit of captious criticism has prompted the preparation of this paper. The field is old but the work is new, and it is being prosecuted by many widely separated and almost independent investigators. My one purpose in pointing out some specific differences or disagreements is to bring about a more perfect harmony among us, hoping thus that we may avoid the criticism and win the more complete confidence of that rapidly increasing class of progressive, educated and even college-bred American farmers who are not only watching closely the progress of our work, but who are already putting our teachings to the practical test. Not infrequently these well-trained and well-educated farmers are prepared to repeat our tenth-acre plot experiments upon a hundred-acre field and with a consequent percentage of accuracy which may even exceed our own.

To more fully appreciate the tremendous importance of this work, we need only to bear in mind the fact that agriculture is no longer merely a means of obtaining a living, but it is now a real business enterprise, and the business of agriculture, especially throughout the great Central West, is rapidly taking its rightful rank as an industry which may be managed and controlled with a good measure of scientific accuracy. The American farmer has a right to expect that, if he adopts the methods which we advocate, the fertility of his soil is secure, that the productive capacity of his land will be increased or, at the very least, that it shall be permanently maintained,—not only for a season, not only for a score of years, but so long as the American farmer shall till American soil.

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* Ohio Agricultural Experiment Station Bulletin **134**, 94-98 (1902).

† Maryland Agricultural Experiment Station Bulletin **68**, 18-24 (1900).

ADDED NOTE.—In connection with the discussion which followed the reading of this and several other addresses relating to this general subject at the convention in Washington, the fact was clearly developed that some of the new analytical methods devised by the Bureau of Soils and used in the work reported in Bulletin No. 22, instead of being "very accurate methods of analysis," are absolutely untrustworthy. This is further established by an examination of the data which are given in the publications referred to in the preceding pages. For example, the following table shows the number of pounds of soluble phosphorus per acre (to a depth of 7 inches) contained in the soils of several fields of the Rothamsted (England) Experiment Station, as determined, first, by the Bureau of Chemistry,* after digesting the soil for 15 hours in two-hundredth normal hydrochloric acid at 40 degrees centigrade; and, second, by the Bureau of Soils,† after shaking the soil for three minutes in distilled water at room temperature.

SOLUBLE PHOSPHORUS IN ROTHAMSTED SURFACE SOILS.
Pounds per acre (7 inches deep).

Soil Sample No.	Obtained by Bureau of Chemistry; 15 hours' extraction with dilute acid.	Reported by Bureau of Soils; 3 minutes' extraction with distilled water.
B 1 a	1	13
B 2 a	2	..
B 3 a	1	7
B 4 a	5	11
W 3	1	7
W 10 a	1	8
W 11	4	8
W 13	4	10

It will be observed that the Bureau of Soils by three minutes' extraction with distilled water reports from two to thirteen times as much soluble phosphorus from these soils as the Bureau of Chemistry obtained by fifteen hours' extraction with dilute acid. The Bureau of Chemistry determined the phosphorus by the absolute gravimetric method of the Association of Official Agricultural Chemists and there is no reason to doubt the accuracy of the results thus obtained. The Bureau of Soils used a newly devised colorimetric method which evidently gives results about a thousand percent above the truth. It should be stated that samples B 4 a, W 11, and W 13 are from plots that had received nearly 400 pounds of acid phosphate each year for forty years. This accords with the larger amounts of phosphorus obtained from the samples from those plots by the dilute acid extraction. It needs scarcely to be stated that it has long been common chemical knowledge that water dissolves but the merest trace of phosphorus from soils. Warrington‡ reports less than one pound of phosphorus per acre in drainage water during the entire season.—*C. G. H.*

*Journal American Chemical Society **24**, 94 (1903).
†United States Dept. of Agriculture, Bureau of Soils, Bul. No. **22**, 45 (1903).
‡"Investigations at Rothamsted Experimental Station," United States Department of Agriculture, Office of Experiment Station, Bulletin No. **8**, 101 (1892).