Caring for the Fertility of Illinois Soils

By L. H. Smith and F. C. Bauer
UNDERLYING the permanent and profitable productivity of the soil is the maintenance of good physical condition, favorable biological activity, a suitable soil reaction, and an adequate supply of available plant-food elements during the growing season. The chief practices which accomplish these ends are—

1. Adequate drainage
2. Application of limestone where necessary
3. A good cropping system, including suitable legumes for soil improvement
4. Provision for active organic matter by returning regularly animal and plant manures
5. Purchase of mineral plant-food elements to supply deficiencies

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As an outgrowth of the soil investigations that were started nearly thirty years ago by the University of Illinois, a body of ideas was gradually evolved concerning the management of soils, which eventually took the form of a doctrine or philosophy of soil management. The principles embodied in this doctrine were intended to apply to the more common soils of Illinois and to similar areas, and as the conception spread it finally became known over the state as the "Illinois system of soil fertility."

Altho its general purport seems to be clear enough, and the principles which it involves have been stated again and again, no precise definition of this "Illinois system" was ever formulated, so far as is known. Naturally, therefore, different ideas with respect to certain details have been read into it, with the result that considerable confusion concerning it has prevailed. The following statement seems in our judgment to be a reasonable pronouncement of the essential principles involved in the Illinois system of soil fertility.

**BASIC PRINCIPLES OF A SOIL MANAGEMENT PROGRAM**

The dominant idea of the Illinois system of soil fertility is to make provision for a permanent as well as a profitable agriculture, with emphasis upon permanency. This calls for a program of soil management which recognizes the necessity of maintaining good physical condition of the soil, favorable biological activity, suitable soil reaction, and an adequate supply of available plant-food elements during the growing season. The chief practices which accomplish these ends are: adequate drainage, application of lime where necessary, maintenance of a cropping system that provides a satisfactory rotation and utilizes legumes for soil improvement, provision for active organic matter in the soil by returning animal and plant manures, and the purchase of mineral plant-food elements where such elements are deficient.

**A Philosophy of Soil Management—Not a Formula**

The above statement attempts to set forth briefly the guiding principles in the proposition of a permanent and profitable system of crop production. There remain many deviations in details to be determined according to circumstances. Such details will vary with different types of soil or even within a single type according to the way the land has been handled; they will vary with the kind of enterprise followed,
whether grain farming, livestock farming, or fruit farming; and they will vary with changing economic conditions, such, for example, as affect the accessibility and the cost of different forms of fertilizing materials. In short, to be workable the system must be comprehensive and it must be sufficiently flexible in its details to permit adjustments to numberless varying conditions.

As stated above, various conceptions have been held concerning this system of soil management. One of the most prevalent notions, and one of the most erroneous, is that the Illinois system definitely prescribes the application to the soil of certain specific fertilizing materials, and the omission of, or the substitution for, any of these materials represents a violation of the system.

**Different Soils Call for Different Treatment**

The impracticability of any rigid system of soil treatment is well demonstrated in the results from the several soil experiment fields scattered over Illinois. On twenty-six of these fields the cropping program is so arranged as to permit a comparison of eight different systems of soil treatment. The net returns from these eight different systems show the following interesting facts. On four fields the highest profit has been realized by the application of stable manure alone. On 16 fields manure with limestone gave the best returns. On one field manure, limestone, and rock phosphate proved the best combination. On one field crop residues (of which system green manuring is an essential part) produced the largest profit. On two fields residues, limestone, and rock phosphate was the most economical treatment. On two fields residues, limestone, rock phosphate, and potash salt was the winning combination. To be sure, the deciding difference in a few cases was too small to be significant, but on the whole the total number of comparisons is sufficient to bring out clearly the principle that soils differ greatly in their response to fertilizer treatment.

A further fact of great importance brought out in a study of the data accumulated from these fields is that a given piece of land seldom responds to soil treatments in the same manner through its history. The most efficient treatment during one rotation period does not necessarily remain the most efficient in another period.

Thus there seems to be no single system of treatment that will serve as a panacea for all soil ailments any more than there is a single remedy for the ills of mankind.

**Soil Problems Exceedingly Complex**

The complexity of soil problems and the difficulties in their solution are immediately apparent when one considers the fact that the soil is not, what it too often has been regarded, simply a mass of inert matter like the rocks from which it has developed and to which certain sub-
stances may be added with definite predictable effects—it is a dynamic, ever-changing body charged with living organisms whose reaction must be reckoned with in any kind of soil treatment. Action and reaction, biological as well as mineralogical, are constantly going on. Under the continual change of temperature and moisture and the action of growing plants, conditions within the soil are never quite the same today as they were yesterday and those of tomorrow will differ slightly from those of today. In other words, equilibrium is never quite reached.

Furthermore, in using the term “soil” in a generic sense, as in the foregoing statement, it should be borne in mind that in reality there are various kinds or types of soil each with its individual characteristics with respect to physical and chemical make-up and with its own responses to external treatment. With this conception of the individuality of soils it is easy to understand how a given soil treatment may produce a certain effect in one situation and a wholly different effect in another.

**Economic Conditions Constantly Changing**

Thus far only the “natural” complexities involved in a system of soil management, or those that have to do directly with the soil itself, have been considered. But this is not the whole problem—the ever-changing economic conditions by which market prices are affected are also to be taken into account. Whether, for example, a certain increase in the yield of wheat produced by a given soil treatment will be profitable depends directly upon the price of wheat as well as upon the cost of the treatment, and every farmer knows only too well something of the violent fluctuations in market prices that have taken place in recent years. Furthermore, costs of fertilizing materials change from time to time, and these changes do not necessarily run parallel with the fluctuations in value of farm products.

With these facts in mind it is not difficult to understand that, from the standpoint of financial profits, a soil management practice perfectly recommendable this year may become wholly unprofitable in another year and, vice versa, a practice that is unprofitable under present conditions may become highly profitable at another time.

**Certain Basic Principles Well Established**

The above remarks suggest something of the difficulty of prescribing definite recommendations for specific soil treatments and of the futility of making blanket recommendations to cover the requirements of all soils and all crops at all times. In presenting these difficulties there is no intention to discourage efforts at planning programs of soil improvement; the purpose is rather to set forth some of the uncertainties involved and, in particular, to warn against hasty conclusions based upon scanty experience or superficial observation. Further-
more, an understanding of these complexities may help to explain the action of the soil investigator when at times he hesitates to answer with perfect confidence and self-assurance some of the numerous questions put to him.

In spite of the complexities and uncertainties involved in the problem of soil improvement, there are certain broad underlying principles that are basic and that must be taken into consideration in laying out any fertility program. These principles have been set forth in the introductory paragraphs describing the "Illinois system."

**PROVISION FOR PLANT FOOD IN A SOIL MANAGEMENT SYSTEM**

In the above discussion only the more general aspects of the soil management problem have been considered. Providing for an adequate supply of plant food calls for most careful consideration. The main ideas in this connection are centered around organic matter, limestone, nitrogen, phosphorus, and potassium.

**Organic Matter**

Organic matter plays a vital role in the maintenance of soil fertility, and no well-ordered program of soil management can fail to take this fact into account. Indeed so well established has this fact become that the more progressive fertilizer firms now emphasize in their recommendations the necessity for providing organic matter as a basic treatment.

Organic matter acts beneficially in two ways—it helps to maintain favorable physical conditions in the soil and it supplies food material for the microscopic organisms which inhabit the soil and which in turn, thru their life processes, effect many of the necessary chemical transformations that render plant food available for growing crops.

The main sources of supply of organic matter are stable manure, crop residues, and green manures.

In the soil experiments referred to earlier, the system of treatment that most frequently returned the greatest profit was manure with limestone. Of the eight systems compared, this proved to be the winning treatment on more than 60 percent of the fields. This indicates the very great value of stable manure as a soil builder and suggests the importance of its careful conservation and use on every farm where this material is available. On most farms, however, there is not sufficient animal manure produced to cover the land and thus it becomes necessary to resort to some other supply of organic matter. The alternative here lies in the so-called "crop residue" system, in which unused materials, such as stalks, straw, and chaff are returned
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to the land and plowed under along with an occasional leguminous green-manure crop.

In connection with the application of organic matter, an important distinction between kinds with respect to chemical make-up has come to be recognized within the last few years. It is commonly observed that an excessive application of straw or similar material is likely to produce a depression in crop growth which may result in lowering the yield. In addition to the unfavorable physical effect of plowing down a mass of decay-resistant material, particularly if dry weather ensues, a detrimental chemical effect may also follow. The large quantity of cellulose contained in straw stimulates the activities of a certain set of microscopic organisms. These may become so active as actually to compete with the growing plants for nitrate and so under certain circumstances cause nitrogen hunger. Good judgment must therefore be exercised in applying strawy material. Heavy applications should ordinarily be avoided unless they can be plowed under with a good growth of legumes or else applied at such a time as not to interfere with a crop having a large nitrate requirement.

Limestone

The maintenance of a favorable soil reaction has been mentioned as one of the essentials in a rational system of soil management. For this purpose crushed limestone is recommended for general farm use in Illinois.

In considering the application of limestone to land it should be understood that this material functions in several different ways, and that a beneficial result may therefore be attributable to quite diverse causes. Limestone provides calcium, an element for which certain crops have a high requirement. It corrects acidity of the soil, thus making for some crops a much more favorable environment as well as establishing conditions absolutely required for some of the beneficial legume bacteria. It plays an important role in the chemical transformation of nitrogen. It helps to check the growth of certain fungus diseases, such as corn-root rot. Experience indicates that it modifies either directly or indirectly the physical structure of fine-textured soils, frequently to their great improvement. Thus, working in one or more of these different ways, limestone often becomes the key to the improvement of worn lands.

Soils vary tremendously in their need for lime, and the question arises as to how the farmer is to know whether his land needs lime. One of the most reliable indications as to whether a soil needs limestone is the character of the growth of certain legumes, particularly sweet clover and alfalfa. These crops do not thrive on acid soils. Their thrifty growth, therefore, indicates that the soil is not acid, at least in a harmful degree. In case of their failure to grow, the soil should be tested for acidity.
Much information on this subject as it pertains to Illinois land is to be found in connection with the state soil survey. Some soil types are uniformly acid, and therefore in their description attention is called to the necessity of applying limestone; other types being alkaline throughout, do not need lime, and in the survey this fact is recorded. There are, however, extensive soil types in which the lime requirement is not uniform. It may vary from field to field on the same farm. It often varies from one part of a field to another. It may even change on a given field with the passing of time, especially under heavy cropping. Obviously in such cases a definite recommendation in regard to liming cannot be given, and under these circumstances the farmer is advised to resort to a test which he himself can learn to make. Upon request he may receive from his county farm adviser or from the Experiment Station instructions for making a systematic limestone map of his fields showing not only the areas that need liming but also approximately the amount of limestone to apply. This systematic test on those soils where the lime requirement is so variable is saving many dollars in expenditure for lime where lime is not needed, as well as preventing the waste of clover seed on soil too acid to grow clover.

Nitrogen

The nitrogen problem is one of foremost importance in American agriculture. There are four reasons for this: nitrogen is becoming increasingly deficient in most soils; its cost when purchased on the open market is often prohibitive; it is removed from the soil in large amounts by crops; and it is readily lost from soils by leaching. A 50-bushel crop of corn requires about 75 pounds of nitrogen for its growth; and the loss of nitrogen from soils by leaching may vary from a few pounds to over one hundred pounds an acre in a year, depending upon the treatment of the soil, the distribution of rainfall, and the protection afforded by growing crops.

An inexhaustible supply of nitrogen is present in the air. Above each acre of the earth's surface there are about 69 million pounds of atmospheric nitrogen. Leguminous plants such as clover are able, with the aid of certain bacteria, to draw upon the inexhaustible supply of air nitrogen, utilizing it in their food requirements. In so doing these leguminous plants, thru the decay of their own tissues, add to the soil nitrogen that has been taken from the air and transformed into food material that can be assimilated by other kinds of crops that follow.

By taking advantage of this provision of nature and introducing periodically into his rotation a crop of legumes, the farmer may draw upon this cheapest source of nitrogen for soil building. Therefore, in general farming, that is, in the production of such crops as corn, oats, wheat, and hay, legumes should furnish the main stock of nitrogen,
this stock to be supplemented, of course, by all available manure and by other farm waste materials containing nitrogen. In addition to these home sources of nitrogen supply, various commercial products containing nitrogen are offered for sale on the market. These materials formerly consisted largely of sodium nitrate, a mineral imported from South America; ammonium sulfate, produced in the manufacture of coal gas and coke; and certain waste and by-product materials mainly of organic composition. Within very recent time, however, tremendous developments in the synthetic production of nitrogen compounds from air nitrogen have taken place. Among these new fertilizer materials may be mentioned cyanamid, calcium nitrate, sodium nitrate, ammonium nitrate, and urea.

These developments in the artificial fixation of nitrogen will doubtless have a far-reaching effect in reducing the cost of commercial nitrogenous fertilizers. What the limits may be in this direction one dare not predict. Whether these manufactured nitrogen compounds will become so cheap some day as actually to compete with legume nitrogen is problematical. The day has not yet arrived, however, when we can afford to dispense with legumes as a green manuring crop in the production of grain and hay.

Accepting, then, this principle that legumes and farm wastes must constitute the main source of nitrogen supply, the question arises—can these home-grown materials be supplemented to advantage by the use of commercial carriers of nitrogen?

The impossibility of making blanket recommendations has already been pointed out. The question finally resolves itself into a matter of expense and profit for each individual case. Sodium nitrate is purchased on the market at present at about $65 a ton. If a farmer applies 100 pounds an acre, he provides about two-fifths of an ounce to a hill of corn. A ton would cover 20 acres and the cost would be about $3.25 an acre. Under present prices an increase of four to five bushels of corn, or nearly three bushels of wheat, would be required in order to cover the cost before any profit could be realized.

Under what circumstances might such increases in yield be reasonably expected? It is possible that in many cases where manure or legumes have not been used, such an application of nitrogen would return a profit, but such usage should be regarded as a temporary expedient rather than a permanent practice in soil management.

Under adverse weather conditions, when soil nitrates are formed too slowly or are washed away by excessive rain, an application of nitrogen fertilizer may prove highly beneficial to wheat and corn. It is questionable, however, whether the same expenditure in a phosphate fertilizer for either corn or wheat might not in many cases be a wiser investment than nitrogen.

A peculiar hazard accompanies the application of nitrogen that does not obtain in applying phosphate or potash. Nitrates are readily
washed away, and if circumstances are such that the first crop fails to utilize the nitrogen, little or no residual effect on the following crops can be expected. For this reason special caution should be used against applying excessive amounts of nitrogen. Usually it is well to divide the application of a quickly soluble nitrogen fertilizer, such as sodium nitrate, using a portion at planting time and distributing the remainder at a later date. Nitrogenous fertilizers are often made up of a mixture of materials whose nitrogen becomes soluble with varying degrees of rapidity, thus distributing the action of the nitrogen over a period of time.

**Phosphorus**

Different soil types display great variation in phosphorus content. In Illinois soils a range from 320 to 4,900 pounds an acre has been found in the surface 6\(\frac{2}{3}\) inches, depending mainly on the origin of the soil.

The removal of phosphorus by continuous cropping slowly reduces the amount of this element available for crop use unless its addition is provided for by natural means such as overflow, or by agricultural practices such as the addition of phosphatic fertilizers and the use of rotations in which deep-rooting leguminous crops are frequently grown.

There are several different phosphorus-containing materials that are used as fertilizers. The more important of these are rock phosphate, superphosphate, bone meal, and basic slag.

**Rock Phosphate.**—Rock phosphate is a mineral substance found in vast deposits in certain regions. A good grade of the rock should contain 12 to 15 percent of the phosphorus element. The rock should be ground to a powder fine enough to pass thru a 100-mesh sieve, or even finer.

**Superphosphate.**—Superphosphate is produced by treating rock phosphate with sulfuric acid. The two are mixed in about equal amounts; the product therefore contains about one-half as much phosphorus as the rock phosphate itself. By further processing, different concentrations are produced. The most common grades of superphosphate now on the market contain respectively 7, 8\(\frac{1}{2}\), and 10\(\frac{1}{2}\) percent of the element phosphorus, and even more highly concentrated products containing as high as 21 percent are to be had. In fertilizer literature the term phosphorus is usually expressed as "phosphoric acid" (\(P_2O_5\)) rather than the element phosphorus (P), and the chemical relation between the two is such as to make the above figures correspond to 16, 20, 24, and 48 percent of phosphoric acid respectively. Besides phosphorus, superphosphate also contains sulfur, which is likewise an element of plant food. In general, phosphorus in superphosphate is considered to be more readily available for absorption by plants than that of raw rock phosphate.
Bone Meal.—Prepared from the bones of animals, bone meal appears on the market in two different forms, raw and steamed. Raw bone meal contains, besides the phosphorus, a considerable percentage of nitrogen. If the material is purchased only for the sake of the phosphorus, the cost of the nitrogen represents a useless expense. Steamed bone meal is prepared by extracting most of the nitrogenous and fatty matter from the bones, thus producing a more nearly pure form of calcium phosphate, containing about 10 to 12 percent of the element phosphorus and about 1 percent of the element nitrogen.

Basic Slag.—Basic slag, known also as Thomas phosphate, is another carrier of phosphorus that might be mentioned because of its considerable usage in Europe and eastern United States. Basic slag is a by-product in the manufacture of steel. It contains a considerable proportion of basic material and therefore tends to influence the soil reaction in the direction of reducing soil acidity.

Comparative Value of Different Forms of Phosphorus.—Obviously the carrier of phosphorus that gives the most economical returns, considered from all standpoints, is the best one to use. Altho this matter has been the subject of much discussion and investigation, the question remains unsettled. The fact probably is that there is no single carrier that will prove the most economical under all circumstances because so much depends upon soil conditions, crops grown, length of haul, and market conditions.

The relative cheapness of raw rock phosphate as compared with the treated material, superphosphate, makes it possible to apply for equal money expenditure considerably more phosphorus per acre in the form of rock than in the form of superphosphate, the ratio being, under present market conditions, roughly speaking $3\frac{1}{2}$ to 1; that is to say, a dollar will purchase about three and a half times as much of the phosphorus element in the form of rock phosphate as in the form of superphosphate, and this is an important consideration if one is interested in building up a phosphorus reserve in the soil.

On several of the Illinois soil experiment fields rock phosphate and superphosphate are being compared in systems of management looking toward permanent soil improvement, and are applied in amounts corresponding to approximately equivalent money expenditure. So far as these comparisons show, there appears to be little consistency in the results. In some years and on some crops superphosphate has furnished the greater profit; in other years and on other crops the reverse is true. In some cases neither material has paid for its cost, indicating probably that phosphorus is not a limiting factor in production on these fields. On the whole, therefore, if possible residual effects are disregarded, there is no indisputable evidence for discrimination between the two forms of phosphate.

It should be mentioned that considerable improvement has been effected in the processing of rock phosphate, with the result that a
more finely ground product is now being sold than formerly. Further developments in this direction are in progress, with the idea that this extreme fineness of grinding will make for higher availability of phosphorus. If this extreme fineness of grinding does make the phosphorus more available to plants, then lighter effective applications can be made, thus greatly modifying the use of rock phosphate. It is even proposed that this very finely ground product be applied to corn in small quantities by the hill-drop method of distribution. Tests of this method are now under way, and by another year data may be available upon which to base a more definite opinion than is now possible.

**Potassium**

Our most common soils, the silt loams and clay loams, are well stocked with potassium, although it exists mainly in a very slowly soluble form. Many field experiments in various sections of Illinois during the past twenty-five years have shown little or no response to the application of potassium in the production of our common grain and hay crops. On the light-colored soils of southern Illinois, however, where stable manure has not been employed, potassium has been applied with profit, the benefit appearing mainly in the corn crop.

Peat soils are usually low in potassium content. The Illinois Experiment Station has demonstrated in field experiments located on peat land that the difference between success and failure in raising crops depends upon the application of a potash fertilizer.

Potassium has proved beneficial also on the so-called "alkali" spots occurring on certain soil types that are rather high in organic matter, including peat and very dark-colored sandy, silt, and clay loams. The potassium salts in this case appear to exert a corrective influence over what seems to be an unbalanced plant-food condition caused by an excess of nitrate in the soil.

Potassium fertilizer may be procured in the form of one of its salts, such as chlorid, sulfate, or carbonate of potassium, and any of these materials may be applied, where needed, at the rate of 50 to 150 pounds an acre, according to the method of distribution. For our most common crops about the only basis for choosing among these forms is the matter of price, taking into consideration the potassium content. Kainit is another substance containing potassium, but it is combined with magnesium in the form of a double salt. It is therefore less concentrated than the salts mentioned, and so should be applied in larger quantities. An application of about 200 pounds or more of kainit to the acre is suggested.

**MIXED COMMERCIAL FERTILIZERS**

Having considered separately the three important elements of plant food—nitrogen, phosphorus, and potassium—with regard to their re-
spective places in systems of soil management, we now come to consider their use in combinations as represented in mixed commercial fertilizers.

The Illinois Experiment Station has opposed, with certain reservations, the general use of mixed commercial fertilizers in the production of our great staple grain and hay crops. This opposition has been based upon two main reasons—one economic, the other agronomic. In the first place, mixed manufactured fertilizers have been considered too expensive for crops of such low acre value as corn, oats, and clover, since the essential plant-food materials can usually be had in cheaper forms. In the second place, the continued dependence upon mixed commercial fertilizers as the sole agency for soil enrichment, as has been the usual practice, represents a system of soil stimulation rather than of soil conservation.

The question is fairly raised as to whether these reasons which seemed to be sound in the past are still valid in the light of the changing economic conditions and of the more recent developments that have taken place in the manufacture, sale, and use of fertilizers.

What Are Mixed Commercial Fertilizers?

A mixed commercial fertilizer is a combination of substances containing either two or three of the plant-food elements nitrogen, phosphorus, and potassium. If the material contains all three of these elements, it is said to be a "complete" mixed fertilizer; if only two of the three are present, it is said to be an "incomplete" mixed fertilizer.

A complete mixed fertilizer has the general formula \( \text{N—P}_2\text{O}_5—\text{K}_2\text{O} \) (nitrogen, phosphorus pentoxid, potassium oxid), the proportions of the elements varying according to the way in which the material is compounded. By substituting figures for the letters in this formula, the percentage composition of the fertilizer is indicated. Thus a fertilizer of the formula 5-15-5 contains 5 percent nitrogen, 15 percent phosphorus pentoxid (usually designated as phosphoric acid), and 5 percent potassium oxid (usually called potash). Translated into pounds, this means that a ton of the fertilizer contains 100 pounds of nitrogen, 300 pounds of phosphoric acid, and 100 pounds of potash. For the benefit of Illinois farmers, who probably are accustomed to think in terms of the simple plant-food elements rather than these combinations, it may be explained that the above amounts correspond to 100 pounds of the element nitrogen (N), 131 pounds of the element phosphorus (P), and 83 pounds of the element potassium (K). Changing the formula to read 0-15-5 indicates that no nitrogen is contained in it; 5-15-0 means that no potassium is present; and 5-0-5 indicates that phosphorus is absent.

In compounding these fertilizers several ingredients carrying a certain plant-food element may sometimes be used. A portion of the
total nitrogen, for example, may be furnished by sodium nitrate, while another portion may be carried in dried blood. In addition to these plant-food materials, fillers and conditioners are often used in such amounts as to make the finished product contain the desired percentage of plant food.

As a rule, the actual plant-food content of mixed fertilizers formerly made up a relatively low proportion of the total product. A fertilizer of a 2-8-2 composition, for example, was common, and many brands on the market contained even less of the plant-food elements. It is easily seen that very little plant food would be supplied by a moderate quantity of such a fertilizer. Thus an acre application of 200 pounds of a 2-8-2 fertilizer would furnish only 4 pounds of nitrogen, or about one-twentieth of that which an ordinary 50-bushel crop of corn actually draws from the soil. Within the last few years, however, a very marked change has taken place, and fertilizers of decidedly higher grade are now being put on the market, replacing the less valuable although more expensive products of low plant-food content. This development in the fertilizer industry has been of no little importance in placing the use of commercial fertilizers on a sounder economic footing, although the questions of cost and returns still remain matters for careful consideration whenever the use of a commercial fertilizer is contemplated.

A distinction between what are considered "high-grade" and "low-grade" fertilizers is now being made upon the arbitrary basis of a total of 14 so-called "units of plant food." Thus a 2-8-2 fertilizer carrying 12 units of plant-food would classify as a low-analysis fertilizer. A 2-12-2 fertilizer has 16 units and would therefore be in the high-analysis class. The advantage of the higher grade of products to the consumer is becoming more and more widely recognized by the manufacturers. During the past year the midwestern fertilizer manufacturers agreed to adopt a minimum of 20 units of plant food as rapidly as conditions will allow.

In the very latest developments still more concentrated forms of fertilizer are being produced, of which "nitrophoska" is a good example. This fertilizer contains as much as 60 units of plant food. If the economy of production and the agricultural value justify the general use of materials of such high concentration, there should be a great saving in the cost of transportation and handling thru the use of fertilizers of this type.

Thus has the fertilizer industry gradually developed from a business consisting largely of the working up of refuse and waste material to a highly specialized chemical industry.

The Place of Mixed Commercial Fertilizers

Emergency Situations.—Emergencies arise in which readily available plant food is needed. Adverse weather conditions, such as those
of a backward spring, when biological activities in the soil are slowed down, call for a supply of available plant food immediately after planting time in order that the crop may get a quick start. Under circumstances of this kind the use of a mixed fertilizer might be profitable where ordinarily it would not pay.

Another situation in which abundance of available plant food may become the saving factor is that brought about in combating insect pests and plant diseases.

The Time Element.—The extent of time required to effect certain phases of soil improvement is a consideration that is receiving more and more attention. The question often is raised whether the farmer can afford to wait two or three years for results while a soil improvement system is getting under way, when by the use of quick-acting fertilizers he may receive the benefit in a single season.

The answer to this question depends, of course, upon the amount of the benefit received and the cost of the treatment. It is quite possible, in some cases, that a system of soil improvement can be supplemented to advantage temporarily by the use of a moderate application of commercial fertilizer, while the continued use of the same fertilizer after the more permanent system comes into effect might, or might not, pay.

The Case of the Tenant Farmer.—In tenant farming the most desirable arrangement is one in which tenant and landlord share in the responsibility of maintaining soil fertility. It sometimes happens, however, that the landowner takes little or no interest in any kind of soil improvement, and under short term tenure the tenant has no interest in the permanent productivity of the land but he does want to improve production while he occupies the farm. Under such circumstances the use of commercial fertilizers alone might be resorted to as a temporary expedient, but in no case should such a temporary expedient be allowed to lapse into a permanent practice.

Supplementing a Basic System.—In the situations just described, the use of the commercial fertilizers is to be considered only a temporary expedient incidental to a permanent system of soil improvement, and the question remains as to whether it is wise to use these fertilizers regularly to supplement a more substantial soil fertility system built around legumes and farm manure. There again, as in the other cases considered, the decision whether to employ commercial fertilizers is to be based on costs and profits, and every individual case must be considered on its own merits.

Do Commercial Fertilizers Injure the Soil?

Some farmers have the idea that commercial fertilizers exert a harmful effect upon the soil, in other words, that they "poison" the land. This impression is probably based on the fact that the use
of insufficient amounts of fertilizer, together with the employment of other poor soil management practices, is accompanied by declining yields. Used judiciously, however, that is, applied in amounts adequate to maintain a sufficient stock of plant food or else used as supplementary material, commercial fertilizers should leave no harmful effects that cannot be rather simply counteracted. Some materials may leave either an acid or an alkaline residue which accumulating in the soil may finally require neutralization. Ammonium sulfate is such a substance. This fertilizer, after long continued use, leaves an acid residue, which condition may be corrected by applying limestone.

Quality in Mixed Fertilizers

Because the quality or composition of mixed fertilizers could be so easily misrepresented, the question sometimes arises as to the prevalence of fraud in their manufacture. It may be said that there probably is no commodity the sale of which is more thoroughly controlled by law than is the sale of mixed fertilizers. Each state has its inspection system, so that as a matter of fact the purchaser of commercial fertilizers should be well protected against fraud in composition and weight.

Thus, the question of the use of mixed fertilizer simmers down pretty largely to one of economy.

Reducing Cost Thru Smaller Applications

In connection with the cost of fertilizers a recent development of great significance should be considered, and that is the use of special distributing machinery that makes possible the effective use of much smaller quantities of material than formerly. Corn planting machinery has been devised for dropping fertilizer close to the seed, and a thorough study is being made of the most advantageous way of doing this. This method of applying fertilizers for corn represents a practice that may have large possibilities provided it is not relied upon as the sole method of soil improvement. About one-half as much material is recommended for this method as when the fertilizer is spread broadcast. Experience by the Agronomy Department of this Station with the method is limited to a single season and the results were variable. More extensive experiments are planned and by another year it is hoped that some definite results can be announced.

What Do Mixed Commercial Fertilizers Cost?

In order to get an idea of the expense of applying mixed commercial fertilizers, we may figure the cost per acre based upon the published recommendations and price quotations of a fertilizer company. For the purpose of illustration we may take their recommendations
given for the dark-colored silt or clay loam soils of Illinois on land having had manure and clover.

Thus, for the corn crop, 150 pounds per acre of a 5-15-5 fertilizer is recommended to be applied in drills or hill-dropped. The price of this fertilizer is quoted at $53.15 a ton, which would make the cost $3.99 per acre. According to an official report, the farm value of corn for December, 1928, in Illinois was 70 cents a bushel. At this rate an increase of 5.7 bushels per acre of corn would be required to cover the cost of the fertilizer, taking no account of the extra expense in applying it.

For spring grains the recommendation is to use a 0-21-9 fertilizer at the rate of 250 pounds an acre if drilled or 400 pounds if broadcast. The price is $45.10 a ton, thus making the cost per acre $5.64 drilled or $9.02 broadcast. If the spring grain were oats, valued at 38 cents a bushel, the increase in yield to cover the cost of fertilizer would have to be nearly 15 bushels an acre in case the fertilizer were drilled; if it were broadcast, nearly 24 bushels would be required to pay the cost before any profit would be realized. If instead of oats the spring grain were wheat valued at $1.02 a bushel, the increase in yield necessary to pay for the fertilizer would be 5½ bushels if the fertilizer were drilled and nearly 9 bushels if broadcast.

As an application for pasture and meadows on this kind of land the recommendation given is 500 pounds of a 3-18-9 fertilizer quoted at $52.50 a ton. Such an application would cost $13.13 an acre for the fertilizer.

For alfalfa or clover a 24-percent superphosphate is recommended, the application to be made at the rate of 300 pounds to the acre. At $36 a ton the expense would amount to $5.40 an acre.

For potatoes a 3-18-9 fertilizer is recommended for application at the rate of 500 pounds an acre if drilled or 1,000 pounds if broadcast. At the quoted price of $52.50 a ton the smaller application would cost $13.13 and the larger $26.25 an acre. With potatoes valued at 65 cents a bushel, as they were according to the official report for December 1, 1928, an increase in crop yield of about 20 bushels would pay the cost of fertilizer if applied at the drilled rate and about 40 bushels if applied broadcast.

The above examples afford some idea of the cost of using commercial fertilizers. Unfortunately it is impossible to furnish information with the same certainty concerning the profit that is likely to be derived from these fertilizers, for that will depend upon several varying factors—mainly the amount of increase in yield and the price received for it. What kind of fertilizers will pay and under what particular conditions they will pay must be determined mainly on the basis of actual experience.
The Law of the Minimum

An important principle to be borne in mind in the use of any fertilizer is represented in the so-called “law of the minimum,” that is, that no benefit can result from the application of a given plant-food element unless the need for that element is a limiting factor in plant growth. If, for example, there is already in the soil enough available phosphorus to produce a 40-bushel crop, and the nitrogen supply or the moisture supply is sufficient for only 40 bushels or less, all the phosphorus one might apply would be absolutely ineffective in increasing the yield beyond this 40-bushel limit.

If only one, or perhaps two, of the plant-food elements carried in the mixed fertilizer happen to be needed, then a useless expenditure has been made for the unnecessary element or elements.

It is of interest to analyze the cost of a mixed fertilizer with respect to its content of the respective plant-food elements. Let us suppose that a farmer decides to purchase a fertilizer of the formula 5-15-5 at the quoted price of $53.15 a ton, and applies it for corn at the recommended rate of 150 pounds an acre. At this rate he applies 7 1/2 pounds of nitrogen to the acre which, if purchased on the market as sodium nitrate, would cost at the present price about 21 cents a pound or $1.58 for the acre. Likewise the 10 pounds of phosphorus contained would cost in the form of superphosphate $1.69 and the 6 pounds of potassium would cost, if purchased in the form potassium sulfate, 48 cents. The total cost of the three plant-food elements if purchased in the separate materials would be, therefore, $3.75 instead of $3.99, the price of the mixed goods. The question for the farmer, however, is not so much the market value of the plant-food in the mixed fertilizer as the uncertainty of the need for all three of the elements. If, for example, the land has been under clover or has been well manured, the chances are that purchased nitrogen would have little or no effect, in which case a phosphate-potash mixture might be preferable to a complete fertilizer containing nitrogen. Likewise, unless the soil were in need of available phosphorus or of available potassium, money would be uselessly spent in their purchase. The question of what fertilizer to use—whether mixed, or one of the single carriers—must be answered after considering all the factors involved, including soil, crops to be grown, and amount of manure available, and whatever fertilizer is decided on its use must be considered as constituting only one of the elements in a good system of soil management.

Experiments With Mixed Commercial Fertilizers

Little reliable data are at hand upon which to base recommendations for the use of mixed fertilizer. Reports from other states on the use of these fertilizers are in some cases favorable and in other
cases unfavorable. The Illinois Experiment Station is making an effort to procure definite information on this matter. Last year experiments with mixed commercial fertilizers were started, but the results are too variable to warrant any general recommendations as yet. These experiments are being considerably expanded this year so that they include not only work on several of the older established University soil fields but also a series of cooperative experiments with farmers in different parts of the state.

In addition to this work of strictly investigational nature, the soils extension division of the Agronomy Department is cooperating with county agricultural advisers in conducting demonstration plots in various communities over the state. With the accumulation of results from such a systematic study, the Experiment Station should be in a position in the future to give much more definite advice on the use of commercial fertilizers.

Farmers Can Help Determine Their Own Fertilizer Needs

In the meantime much might be learned by farmers themselves regarding their individual fertilizer needs. There is no better way of gaining definite information regarding the response of a given piece of land to fertilizer treatment than by actual trial. Every farmer might well make a few simple tests on his own land that will show what various kinds of fertilization will do. For this purpose a set of trials such as suggested by the accompanying table would yield information of value.

<table>
<thead>
<tr>
<th>A Set of Fertilizer Tests Suggested for Farm Trial</th>
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<tr>
<td>Rate of application per acre Drilled Broadcast</td>
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<td>Cost per acre Drilled Broadcast lbs. lbs.</td>
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<td>Plot</td>
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Two methods of distribution are suggested—broadcast and drilled. In fertilizing corn it is suggested that the drill method be used. If the latter method is feasible, the fertilizers may be applied on a definite number of rows across the field at planting time.

Where it is desired to study this problem in a little more detail, one or more plots could be added to the plan suggested. If only one is available, it would be advisable to apply potash alone. This could be done by hill-dropping 50 pounds or broadcasting 150 pounds of muriate of potash to the acre. If still another plot is available, it
would be of interest to use a nitrogen carrier such as sodium nitrate or ammonium sulfate alone. Where this can be done, it would be desirable to apply about one-fourth the total amount to be used at planting time and the rest as a top dressing in early spring for small grain or as a side dressing for corn when it is about a foot high. These materials may be used at the rate of 150 to 200 pounds an acre.

Trials of this kind should be made preferably on land that has been kept in a fair state of fertility by means of crop rotations, the use of limestone where necessary, the plowing down of clovers, and the application of manure. The information obtained will be valuable in indicating whether or not such fertilizers can be used profitably as a supplement to fundamental systems of soil management.

It should be borne in mind that in all experimental tests of this sort great care must be exercised in drawing conclusions. Differences between plots are almost inevitable, because the soil of a field is seldom if ever perfectly uniform through, and therefore small differences should be critically considered before being accepted as significant. For this reason it is well to repeat the series of plots. It is particularly risky to base final conclusions upon the results of a single year, because of peculiar seasonal effects. Never are two seasons exactly alike, and the results of this year may not apply next year. If outstanding effects from the fertilizers occur the first year, such results may be taken as indicative and accepted as a tentative guide for further work, but final conclusions should be withheld until these results are well confirmed in subsequent trials.

Let it be emphasized again that in suggesting that farmers make these fertilizer trials, it is assumed that the basic principles of good soil management set forth in the fore part of this circular are either being applied or else are to be adopted as fundamental to the soil-improvement program. It is under this basic system of soil management that thousands of Illinois acres have been brought to a higher plane of productiveness. In other words, this is a system of proven worth and one which Illinois farmers cannot afford to abandon for methods of uncertain outcome.

To what extent mixed commercial fertilizers can be profitably employed in connection with this long-term basic program of soil improvement is a problem of great consequence. No doubt there are many instances in which such fertilizers may be used with profit, but it is just as certain that in many other instances their use would result in financial loss. Before investing in mixed fertilizers, farmers should carefully consider the cost, which fortunately is an item that can be definitely determined. With the investigation now under way, the Experiment Station hopes soon to be in possession of much more definite information than now exists regarding the use under present-day conditions of these mixed commercial fertilizers.