THE PRINCIPLES of MANURING

An Application of Chemistry to Agriculture

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THIS little pamphlet pretends to be no more than it is, a reprint of aseries of news paper articles hurriedly written during the stress of college work. The subject of the nutrition of plants is so large that each phase of it could of necessity be only very briefly considered in space available, and the writer did not attempt to make the discussion of any subject exhaustive. For this reason many things have been omitted that might be discussed with profit in a larger work. Only the more important considerations concerning the maintenance of fertility have been presented, but it is believed that the statements so far as they go are in accord with the best scientific thought and practice of the day.

A large number of typographical errors will be found in the text, as the manner in which this pamphlet was printed made it impossible to have the proof read and corrected. It is believed, however, that the errors are not such that they will hide the meaning in any case, and the indulgence of the reader is asked for these as well as for the other imperfections of the text.

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PART I. Plant Food in General. Its Nature and Source.

FARMING is a business, and the successful farmer must be, first of all, a business man. He follows his avocation, primarily, for the money he can make, and like other business men aims to get the greatest possible return for the money and labor involved. It is not enough to produce crops, but they must be so produced as to yield a profit on the capital invested. To succeed he must be thoroughly acquainted with every detail of his occupation and must strive to stop all leaks and prevent needless waste. At the same time, he must bear in mind that it is a good business principle to spend a dollar whenever he can see that it will come back to him with interest.

Agriculture differs from mercantile pursuits in being not merely a business, but an art as well—the art of producing plants and animals that are useful to man. To understand this art necessitates a knowledge of the principles upon which the art of agriculture is founded (such, for example, as geology, chemistry, botany, physics and others which might be mentioned), and an understanding of these principles is essential to an intelligent and rational practice. A few years since "anyone could be a farmer." It was only necessary to sow and reap, for Nature dealt lavishly with man and gave to him freely of the fertility she had been storing up for countless ages. A system of extravagant and unbusiness-like farming, however, has so impoverished the soil, in some parts of our country, that many farms are already abandoned, having ceased to be profitable, and that, too, in localities where the land once commanded high prices. This fact is the more lamentable because the exhaustion of the soil might have been prevented by an intelligent foresight on the part of our earlier farmers.

Chemistry has done much to explain how the fertility of the land may be conserved, and it is the aim of this short treatise to present, as briefly as possible, the latest views of agricultural chemists and farmers on this important subject. The intention is to make the series thoroughly practical, and for this reason the minimum of theory and the maximum of demonstrated facts will be given, and all technically chemical language will be avoided when possible. Before taking up the subject of manures and fertilizers it is deemed desirable to devote a short time to the consideration of plant food in general—what it is and from whence it comes.

Plants of First Importance to the Farmer.—All agriculture depends on the growth of plants and consequently the profit that accrues to the farmer depends, primarily, upon the value of the crops his farm produces. In some styles of farming the profit comes from the sale of crops that are useful in providing food, fuel or raiment for man, while in others the direct gain comes from the sale of animals or animal products. Even in the latter case the feeding crops that can be grown on the farm determine its earning power, for the sale of animal products is simply an indirect method of marketing the crops.

The profit from the farm is dependent not only upon the total crop produced, but also, and to perhaps a still larger degree, on the yield per acre. It stands to reason that if the crops now produced on two hundred acres could be grown on one hundred, the returns would be greater, provided the labor and other cost involved were not materially increased, for in the latter case the interest on the money invested in one hundred acres of land would be clear gain. On the other hand it is apparent that nothing is gained by increased production per acre if the larger crop is obtained at a total expenditure in excess of that required for the smaller yield. As a matter of fact our most successful farmers have demonstrated that the present average of crops can be doubled and at a cost per acre scarcely more than is now required for the half crop. To accomplish this necessitates a broader knowledge of the food requirements of plants than is possessed by the majority of our farmers. This knowledge being fundamental, it seems strange that more attention has not been devoted to this subject by those vitally interested. Strange as it may seem, it is a fact that, while he has reasonably clear ideas on foods for animals, the average agriculturist has only very vague and often unfounded notions on the subject of plant food and plant nutrition. A thorough understanding of these subjects on the part of our forerunners in agriculture would have rendered it unnecessary to feel concerned regarding the matter considered under the next heading.

(2) Exhaustion of the Soil.—It is a matter of common experience that continued cropping results in a loss of fertility. The experience of the East teaches some lessons by which the West may profit. In the beginning the productiveness of the rich virgin soil seemed unlimited. For years large crops were produced with apparently no decrease of fertility. Sooner or later, however, the crops began to diminish in size, gradually to be sure, but unceasingly, until at last the yield became so small that it no longer paid for the cost and labor of cultivation. This state of affiairs came about more rapidly if the same crop was grown continuously on the same field, as was often done with wheat. The soil was now said to be exhausted and the farms were abandoned. An exhausted soil in this sense means one that will no longer yield profitable returns, and not necessarily one that will produce no crop. As a matter of fact a soil cannot become exhausted, if by exhaustion we mean total inability to produce a crop.

At the experiment station at Rothamsted, England, barley grown continuously on the same plot for forty-three years without the use of fertilizers of any kind yielded in the forty-third year ten (10) bushels of dressed grain per acre; the average for the last eight years being eleven and three-fourths (11¾) bushels. Wheat grown in the same way for fifty years produced in the fiftieth years nine and three-fourths (9¾ bushels of grain per acre; the average for the last eight years being eleven and one-half (11½) bushels. In these cases the soil seems capable of keeping up this yield indefinitely, for the average for the last twenty years is practically the same as the average given above for the last eight years.

While these facts indicate that the soil can never be completely exhausted, it is exhausted to all practical purposes, when the crop produced ceases to be profitable. The first question that naturally suggests itself is—Why does the productive power of the soil diminish?

(3) The Plant Removes Something From the Soil.—It is evident that the virgin soils must have contained large quantities of some substance or substances that were necessary to vigorous plant growth and that these materials were removed from the soil when the crop was harvested. It is not possible to explain the rapid decrease in fertility on any other basis, for it seems to be to a certain extent independent of any changes in climatic conditions. The change in the mechanical conditions of the soil has been suggested as a possible explanation for its decreased productive power, but even this does not fully explain it. It is apparent, also, that plants vary in their power to extract these substances from the soil, for it is well known that a soil may be sterile towards one class of plants and still poduce a luxuriant growth of another. To ascertain what these materials are that the plant removes from the soil, it is necessary to analyze the plant and then to determine the sources of the ingredients found. For the purpose of this study the corn or maize plant is chosen, as it is perhaps the most important of all plants to the American farmer. Before stating the analysis, it is advisable to devote a moment to a few preliminary considerations.

(4) **Elements and Compounds.**—Chemistry teaches that all matter is composed of simple substances called elements. Between seventy and eighty of them are known. They are called elements because they are the simplest substances known and cannot, by any means yet discovered, be separated into simpler or different substances. Iron, gold, silver and sulphur are examples of elements. Two others, both gases (i. e., oxygen and nitrogen) make up the bulk of the air.

Most materials with which we are familiar are complex bodies and combinations of two or more elements. Such bodies are called compounds. While the number of elements is small, there are many thousands of compounds. This is due to the fact that the same elements can combine in many different ways, each combination forming a different compound. Alcohol, sugar, starch and acetic acid, for example, are substances very unlike in their properties, and yet all consist of the three elements, carbon, hydrogen and oxygen, though these elements are present in different proportions. Plants are composed of a large number of compounds and an ideal analysis would first separate the plant into its compounds and then these compounds into the elements of which they are composed. Approximately such an analysis can be made.

(5) **Chemical Composition of the Corn Plant.**—If a quantity of green corn is allowed to wilt in the sun it loses a large percentage of its weight, due to the evaporation of the water which it contains. If the remainder is now heated in an oven at 212 degrees F. it again decreases in weight, but finally reaches a point where the weight does not change, because all the water is now driven off. Water is composed of the two elements, hydrogen and oxygen. What remains after expelling the water is called the dry matter of the plant. The dry matter burns on being ignited and a very small amount of mineral matter remains which is called ash. The part that burned and completely disappeared is known as organic matter. The organic matter is composed of four classes of compounds known as proteins, fats (ether extract), crude fiber and carbohydrates (nitrogen free extract), and these compounds in turn are made up of the four elements, carbon, oxygen, hydrogen and nitrogen. The ash contains the elements chlorine, potassium, phosphorus, calcium, magnesium, iron, sulphur, sodium and silicon. The following table shows the ingredients found in one thousand pounds of the matured corn plant, i. e., when the plant is in condition to be cut for shocking:

COMPOSITION OF THE CORN PLANT.

Corn Plant 1000 lbs.	Water 793	Hydrogen 88.1 Oxygen 704.9		
	Dry Matter 207	Organic Matter 195	Protein 18. Fat 5. Fiber 50. Carbohydrates 122.	Nitrogen 2.9 Carbon 90 5 Oxygen 88.9 Hydrogen 12 7
		Ash 12	Chlorine 0.4 Potash 4.0 Phosphoric Acid 1.2 Lime 1.6 Magnesia 1.4 Iron Oxide 0.3 Sulphuric Acid 0.3 Soda 0 4 Silica 2 4	

(NOTE.—All of the elements mentioned above as occurring in the ash, with the exception of chlorine, are combined with oxygen. In the table the names under "ash" represent these combinations, i. e. potash is composed of potassium and oxygen: phosphoric acid is phosphorus and oxygen; lime is calcium and oxygen, etc)

From what has been said it will be seen that of the elements known, only thirteen (13) are found in plants, for what is true of the corn plant holds true of all other plants. It will be shown that of this number, three are probably not necessary to plant growth, leaving only ten elements that are essential. The table shows that three elements (i. e., hydrogen, oxygen and carbon) make up ninety-eight and one-half (98½) per cent of the entire composition of the plant, the remaining elements constituting only one and one-half (1½) per cent.

(6) Importance of Water to the Plant.—One of the most striking points brought out by the chemical analysis is the large proportion of water that enters into the composition of the plant. A reference to the table shows that nearly eight hundred (800) of the one thousand (1,000) pounds of the matured corn plant consist of water in a form that can be driven off at a heat not above the boiling point. In the organic matter is found 12.7 pounds of hydrogen and 88.9 pounds of oxygen, which practically all came originally from water, making a total of nearly 900 pounds derived from this source. These figures represent but a small part of the water actually required by the crop. Experiments have shown that approximately 300 pounds of water passes through the plant for each pound of dry matter produced, so that 1,000 pounds of corn uses at least 30 tons of water during its growing period. As this quantity of corn can be raised on one-thirtieth of an acre, it follows that to mature an acre of corn the crop must be supplied with 900 tons of water, or a quantity that would make a layer over the acre eight inches deep.

This, again, takes no account of the amount of water lost from the soil by percolation or drainage. It has been estimated that this quantity is at least equal to that used by vegetation, so that one acre of corn probably requires a precipitation of at least 1,800 tons of water. These statements show clearly the necessity of carefully conserving the moisture of the soil, a point that cannot be too strongly emphasized.

The water all enters the plant at its roots, being absorbed from the soil, and all but a small part of it is given off from the leaves by evaporation or transpiration. Water is important to the plant in several different ways. It is, first of all, the most important food of the plant—in the sense that it supplies the matter composing almost nine-tenths of the weight of the plant. It is also necessary to enable the other food in the soil to enter the plant as these materials can be absorbed by the plant only when they are in solution.

Water is needed to give stiffness or rigidity to the more succulent parts of the plant, as is shown by the drooping of plants when the supply of water is insufficient. It is probable that water performs an important function in controlling the temperature of the plant. The chemical processes in the plant cells produce heat and the excess of heat is removed by transpiration of water through the leaves, just as it is removed from our bodies by the transpiration (perspiration so called) through the skin.

So important to vegetation is the water supply that some investigators claim that the question of fertility is wholly one of having present in the ground the proper amount of moisture and is independent of the chemical composition of the soil, except as this composition affects its power to furnish the plant with water. This view is undoubtedly extreme and is not generally accepted. There is no doubt, however, that the proper condition of moisture is the most important factor in determining the fertility of the land, and that more soils fail to produce good crops for lack of it than for any other cause. In few cases is the water supply sufficient to produce the maximum crop of which the soil is capable.

(7) Part of the Oxygen From the Air.—A small quantity of the oxygen in the plant probably comes from the air. One-fifth the volume of the air is oxygen and the plant uses this to some extent. Plants breathe in much the same manner that animals do, for all cells must have a supply of oxygen in order to live. The oxygen of the air combines with the materials in the cells, one of the results being the production of heat, just as the oxidation taking place in the animal body produces heat. That heat is evolved by the living vegetable cell can easily be proven experimentally by confining the plant in such a way as to prevent radiation. The rapid heating of silage during the filling of the silo is doubtless due to the breathing process of the cell, the heat in this case being unable to escape.

(8) Carbon in Plants Derived From the Air.—Nearly one-half of the dry matter in the plant consists of the element carbon, all of which is derived from the carbonic acid gas that constitutes about four-hundredths of one per cent of the volume of the atmosphere, or about one part in ten thousand. Carbonic acid gas is a compound of the elements carbon and oxygen. Green plants have the power to decompose this gas, retaining the carbon, and setting free the oxygen. This process is known as the "fixation (sometimes assimilation) of carbon," and takes place principally in the leaves. The power to fix carbon is dependent in some way on the presence of the green coloring matter (chlorophyll), so that it is only those plants having green leaves that can use the carbonic acid. Such plants as mushrooms and other fungi, for instance, cannot obtain their carbon in this manner, but must procure it through the decomposition of organic matter, or, in other words, must have their food previously prepared for them. Green plants, on the other hand, can manufacture their own food from the inorganic materials of the soil and the atmosphere.

(9.) Sunlight Necessary to Carbon Fixation.—The decomposition of carbonic acid by the plant, and the assimilation of the carbon, takes place only during the daytime. A certain amount of energy is necessary to break apart the carbon and oxygen of carbonic acid and this energy is furnished by the sunlight. The stronger the light the faster the fixation of carbon, which explains the commonly observed fact that most plants grow more vigorously in full sunlight than in shade or diffused light. The plant has not power to use carbonic acid in the absence of light, so that this process ceases during the night.

It is well known that seeds will germinate in the dark and produce a feeble, spindling growth of pale foliage, but that the plants so produced soon cease to develop. Such plants grow until they exhaust the food stored in the seed, but have no power to use the food in the air and soil, and analysis shows that the plant contains less dry matter than was present in the seed.

In the presence of light, however, the plant absorbs the carbonic acid of the air and causes the carbon to combine with the water and other substances taken in through its roots, to form carbohydrates, proteids and other complex compounds of which the plant is composed. It is now generally believed that the green plants derive their carbon solely from the carbonic acid of the atmosphere and are not dependent in any way upon the carbonaceous matter in the soil; in fact, that they are incapable of using carbon except in the form of carbonic acid gas.

Numerous experiments have proven that the supply of carbon in the air is ample for the largest crops. To be sure, in certain pot experiments a larger yield was obtained by increasing the carbonic acid in the air, but under field conditions the yield is limited by other factors and never by the supply of carbon.

All processes of fermentation or decay, all burning and the breathing of animals, combine to return carbonic acid to the air as fast as it is removed by growing plants, consequently the amount of this gas in the atmosphere remains constant. In all probability that now present in the air has been many times built up into organic matter only to be again set free by its decomposition.

(10) Carbon Costs the Farmer Nothing.—The point of practical importance brought out by this study of the fixation of carbon is that the carbon is furnished free of cost. In other words the carbonaceous matter produced in the crop results in no impoverishment of the soil. There is no need then, of supplying strictly carbonaceous manure to the field, as the crop does not use the carbon in the soil. It will be shown later that such manures may indirectly be beneficial to the plant.

(11) The Nitrogen Problem.—A reference to the table given in section 5 shows that only about one and one-half (1½) per cent of the dry matter of the corn plant consists of nitrogen. Some plants contain more nitrogen than this, but the amount rarely equals three per cent of the dry matter or six-tenths of one per cent of the green plant. In spite of the small quantity of nitrogen in the crop it is the most important of all plant foods from the practical point of view. In fact, the solution of the problem of the maintenace of fertility depends upon an economical method of conserving and renewing the nitrogen supply of the soil. This does not imply that it is more necessary to vegetation than are the other constituents, but that it is the most expensive element to furnish by means of fertilizers and is also, unfortunately, the element most easily lost and wasted.

(12) The Nitrogen of Plants Comes From the Soil.—Most of the crops raised by the farmer are entirely dependent on the soil for their supply of nitrogen. Most of the nitrogen present in the soil is locked up in the insoluble organic matter and in this form is not available to plants.

Some of the nitrogen exists in simple compounds called nitrates, which consist of nitric acid combined with one of the mineral elements of the soil. The majority of farm crops can use only that part of the nitrogen in the soil that is present as nitrates, so that so far as the nitrogen is concerned the fertility of the soil depends on its nitrate content. The nitrate present in the soil at any one time is exceedingly small, but, under proper conditions, the supply may be renewed with sufficient rapidity to meet the needs of the plant.

(13) Source of the Nitrogen of the Soil.—A small part of the nitrogen in the soil is derived directly from the atmosphere. Minute traces of ammonia (a compound of nitrogen and hydrogen) are always found in air and during electrical storms small quantities of the nitrogen and oxygen in the atmosphere are combined to form nitric acid. These substances are dissolved in the rain water during showers and are carried into the soil. The quantity received by the soil from this source is very small, amounting only to from six to eight pounds per acre per year, the maximum amount being less than one-tenth that required by a crop of corn. Nearly all of the nitrogen in the soil is present in the more or less decayed organic matter left behind by the plants that it has previously produced. Plants build up the nitrogen into complex protein compounds and, under natural conditions, when they die these substances, in connection with the other constituents of the plant, become a part of the soil. As long as the nitrogen remains in this form it is of no value to the new generation of plants, for the organic matter must first be decomposed and the nitrogen changed into the form of nitrates.

(14) Nitrification.—The soil must not be regarded as an inert mass of mineral matter and refuse of former plant growth. It is, in fact, an immense laboratory in which millions of tiny workmen are bringing about marvelous chemical changes. The principal factors concerned in these transformations are bacteria, of which, it is estimated, there are present in the neighborhood of one hundred fifty millions in each ounce of surface soil. Some of these bacteria cause the fermentations and decay that return the carbonic acid to the air. Others, and these are of particular interest here, bring about the decomposition of the nitrogenous organic matter with the ultimate production of nitrates.

The transformation of organic nitrogen into nitrates undoubtedly results from the action of more than one species of bacteria and takes place in three or more different steps. The organisms necessary to produce these changes are ordinarily present in all soils. Nitrification takes place only when the temperature is more than five degrees above freezing and becomes more rapid with rise of temperature. Hence, it ceases during the winter months and is most vigorous during the hot months of midsummer. The nitrifying bacteria cannot live without a sufficient supply of oxygen, for this reason stirring the soil increases the rate of nitrification. The nitrifying bacteria cannot thrive in a soil that is acid, so that the presence of carbonate of lime or some other substance that will neutralize any acid produced in the soil is essential to nitrification. All of these points will be discussed in greater detail later. for the present it is sufficient to emphasize the importance of the process of nitrification to the growing crop. So vital, indeed, is the subject, that successful agriculture may be said to depend largely on providing proper conditions for rapid nitrification.

(15) Denitrification.—While the nitrifying bacteria may be said to be the farmer's friends, there are, unfortunately, in the soil other organisms that produce evil results. One class of these, known as denitrifying bacteria, decompose the nitrates, and perhaps some other nitrogenous compounds, with the final result that the nitrogen is set free and returned to the air in its elemental condition. This process, of course, robs the soil of a part of its nitrogen and is especially unfortunate in that it removes the part that was most available to the crop. The conditions that are prejudicial to nitrification (i. e., lack of oxygen and presence of acidity) are those that favor denitrification, so that the farmer in producing proper conditions for the former desirable process is at the same time preventing the injurious denitrification.

(16) Can Plants Use Free Nitrogen of the Air?—About four-fifths of the volume of the air consists of the element nitrogen, so that if this was generally available to plants, there could be no such thing as "nitrogen starvation." Perhaps no question in the realm of agricultural chemistry or plant physiology has received so much attention as the relation of the plant to the nitrogen of the atmosphere and many points still remain to be investigated. The question heading this section can best be answered by a very brief historical review of the subject. At one time it was generally believed that the air was the sole source of the nitrogen supply for the plant. The first important experiments that indicated the contrary were those of Boussingault, in which he grew plants in sterile soil free from nitrogen, the plants being so protected that they came in contact with no nitrogen save that of the air. The plants grew for a short time only, and on analysis showed that they contained no more nitrogen than was present in the seed. Similar experiments conducted by Ville gave contrary results. To decide the matter a great number of painstaking experiments were carried out at Rothamsted, England, all of which confirmed the results obtained by Boussingault and the question was considered settled by most experimenters. It occurred to an American investigator (Atwater) that plants grown under natural conditions might use free nitrogen, even though they did not under the conditions of these experiments. He, therefore, grew plants in pots in the open, analyzing the soil before, and the soil plus the plant at the end of the experiment, correcting for the nitrogen carried down in the rain water. He found that while in most cases there was no gain of nitrogen, in some cases there was and that the plants showing a gain of nitrogen invariably belonged to the legumes. It remained for Hellriegel to explain this phenomenon. He repeated the experiments of Boussingault with this variation, that he added to the soil a small quantity of water leached from a natural soil, so as to introduce any bacteria that might exist naturally in the earth. He found that the legumes grew vigorously while the cereals produced only feeble and short-lived plants. An examination of these legumes showed that they all had little nodules on their roots and these nodules were found to contain innumerable bacteria.

Further experiments have demonstrated that when leguminous plants are grown in soils containing the proper bacteria they can indirectly make use of free nitrogen and are practically independent of the nitrogen in the soil. This property is not a function of the legume itself, but of the bacteria that produce the nodules, and in the absence of these organisms the legumes are quite as dependent upon the supply of nitrates as are the other orders of plants. For all practical purposes then, it may be considered that clover, peas, beans, alfalfa and other legumes derive the bulk of their nitrogen from the air and that in growing them the farmer is not decreasing the nitrogen content of the soil.

(17) Inoculation of the Soil.—Experience has shown that all soils do not contain the bacteria necessary to the fixation of free nitrogen by legumes. They may be introduced into a field by sowing with the seed a small quantity of soil from a field in which the legume has been successfully grown. This has been done so often as to leave no doubt of its practicability. Late investigations have shown that the same species of bacteria will not do for all legumes, so that a soil, for instance, may grow clover to perfection when soy beans or alfalfa will not thrive on it at all. This fact explains many of the disappointments experienced by farmers in the trials of some of the more recently introduced leguminous crops.

(18) Other Ways in Which Nitrogen Is Fixed.—Within the last few years a number of bacteria have been discovered in the soil that have the power of using free nitrogen and which do not grow in connection with the higher plants. These bacteria are found in most soils and may be an important factor in maintaining the supply of nitrogen in the soil. At the present time it is impossible to say if the nitrogen added to the soil in this way is of any considerable moment.

(19) Mineral Constituents of the Plant.—There is still to be considered the mineral matter found in the ash (see Section 5), or that material which remains when the organic part of the plant is destroyed by burning, and which corresponds exactly to the ashes left in the stove after burning wood. The substances found in the ash are all derived from the soil. It has not always been thought that they were necessary to plant growth. The earlier writers on agriculture considered only the organic matter of the soil and certain constituents of the atmosphere as of any importance to the plant. These writers thought the presence of mineral matter merely accidental and due to the fact that the plant took them in because they were dissolved in the necessary soil water, and had no way of rejecting or removing them. Later writers, pre-eminent among whom was Liebig, proved that the ash ingredients were necessary to the plant. A very simple experiment was sufficient to show that at least some of the mineral matter was essential to plant growth. Seeds were planted in pots containing quartz-sand, to one of which nitrogen compounds alone were supplied, and to the other nitrogen and a small amount of plant ash. The plants in the pot which received the ash grew to maturity, while those in the other pot made only a feeble, short lived growth.

(20) Essential and Non-Essential Elements.—The experiment just described proves that there is something in the ash that is required by the plant, but does not show whether a part only or all of the ingredients are essential. This question naturally interested a number of investigators and soon a mass of evidence was at hand. In order to determine which elements are essential, plants were grown, either in especially prepared sand, or by the "water-culture method," in such a way that they were supplied with all the elements occurring in plants with the exception of the one element under investigation. If the plant grew to maturity the element which was missing was deemed non-essential. If, on the other hand, the plant failed to develop, that particular element was considered to be essential.

The numerous experiments of this kind which have been carried on show, that of the ash constituents, potash, lime, phosphoric acid, magnesia, iron and sulphuric acid are absolutely essential to plant growth. Toward soda, chlorine and silica plants seem to be indifferent, as they can be grown to maturity in the absence of these substances. For this reason it is generally considered that only ten of the thirteen elements found in the plant are essential to its growth, soda, chlorine and silica being thought non-essential. Accepting this view, and referring again to the table in Section 5, it will be seen that 1,000 pounds of corn plant contain only 9 pounds of essential mineral matter, or about 0.9 per cent. Attention is called to the fact that these experiments extended over only one generation and that it is possible that an attempt to grow the crop through successive generations in a soil devoid of soda, chlorine, or silica might show different results.

(21) One Element Cannot be Substituted for Another.—The experiments mentioned above have shown, not only that certain chemical elements are necessary to plant growth, but also that it is not possible to replace these essential elements even by others which are similar in chemical properties. In the chemical laboratory, for instance, it is found that soda and potash are very much alike in their action, and one may be used in place of the other in many operations. It would be a great thing for agriculture, if soda could be substituted for potash as a plant food, as compounds of sodium are very cheap compared with potash compounds. This point has been thoroughly investigated, and it has been demonstrated (by the latest experiments especially) that soda cannot take the place of potash as a fertilizer. As a certain amount of each of these elements is required for a certain yield, and none of the elements can be replaced by another, it seems to follow that the crop will be limited by the amount of the essential element present in least proportion, compared with the requirements of the crop. In other words, if a field of corn can obtain potash sufficient for only half an average crop, no more than this can be produced, no matter how much of the other forms of plant food are present.

(22) **How the Mineral Matter Enters the Plant.**—It seems evident that the mineral matter must be taken up in some way by the roots. All are familiar with the fact that the soil is not a solid mass, but consists of small particles or "grains" with air spaces between, these spaces in the surface foot amounting to fully half the bulk of the soil. These soil grains vary in size according to the character of the soil, being very fine in clay and comparatively coarse in sandy soils. The roots of the plant push down between these soil grains, branching more or less, and spreading throughout the soil. Surrounding the growing tip of the root are great numbers of fine root-hairs that work their way in between and around the small soil grains, adhering closely to them and covering an immense amount of surface. It is on these root hairs that the plant is dependent for the absorption of its water and mineral food. It was once thought that plants actually took in the very small solid particles of soil, and that the purpose of cultivation was to render the particles small enough for the plant to absorb It is now known that no food can enter the plant unless it is in solution. Each soil grain is surrounded by a film of water, and this water contains dissolved in it small quantities of the mineral ingredients of the soil, including nitrogen in the form of nitrates. The root hairs absorb the moisture as it is required by the plant and with it such mineral matter as it needs. Both water and the dissolved matter enter the plant by the process known as osmosis, a process that cannot be explained in the brief space allotted to this subject. Suffice it to say, that each element is absorbed independently of the others, and that the plant can, in a way, refuse to absorb more of any one ingredient, when it has all that is needed for its growth. This "selective power" of the plant (if it may be so called) is shown by the fact that two different kinds of crops grown on the same soil may differ greatly in their composition. The ratio between the chemical elements found in them may be entirely different in the two crops and may be, in a great measure, independent of the ratio existing between these elements in the soil water.

(23) **Soil Solutions Very Dilute.**—The amount of mineral matter dissolved in the soil water is very minute. In Section 6 attention was called to the fact that at least 300 pounds of water must pass through the plant to produce one pound of dry matter. The fact that the soil water contains mere traces of plant food probably accounts, in some measure, for the immense quantity of water used by the plant, as it must absorb this water to obtain the food it requires. The plant is not entirely dependent upon the mineral matter actually dissolved in the soil water for its supply of food. The roots have the power of secreting an acid substance that has a solvent action on that part of the soil that is insoluble in pure water. This is shown by the root tracings often seen on pieces of limestone in the soil. It may be shown by growing a plant in a small quantity of soil placed on a piece of marble. If the marble is examined after a time, the outlines of the roots can be seen distinctly where the acid substance has cut into its surface. How great a factor this property of the plant is, cannot be stated at present.

(24) **Function of the Different Food Elements.**—Now that the source of the different elements required by the plant has been briefly discussed, some of the readers of this article may desire to have explained the special function in the vital processes of the plant, that is performed by each of these substances. Unfortunately but little is known in regard to this subject, for up to the present time it has almost defied investigation. Carbon, oxygen and hydrogen are found in all the organic compounds of the plant, and, as has been shown, form 98½ per cent of the green corn crop. Nitrogen is a constituent of proteids and is necessary to their formation. Sulphur is found in some of the proteids, but its special function is not known. Phosphoric acid is supposed to be in some way connected with the transportation of the proteids from one part of the plant to another. Potash is thought to be necessary to the conversion of starch into sugar, and, consequently, its removal from the leaves to other parts of the plant. As starch itself

is insoluble, it must be converted into sugar before it can be transported. Iron is necessary to the production of chlorophyll. A plant grown in a soil devoid of iron contains no chlorophyll and, therefore, does not possess the power of fixing carbonic acid gas and manufacturing starch. Lime probably performs a number of functions, one of which is to neutralize the poisonous oxalic acid formed in the plant and render it harmless by producing the insoluble calcium oxalate. Of the part played by the other elements practically nothing is known.

(25) Other Ways in Which Plant Food Is Lost.—In Section 3 it was suggested that the decrease in fertility of a soil might be due to the fact that the crop removes from it something that is essential to plant growth, and the following sections have been devoted to determining what these essential elements are. Before proceeding to apply the knowledge thus gained, it is desirable to mention briefly two or three ways in which plant food may be lost other than by removal of the crop. First, by leaching of the soil, or removal of plant food in the drainage water. For practical purposes, nitrogen may be said to be the only element lost in this way. As the nitrogen removed by leaching is all in the form of nitrates, any loss from this cause is extremely unfortunate. The soil has the power of fixing most of the mineral elements so that only traces of them are lost in the drainage water. The fact that certain mineral fertilizers are fixed by the soil can be shown by a simple experiment. A tall cylinder is filled with soil and to it is added a quantity of water in which is dissolved compounds containing nitrate nitrogen, phosphoric acid and potash. If the water that leaches through this soil is analyzed it is found that the potash and phosphoric acid have been removed by the soil, but that the nitrogen all remains in the leachings.

Second, by surface washing. In hilly countries this may be a very important factor. As the soil is removed bodily from the surface of the field, it follows that the loss in this case falls on all the food elements. It affects nitrogen and phosphoric acid more than the other ingredients. Most of the nitrogen is in the organic matter which is near the surface and, being lighter than the rest of the soil, is more easily washed away. In most soils the first foot contains a larger proportion of phosphoric acid than the subsoil.

Third, by denitrification. This has been referred to in Section 15 and may be of great moment in a soil that is not properly managed. The conditions that are desirable in the soil are such as best prevent denitrification, so that the farmer who understands his busines need not fear this source of loss.

It will be seen that in all these cases the heaviest loss falls on the nitrogen, the most expensive element to supply, and emphasizes a former statement, that the maintenance of fertility is largely a question of an adequate supply of nitrogen.

The next subject to be discussed is the amount of plant food removed by the crop in its relation to the composition of the soil.

(26) A Small Part of the Plant Food Is Derived From the Soil.—Attention is again called to the fact that the atmosphere is the original source of 98½ per cent. of the materials found in the green plant; the carbohydrates, fats and fiber being composed of elements supplied in the form of water and carbonic acid gas. These substances are furnished free of cost in humid climates, the supply being practically beyond control, and their use by the plant results in no impoverishment of the soil. The subject of practical importance to the farmer is the supply of the other 1½ per cent. of the plant, consisting of nitrogen and the ash elements which are derived directly from the solid portions of the soil. It has been shown that seven of these elements are essential to plant growth. Experience has proven that only three of these elements (i. e., nitrogen, phosphoric acid and potash) are likely to become exhausted, or in other words, that nothing is gained by adding to the soil any of the other elements of plant food. This is due to the fact that the plant uses nitrogen, phosphoric acid and potash in rather larger quantities than the other elements, and that they existed in smaller quantities in the soil, and not because they are any more essential to the plant. Occasionally soils are found that are actually deficient in lime, but in most cases lime is present in sufficient abundance for the growth of the plant. In this study of the effect of the removal of the crop upon the amount of plant food in the soil, then, it will simplify matters to confine attention to the three substances, nitrogen, phosphoric acid and potash, assuming that all the other elements are present in the soils in abundance.

(27) **Amount of Fertility Removed by Crops.** The different crops vary greatly in the amount of the three valuable fertilizing ingredients which they contain. The following tables gives the amount of nitrogen, phosphoric acid and potash in 1,000 pounds of some of the important crops, the different materials being selected to show something of the range of composition.

Table 2.—Amount of fertilizing ingredients in crops:

1000 POUNDS OF—	Pounds of Nitrogen	Pounds of Phosphoric Acid	Pounds of Potash
Corn Fodder, with ears.	17.6	5.4	8.9
Corn, ears only........	14.1	5.7	4.7
Timothy Hay..........	12.6	5.3	9.9
Wheat, grain	20.2	8 7	5.5
Oats, grain............	16.5	6.9	4.8
Clover Hay	21.2	5.5	18 7
Tobacco	24.5	6.6	40.9
Cabbage	2.4	1.4	5.8
Potatoes	5.7	1.2	3.8

Notice the great difference in the amount of fertilizing materials removed in one thousand pounds of the various crops as shown especially in the table under nitrogen and potash. For the purpose of this discussion the per cent. of fertilizing ingredients in the crop is not of so much importance as the total amount removed by it from each acre of ground. The next table gives the amounts of nitrogen, phosphoric acid and potash removed from an acre by a few of the common crops. (Compiled by Van Slyke.)

Table 3.—Amount of fertility removed from an acre:

KIND OF CROP	YIELD	Lbs. of Nitrogen	Lbs. of Phosphoric Acid	Lbs. of Potash
Corn, grain only.	45 bus.	63	24	26
Clover Hay.....	2 tns.	82	18	88
Cabbage........	15 "	100	35	135
Barley..........	30 bus.	56	17	51
Wheat..........	15 "	31	10	13
Wheat	30 "	62	20	26
Oats............	45 "	45	16	37
Tobacco	1600 lbs.	76	16	200
Timothy Hay...	1½ tns.	38	15	45

An interesting point brought out by the table is the great difference in the total amount of plant food removed from an acre by the various crops. It is readily seen that certain crops must exhaust the fertility of the soil more rapidly than others, and common experience shows that the plants which remove large quantities of the essential plant foods are those that most quickly render the soil unfertile.

(28) **Amount of Plant Food in the Soil.**—The bearing of the above facts upon the question of the maintenance of fertility cannot be fully shown unless the amount of plant food existing in the soil is determined. Large numbers of analyses of soils have been made and, as might be expected, these analyses show great variations in the composition of the soils. The following table gives the amount of nitrogen, phosphoric acid and potash in the first foot of typical sandy loam, clay loam and clay soils.

Table 4. Amount of plant food per acre in the surface foot.

KIND OF SOIL	Nitrogen, Lbs. per acre	Phosphoric Acid, Lbs. per acre	Potash, Lbs. per acre
Sandy Loam	3,736	7,326	28,669
Clay Loam.... ..	4,789	4,935	44,827
Clay...............	3,250	5,600	12,600

The large amount of plant food present in the soil is surprising in view of the fact that it is so hard to maintain a satisfactory yield of crops. Comparing tables three and four it is seen that the analyses of the clay loam soil shows the presence of sufficient nitrogen for 77 crops of wheat yielding 30 bushels to the acre; enough phosphoric acid for 246; and potash to supply 1724 such crops. The second and third foot contain nearly as much phosphoric acid and potash as the surface foot, so that so far as these two substances are concerned the supply seems almost inexhaustible. Although the chemical analyses of many soils upon which wheat has been grown show fully as large amounts of plant food as the clay loam under discussion, experience has demonstrated that long before the smallest number of crops mentioned above (i. e., 77,) have been produced the yield has so decreased as to be unprofitable.

(29) **Chemical Analysis Does Not Show Available Plant Food.**—The reason for the apparent inconsistency between the analyses of soils and the actual results in raising crops is found in the fact that the chemical analyses give the total amount of nitrogen, phosphoric acid and potash in the soil, but do not indicate what part of these foods is available to the plant. The greater proportion of these substances is locked up in insoluble compounds in which form the plant is incapable of using them. Smaller quantities have been changed by the forces of nature into forms in which they are available to plants. While the amounts of these materials removed by the crop seem insignificant when compared with the total plant food in the soil, they may be very large in comparison with the available part. The unavailable or "potential" plant food, is gradually being made available, but not with sufficient rapidity to replace that removed from the field at harvest. It will thus be seen that present fertility of the soil depends not upon the potential plant food it contains, but upon that which is immediately available to the plant, and the yield will be limited by the element of this available plant food present in least quantity. Continual cropping of the soil, with the removal of everything from the field, results in the exhaustion of the plant food that has been rendered available during the past ages. The next subject that suggests itself is the origin of the plant food and the manner in which it became available to plants.

(30) **Origin of the Soil.**—All soils are derived primarily from the igneous or original rocks, of which the granites, trap, etc., are good examples. Geology teaches that the earth was once a molten mass, and that, on cooling, it solidified into rocks, of which those mentioned are types. These rocks must have contained all of the mineral or ash elements of plant food, as no other source of them is conceivable. This plant food, however, was present in insoluble compounds and in this form was not available to plants. The conversion of this potential plant food into available forms was brought about by a number of agencies. Fortunately these changes can be studied at first hand in the lava beds resulting from volcanic eruptions, and which have been transformed, in an incredibly short time, from beds of solid rock into more or less fertile soils, by a series of changes much like those to be described.

Evidently the first step toward the conversion of the solid rock into soil must have been the act of pulverization. A number of natural agencies have taken part in the grinding of the original rock into the small particles in which they are found in the soil. The rocks have been disintegrated through the influence of heat and cold, freezing and thawing, and by the action of air, water and ice. Such rocks as the granites, for instance, can easily be seen to consist of several different minerals. These substances are differently affected by heat and cold, expanding and contracting at different rates, and for this reason the effect of changes in temperature is to separate the rock into its component parts. All rocks are more or less porous and consequently absorb water, and the expansion of this water upon freezing tends to break the mas sinto fragments. Perhaps more important in this grinding process than either of these factors is the action of running water, and moving ice in the form of glaciers. There is not space to discuss these forces in detail, but it will be sufficient for the purposes of this paper if it is kept in mind that all these influences combine to disintegrate and grind the surface rocks into smaller and smaller fragments, until they are reduced to the finest particles found in what is called the soil.

A soil produced by mere pulverization of the rocks would not furnish proper food for the higher plants, as one can readily imagine if he thinks how unsuitable pulverized granite would be for plant production. The essential elements locked up in these insoluble compounds must be transformed into materials that the plant can assimilate, and water is an important factor in bringing about these chemical changes. Pure water has very little solvent effect upon the minerals of which the igneous rocks are composed. The water that enters the ground has dissolved in it small amounts of carbonic acid gas derived from the air and water containing this gas will dissolve these minerals in appreciable quantities.

All the processes enumerated unite in transforming the mineral matter of the rocks into forms available to plants, but the mineral foods alone cannot support the higher plant life. It has been shown that to grow crops the soil must contain available nitrogen, and this must have originally been derived from the air. In a previous section (13) it was mentioned that small quantities of combined nitrogen were carried into the soil by the rain-water and this amount, though very small, would probably be sufficient to enable plant growth to begin. Some bacteriologists believe that the species of bacteria mentioned in section (18), which can live on mineral food alone, deriving all their nitrogen from the air, were important factors in the early nitrogen supply of the soil.

Vegetation begins with the very simplest forms of plants and is of course very scanty at first. These plants on dying become a part of the soil, all of the plant food used by them being thus returned. Food that has once been used by plants is very readily made available to succeeding crops, through the processes of decay and nitrification which have been described. The soil is now able to produce a larger crop, as it contains the plant food in the previous growth in addition to that added through the agencies detailed above. In this way the growth gradually becomes more abundant. The plants on decaying give rise to humus and this increases the fertility of the soil both by being a source of plant food and by increasing its water-retaining power. It will be shown later that humus is a very important factor in fertility. During the decomposition of the plants that give rise to humus, acid substances are formed which act on the rocks in such a way as to make more of the plant food available. One of the products of decay or fermentation is carbonic acid gas and this is dissolved in the soil-water and, as has been mentioned, water containing this gas is an important help in disintegrating the rocks.

As the plant food increases from these various causes the lower and simpler forms of plant life are gradually replaced by those which are more highly organized. With the advent of plants bearing roots other factors in the formation of soils are introduced. The roots secrete an acid substance that has a solvent effect on the mineral matter of the soil (see section 23), and assist mechanically in breaking down the rocks. All are familiar with the tremendous force exerted by plants in breaking apart rocks and stone if once their tender rootlets obtain a foothold in a crevice. The roots penetrate the soil sometimes to great depths and, as they decay after the death of the plant, they leave little channels in the soil which serve to carry down water laden with carbonic acid, as well as to introduce the oxygen of the air that, in its turn, is a factor in bringing about chemical changes in the soil which assist in making plant food available.

Sooner or later in the process of soil formation, plants of the pulse family (leguminous plants) such as clover, vetches lupines, etc., become introduced. These plants, as has been shown, can, through the agency of the nodule forming bacteria in the soil, derive part of the food from the free nitrogen of the atmosphere. This peculiar property of leguminous plants is of paramount importance, for it is undoubtedly Nature's principal method of increasing the supply of nitrogenous food in the soil (see section 16). The nitrogen compounds accumulated by these plants eventually become a part of the soil through their decay.

(31) **Nature's Methods Contrasted With Man's.**—The important lesson to be learned from a study of the origin of the soil is, that nature undisturbed has many ways of adding to the supply of available plant food. The various forces that have been under discussion have all tended to change more and more of the potential food into forms that can be assimilated by the plants so that the amount of vegetation which the soil can produce has been constantly increasing. Under natural conditions, this growth is not removed from the ground but is again made available, so that the soil is constantly increasing in fertility. It will thus be seen that the fertility of the virgin soils is the result of accumulations due to a variety of forces acting doubtless through countless ages, a period during which practically nothing had been removed from the soil while much had been added to it.

Man, on the other hand, has reversed this process, and while adding little to the soil has removed much from it. Through the constant harvesting of crops and by leaving the ground bare and exposed to the action of the elements, he is rapidly depleting nature's store of food and the yield steadily becomes smaller. The effect on the mechanical condition of the soil due to the removal of all vegetation is serious, for in this way the soil is deprived of its humus making materials which is unquestionably quite as important as the actual loss of the chemical elements of fertility.

(33) **How to Prevent Exhaustion of the Soil.**—Although Nature's method of maintaining the fertility of the soil is without doubt the most effective, it is of course impracticable for the farmer, for he must remove most of his crops from the field in order that they may be put to the various uses for which he raises them. A study of the formation of the soil, however, suggests two things that he can do to prevent the exhaustion of the fertility. The first is to so treat the soil as to assist and hasten nature in the process of converting potential plant food into available forms; and to guard against a too complete destruction of the organic matter in the soil. The second is to return to the soil an amount of nitrogen, phosphoric acid and potash equivalent to that removed by the crop.

PART II. Making Potential Plant Food Available.

(34) **Tillage.** — The most efficient means of assisting nature in the conversion of unavailable food into forms that the plant can use is good tillage of the soil. Tillage, in the sense in which it is used in this article, signifies any operation of stirring and pulverizing the soil by means of plows, harrows, cultivators or any other implement, either before or after the seed is sown. Obviously it would not be in keeping with the purpose of this paper to describe the tools to be used or the methods of operation, so that a brief account of the benefits to be derived from tillage is all that will be considered here.

The most noticeable result of thorough tillage is that the soil is made finer, the large lumps being broken up into smaller particles, and in this way nature's work in the formation of soils is accelerated. Pulverization of the earth is beneficial in many ways. In the first place, loosening the soil makes it easier for the plant roots and root-hairs to penetrate it. It has been mentioned (22) that all soils are composed of grains, of greater or smaller dimensions, separated by air spaces. The tender root-hairs must push their way in between these soil-grains as it is impossible for them to penetrate the solid particles themselves. It must be evident that the more the soil is pulverized the larger the number of the openings between grains, and, consequently, the greater the room for root growth.

The plant is dependent upon the root-hairs for its supply of mineral food, and as these hairs grow only between and around the soil grains, it is apparent that they can feed only on the surfaces of these particles. Good tillage increases the amount of surface exposed to the roots by breaking the large lumps into small grains; the more complete the pulverization the larger the area from which the plant can obtain its food. The rapid increase of surface due to breaking down the lumps in a soil in poor tilth seems almost unbelievable to one who has given the subject no thought. An example will serve to illustrate what is meant: A cube two inches on the side presents a surface of 24 square inches. If this cube is cut once in each direction, eight cubes are formed, each one inch on a side, giving a total of 48 square inches of surface, so that cutting only once in each direction doubles the amount of surface, and, theoretically, a plant should be able to derive twice as much food from the eight small cubes as from the large one.

Tillage not only increases the amount of surface on which the plants can feed, but, at the same time, enlarges the water supply of the plant by giving the soil greater capacity for holding moisture. Attention has been called to the fact that each soil-grain is surrounded by a film of water which is called the capillary water or film moisture. The plant is dependent on this film moisture for its supply, and it is readily seen that the amount of capillary water that the soil can hold depends upon the aggregate surface area presented by the particles of which it is composed. The rate at which this area and the consequent amount of available moisture increases is strikingly brought out by King, in his book entitled, "The Soil," from which the following is quoted: "Suppose we take a marble exactly one inch in diameter. It will just slip inside a cube one inch on a side, and will hold a film of water 3.1416 square inches in area. But reduce the diameters of the marbles to one-tenth of an inch, and at least 1,000 of them will be required to fill the cubic inch, and their aggregate surface will be 31.416 square inches. If, however, the diameters of these spheres be reduced to one-hundredth of an inch, 1,000,000 of them will be required to make a cubic inch and their total surface area will be 314.16 square inches. Suppose, again, the soil particles to have a diameter of one-thousandth of an inch. It will then require 1,000,000,000 of them to completely fill the cubic inch, while their aggregate surface must increase to 3141.59 square inches." Another way of stating the same fact is that if an acre of ground is so tilled as to reduce the average diameter of the soil particles to one-tenth the original diameter, the plant now has ten acres from which to draw its supply of water and mineral food for each acre it had before; and the soil is enabled to hold as film moisture ten times as much water as it could in the first instance. It must be apparent that the loosening of the ground incident to tillage makes it easier for the rainwater to enter the soil and tends also to prevent loss by surface washing.

Tillage is useful in the spring in causing the soil to dry out more quickly so that planting may be done, and also has a tendency to make the ground warmer. For this purpose it is conducted in such a way as to expose the maximum amount of surface to the action of the sun and atmosphere. Later in the season tillage is used to prevent loss of moisture, and for this purpose the process is so carried on that a thin layer of very dry earth is produced at the surface to prevent evaporation. Under ordinary conditions, where the soil is somewhat firm, water is drawn up from below by capillary attraction to replace that removed from the surface by evaporation. As this evaporation may be very rapid in the hot, dry weather of midsummer, the result is that the water is virtually pumped out of the soil until it is too dry for good plant growth. If something is done to break this capillarity, the water cannot be brought up from below. This is the end accomplished by the "earth mulch" which is simply a layer two or three inches deep of very dry soil, so dry and loose that it cannot take up the water from the layer next beneath it. The same end can be attained by covering the ground with loose straw or other similar material, the principle underlying both kinds of treatment being the same. To make an effective earth mulch the cultivation should be shallow and frequent; the aim being to make the layer as dry as possible. A rain, of course, will again compact the loose earth and renew the capillarity, so that the cultivation should be repeated as soon as possible after a rain. Even in absence of rain the mulch will sooner or later become compact of itself if left too long without stirring. Thorough cultivation of the soil tends to keep the temperature as well as the water supply more uniform.

Stirring the soil is beneficial in bringing together particles which have not before come into contact. In this way chemical changes may take place that render potential plant food available, for substances having different chemical properties are thus enabled to act upon each other. The changes whereby potash and phosphoric acid become "fixed" in the soil are reactions of this class. (25).

The changes brought about by freezing and thawing may also be accelerated by proper tillage. This is made use of by some farmers who plow heavy, lumpy land in the fall so that it may be exposed to the influence of the weather during the winter. For this purpose the land is so plowed as to leave it rough and with the largest possible area exposed to the weather. Freezing and thawing bring about disintegration of the clods in much the manner mentioned in the section on formation of the soil, and the resulting improvement is most remarkable in some classes of soils.

One of the most beneficial results to be obtained from tillage is the aeration of the soil. The introduction of the oxygen of the air into the soil is of benefit in a number of ways. In the first place a certain amount of air in the soil is necessary for the growth of all plants usually raised on the farm. The roots cannot live without air any more than those parts which grow above ground. That air is needed by the roots can easily be shown by placing a pot containing any ordinary plant (not an equatic plant) in a jar of water so that the soil will always be saturated. In a short time the bad effects will be noticeable on the plant. The plant does not decline because the water is injurious but because the presence of the water excludes the air from the roots.

The oxygen of the air has a direct chemical action on the mineral matter of the soil that tends to make it soluble. It also prevents the formation of certain compounds (notably the sulphides of iron) which are injurious to vegetation.

All fertile soils contain a considerable amount of organic matter and the presence of oxygen is necessary to its decomposition. Attention has been called to the fact that the soil contains innumerable bacteria, a part, at least, of which are concerned in the decay of the organic matter, and those which are beneficial to the farmer cannot live without oxygen. One class of these bacteria decompose a part of the organic matter with the formation of carbonic acid gas, and it has been shown that this gas dissolved in the soil water is a great factor in making plant food soluble. As this decomposition goes on more rapidly in well-aerated soils it will be seen that this is one reason for the increased fertility due to thorough tillage. The nitrifying bacteria previously mentioned (14) thrive only in the presence of a sufficient supply of oxygen. It has been shown that most of the nitrogen of the soil is locked up in insoluble organic compounds and that before it can be used by plants it must be converted into the form of nitrates. This process only takes place in a soil well supplied with oxygen, and experience has proven that this process is very materially hastened by frequent cultivation. The extreme importance of this process of nitrification has already been commented upon (14), and it only remains to say that tillage would pay for itself if it did no more than hasten nitrification.

The bacteria that enable leguminous plants to use free nitrogen are also dependent on the air in the soil, for not only do they need oxygen, but experiments have shown that it is only from the air in the soil that they can draw their supply of nitrogen. It is necessary, therefore, in order that leguminous plants may profit by the nodule forming bacteria, to have the soil in such a condition of tilth that the air may freely circulate through it.

Thorough aeration of the soil also prevents the action of the denitrifying bacteria (15), as these bacteria thrive best in a soil devoid of oxygen. Acidity of the soil is also favorable to the growth of the denitrifying bacteria, and the presence of sufficient oxygen in the soil tends to keep it sweet (i. e., to prevent the formation of acid).

Lastly, tillage is useful in destroying weeds. It is undesirable to allow weeds to grow because they rob the crop of its moisture and plant food. All plants during their growth pump up water by means of their roots and give it off through the leaves. It has been shown (6) that at the best the supply of water in the ground is seldom sufficient for a maximum crop, so that any water that is drawn from the soil by the weeds works a positive injury to the desirable plants. While it is probable that the weeds work greatest injury to the crop by depriving it of water they also rob it of its mineral food. Some farmers argue that if the plants remain on the ground they are removing no plant food, but it must be remembered that they are using that portion of the plant food that would be available to the crop and that the weeds must decay before this food is again rendered available, so that so far as the present crop is concerned the food is as completely removed as it would be if taken from the field.

The destruction of weeds was formerly regarded as the only reason for tillage after seeding. It is now known that stirring the soil has a distinct value in itself and that the destruction of weeds is really secondary. In fact, if the farmer so tills his soil as to reap the maximum benefits to be derived from this process he will have no need to worry about the weeds.

(35) Drainage. An important method for increasing the fertility of some classes of soils is that of underdraining by use of tile or other means. Water exists in the soil in two principal conditions, viz: as the film or capillary moisture previously discussed (34), and in the form known indiscriminately as free water, ground water, or hydrostatic water. In the latter condition the water occupies the spaces between the soil grains, and is not held by the attraction of these particles. The surface level of this free water is known as the "water table" and is situated in some soils very near the surface, while in others it is many feet below. The exact position of the water table can be readily ascertained by sinking a hole to such a depth that water will stand in it; the level of the water in the hole being practically that of the water table. It is this free or ground water that supplies shallow wells and the ordinary springs. In some cases the water table may be at or above the level of the ground, as is obviously the case where marshes and lakes exist.

When the level of the free water is near the surface of the ground, the soil will be greatly benefited by some system of underdrainage as this hydrostatic water is, for several reasons, injurious to the crop. Ground water limits the feeding space available to the plant, and, consequently, the amount of food it can obtain. Those plants that are of importance to agriculture must have their roots supplied with air (34), and investigations have shown that such plants do not send their roots below the water table, because the spaces between the soil particles below this level are filled with water, thus preventing the entrance of air. In other words, the depth to which the plant will send its roots is determined by the position of the water table.

Free water makes the soil cold. A great deal more heat is necessary to warm water a certain number of degrees than is required to raise the temperature of the same weight of the dry matter of the soil the same amount. A soil, therefore, that contains much water is harder to heat than one that is comparatively dry. A very wet soil causes plant food to become locked up in unavailable forms and in some cases compounds are produced which are actually poisonous to the desirable plants. An excessive amount of water in the soil also dilutes the plant food in solution and makes it more difficult for the plant to procure sufficient nourishment.

One of the most important considerations in this connection is the fact that the presence of free water in the soil prevents nitrification and promotes dentrification. In a water-logged soil nitrates are rapidly decomposed, the nitrogen being given off to the air in the free or elemental condition; and for this reason not only is the nitrogenous food in the soil destroyed, but the application of nitrogen fertilizers to such a soil results in great waste of this valuable element of fertility.

Underdraining the field results in lowering the water table to the level of the drain, the water flowing off through the tile instead of standing near the surface as stagnant water. A few ways in which this is of benefit to the soil may be indicated. The removal of the free water from the soil above the drain allows the entrance of air, and for that reason increases the depth to which the roots will penetrate. The entrance of air with its oxygen and carbonic acid, and the consequent greater depth reached by the roots and earthworms, are factors of importance in improving the texture of the soil. The rains will now soak down through the soil instead of running off the surface, and in this way the nitrogen in the rainwater is added to the soil, and surface washing is to a certain extent prevented. Rain in the spring is warmer than the ground and, as it percolates through the soil, has a beneficial effect in warming it, thus putting it in condition to promote plant growth much earlier in the season. Evaporation of water from the surface of the soil tends to keep it cool and, as the amount of water near the surface is decreased by drainage, evaporation is also lessened. Well-drained lands, therefore, maintain a higher temperature throughout the season than do those containing much free water.

Paradoxical as it may seem, underdraining increases the amount of water available to the plant. The crop depends almost entirely on the capillary or film moisture for its supply of water, and as has been said, the roots do not enter that part of the soil containing free water. Lowering the water table greatly increases the total amount of film moisture, as all that part of the soil from which the free water has been removed is capable of holding capillary water. It will thus be seen that while the total amount of water in the soil is decreased by drainage, that which is of use to the plant is made much greater.

Drainage prevents injury from drouth, for by means of it the plants are encouraged to make deeper root growth and, therefore, are not so easily affected by the extreme drying of the surface of the ground that takes place in times of scanty rainfall. It will readily be seen that tiling draining determines the highest point the water table can reach, but that in dry weather the level of the ground water may be much below the drain. It is sometimes thought, for this reason, that part of the water from summer rains, that would otherwise be absorbed by the soil below the drain, may be lost through the tile. Experience has shown, however, that the water does not percolate into the drains, as some suppose, and that it is only when the rainfall is sufficient to raise the water table to the level of the drains that any water is removed by them. It is a matter of common observation that, except in the case of quite low lands, it is only the very heavy summer rains that cause the drains to run. It will thus be seen that it is merely the excess of water which is removed by underdraining and not that part which is of most importance to the plant. Although the crop probably makes little direct use of the free water of the soil, one must not lose sight of the fact that this water may be drawn into the upper layers of the soil by capillarity to replace that lost by evaporation, and for this reason the underdraining should not be so deep as to interfere seriously with capillary action.

Drainage lengthens the season of plant growth. Soils that are well drained warm up earlier in the spring than they would otherwise, due as has been explained, to the decreased evaporation incident to the removal of the hydrostatic water, and to the fact already mentioned that dry soils heat more quickly than wet ones. Plants need a certain amount of warmth in the soil before they will grow so that anything that increases the time that the soil is warmed to the proper temperature lengthens the season of growth. Nitrification and the other processes by which plant food is made available also take place more rapidly in warm soils.

Strangely enough, experience has shown that it is not merely low lying soils which are benefited by underdraining. In many cases heavy clay soils in elevated positions, especially if underlayed by rather impervious subsoils, are greatly improved in tilth by tiling. In such soils the percolation is so slow that practically the same effect is produced as would be expected if the general level of the ground water were near the surface. These soils are made more mellow by drainage and respond more readily to early tillage. Clay soils are often puddled by the fine particles in the soil water being deposited in the spaces between the soil grains, thus cementing them together. The use of tile will often prevent this by causing the water to sink more rapidly through the soil. Tile drained fields are not so apt to be injured by hauling heavy loads over them as are those not so treated.

(36) Irrigation. There are large areas in this country which, for lack of sufficient water, produce very scanty vegetation, although in many instances the soil is well supplied with the other materials essential to the plant. The results to be derived from irrigation on such soils are too well known to call for common here. The work of investigators in the so-called humid climate east of the Mississippi (notably that of King) has shown that even here the total rainfall is seldom sufficient for a maximum yield of the staple crops, and the precipitation is distributed so unevenly throughout the season that a comparatively small part of it can be used by the crop.

Many market gardeners recognize the fact that some system of irrigation is necessary for the most profitable returns, and are in the habit of supplying water artificially to their more valuable crops. Marshall P. Wilder, when asked to name the three things most essential to successful strawberry culture, is said to have replied: "First, plenty of water; second, more water; third, still more water."

At the present time irrigation of the staple farm crops is not practiced to any large extent in the humid parts of this country. King has shown that the yield of these crops can be greatly increased by supplementing the rainfall with irrigation. Two examples will suffice: An average of two crops of potatoes gave an increase of 105 bushels per acre due to irrigation. In 1894 he reports a crop of flint corn yielding 14.5 tons of dry matter per acre on an irrigated plot while the same corn yielded four tons when receiving only the natural rainfall.

It is more than probable that the future will see irrigation in extensive use east of the Mississippi, but at the present time it is only in the experimental stage and it has yet to be demonstrated that it will be profitable with ordinary crops under practical conditions. It is to be hoped that experiments along this line will soon be made, but they should be undertaken only by men who have made a study of the subject, for in humid climates irrigation in untrained hands may produce more harm than good.

(37) Bare Fallows.—The practice of fallowing or resting the land is a very old one, being mentioned in the twenty-fifth chapter of Leviticus, where the people are commanded to rest the land every seventh year. ("The seventh year shall be a Sabbath of rest unto the land.") It would be interesting to know if this law was introduced into the Jewish code from a knowledge of the effect of fallowing on the soil, or if it had more to do with the mystical meaning that seems to be associated with the number seven in the Hebrew religion.

A study of the history of agriculture leads one to believe that when the nomadic tribes first settled down to anything like systematic cultivation of the soil, they grew one crop (probably of the wheat family) continuously on the same field until the soil became so impoverished that it could no longer be tilled with profit. They then moved to other sections, where virgin soil was to be found, and repeated the process. In the course of time it was discovered that those lands which had been abandoned would again produce good crops after a period of "rest," as it is called. This led to the practice of cropping the land one year and allowing it to idle the next. It was later discovered that if the soil was frequently stirred during its resting period the growth on the following year would be much more luxuriant than if the ground was left undisturbed. From this beginning arose the practice of summer or bare fallowing, as it is understood today. Later experimenters found that practically as good results could be obtained by the use of the so-called "fallow crops" in place of the year of rest. These are simply crops like Indian corn, turnips, potatoes, etc., which are intertilled and kept free from weeds during at least a part of their period of growth, and their introduction has practically done away with the use of the bare fallow in most localities.

It is well understood that what was formerly called resting the land is in reality a method of bringing about ideal conditions for the transformation of potential food into forms available to the plant. This practice of fallowing the land had practically fallen into disuse, but is being so strongly advocated in some quarters at the present time that it seems proper to briefly discuss the subject here.

The chief advantages claimed for summer fallowing are: (1) It makes plant food available, thus increasing the succeeding crop. (2) It enables one to rid the land of weeds. (3) It destroys large numbers of injurious insects. It is doubtful, however, if under good conditions of tillage and soil management, fallowing is ever necessary. It adds nothing to the soil, but merely presents conditions that are favorable to the conversion of potential plant food into available forms, and the increase in the crop following the fallow is seldom sufficient to recompense the farmer for the year of non-production. The crude methods of cultivation in use in earlier times doubtless made fallows necessary, but the introduction of modern machinery and more rational methods of tillage have for the most part removed this necessity.

There is no doubt of the efficiency of fallowing as a method of making plant food available, especially if the soil is frequently stirred. The conditions brought about by this treatment of the soil are just those that hasten nitrification, for it has been shown that the nitrifying bacteria thrive best in a warm, well aerated soil. The result of fallowing is that during the hot summer months the process of nitrification goes on very rapidly, and, as there is no growth to remove them, the nitrates accumulate in the soil in large quantities. Attention has been called to the fact that the nitrates are easily leached out of the ground if present in any considerable amount. One of the dangers of the practice of fallowing is that if the land is left bare during the heavy rains of fall and winter a large part of the nitrates formed during the summer months may be lost in the drainage water, a state of affairs that is to be avoided if possible. At the New York (Geneva) Experiment Station experiments were made to determine this point. Lysimeters were constructed to simulate natural conditions as nearly as possible and yet allow the collection of the drainage water. On one of these lysimeters grass was allowed to grow, being frequently mowed as is done on a lawn. The soil in another was kept bare, no plants at all being allowed to grow, and the surface was frequently stirred. The drainage water from the lysimeters was all collected and the nitrogen determined. It was found that in the case of the lysimeter on which the sod was growing practically no nitrogen was lost in the drainage water, while in the other the loss amounted to from 218 to 357 pounds of nitrogen per acre each year. There is no doubt that these figures are in excess of the loss which would actually occur under field conditions, as the drainage in the lysimeters was perfect, and there were practically none of the effects of capillarity which would have obtained in the field. They show, nevertheless, in a marked way the danger of great loss of nitrogen if the summer fallow is followed by heavy fall rains. It was found that the loss was small in the summer months, nearly all of it occurring during the fall and winter. This loss of nitrogen amounts to from two to four times that removed by a crop of corn, and it will be remembered that it is the nitrogen which is in the form most available to plants that is lost by leaching.

These experiments are also interesting in that they show how slight is the danger of loss of nitrogen if a crop is kept growing on the land. Numerous other experiments have confirmed this observation, that if the field is covered with a growth of plants practically no nitrogen is lost in the drainage water, not because the nitrates are not formed, but because the plants appropriate them as fast as they are produced. If then, the field which has been lying idle during the summer is planted to a crop before the fall rains begin, the loss of nitrogen will probably be prevented. The whole secret of preventing the leaching of nitrogen from the soil is to have some crop on it during all the growing season. Nitrification takes place very slowly after the warm weather of summer has passed, so there is little danger of loss of nitrogen through leaving the ground bare in the late fall, provided a crop has been growing on it during the period that was favorable to nitrification. For this reason there need be no fear of loss of nitrogen as a result of fall plowing.

There are, however, two sides to the question of the desirability of summer fallows. King cites experiments of his own which show (by determinations made April 30) that the plots which had been fallow the previous year contained 245 pounds more nitrate nitrogen per acre than the corresponding plots on which crops had been produced. His experiments further showed that the amount of nitrate nitrogen in the fallow plots at that date was actually more than it was on Aug. 22 of the year before. "From this it is clear that the crops on fallow ground start out in the spring under conditions very superior to those on the fields which had not been fallow" (King). Unfortunately these experiments throw no light on the losses through drainage, and it is impossible to decide whether this desirable condition in the spring has not been brought about by too great a drain on the total nitrogen supply of the soil.

Summer fallowing has a tendency to conserve the moisture of the soil, as one can readily imagine when he recalls the rapid rate at which plants remove water from the ground. (6) The tillage incident to the fallow also prepares an earth mulch and prevents loss of water by evaporation. At the Wisconsin Experiment Station it was found that in the spring following a summer fallow the land which had been fallowed contained 203 tons more water per acre than did that which had been cropped the previous year. The following quotation is the closing paragraph of King's work, entitled "The Soil":

"In very wet climates or more especially in those which have heavy rainfalls outside the growing season, so that excessive percolation and loss of plant food through drainage is large, summer fallowing in broad fields cannot be recommended. But in dry countries, where the loss of plant food through drainage channels is small, broad field summer fallowing may in some cases prove decidedly advantageous, because with the deficient rainfall, there may not be moisture enough to mature a crop and at the same time to develop a sufficient store of plant food from the native fertility of the soil to meet the demands of the next season. At all events, the arguments urged against fallowing in countries like England do not apply to tne semi-arid districts of the world with equal force!"

The claim that fallowing is efficient in the destruction of weeds and injurious insects is a valid one, but the same results can probably be obtained by a judicious rotation and by the use of cultivated crops, without allowing the ground to lie idle. After all, the practical question is whether the one crop after the fallow is equal to the two crops that would otherwise be produced, and the concensus of opinion among practical farmers seems to be that it is not. This is one of the many problems in agriculture which calls for more thorough investigation and, fortunately, is receiving the attention of some of our experiment stations at the present time, so that more scientific data may be hoped for in the near future.

While the long summer fallow is to be recommended only when the soil has been abused and has become so foul with weeds that no other method will remove them, frequent use should be made of the short fallow (i. e., between crops). It will be found advantageous in many instances to plow the land immediately after the removal of one crop and keep it well stirred until the planting of the next. By this means loss of moisture from the soil is prevented and the decomposition of the organic matter is hastened, so that a large supply of plant food is prepared for the succeeding crop. Barley or clover, for instance, is often followed by a fall planted grain and some weeks intervene between the harvesting of the one and the planting of the other. If the field be plowed immediately after the first crop has been removed and cultivated frequently the results will be beneficial in starting the next crop with a larger supply of nitrates and moisture than would have ben present if the ground had remained undisturbed.

In the case of the fallow or cultivated crops previously mentioned the process of nitrification between the rows is accelerated, as it is in the bare fallow, but the growing plants appropriate the nitrates almost as rapidly as formed and hence prevent loss of nitrogen in the drainage of water.

(38) Humus and Green Manuring.— Loss of fertility in a soil is, in a great number of instances due to the rapid decrease in the amount of humus which it contains. Humus is the product formed by the partial decay of organic matter, and is the material that gives the rich, black appearance to some soils. It is formed in most cases from the plants which have previously grown on the field, and have later become a part of the soil. It may also arise from animal or vegetable materials added as manures. Virgin soils are comparatively rich in humus, but investigation has shown that continued cropping with no provision for maintaining the supply of humus may result in its being decreased from one-third to one-half in a period of not more than fifteen years.

Humus is generally considered to be a necessary ingredient of fertile soils. To be sure, soils may be prepared containing no organic matter which will produce good crops under artificial conditions, where the water supply, etc., are under complete control. Under field conditions, however, a sufficient supply of humus is of paramount importance. Humus increases the power of the soil to absorb and retain water and, consequently, a crop grown on a soil containing a fair amount of humus is less likely to suffer from drouth. The following table giving the amount of water held in a cubic foot of the different varieties of soil illustrates this point.

Kind of soil.	Pounds of water in one cubic foot.
Sand	27.3
Sandy clay	38.8
Loam	41.4
Humus	50.1

It will be seen that the quantity of water increases with the amount of humus present, the sand containing the least and the loam, which has the largest percentage of humus, with the exception of the strictly humus soil, containing much more. The organic matter in the high humus soils acts like a sponge to absorb the water, but at the same time holds it in such a condition that it is available to the crop. The peats are examples of extreme humus soils and, as is well known, may hold more water than is desirable.

Humus is also valuable in improving the physical condition of the soil. Sandy soils are made more compact by its presence and better able to supply the crop with moisture. Clay soils, on the other hand, are made more mellow by the addition of humus forming materials. Clay is liable to become too compact unless there is a certain amount of organic matter present to prevent it. In other words, humus forms loam, for a sandy loam is simply a sandy soil well supplied with organic matter, and a clay loam is clay which has been made light and mellow by the same material.

Humus is of importance because it is a store house of plant food, especially nitrogen. It has been shown that most of the nitrogen of the soil is present in the more or less decomposed organic matter. Besides the nitrogen the humus contains phosphoric acid and potash in highly available forms, or assists in rendering them available, for the crop is enabled to obtain much more of these substances from a soil rich in humus than from one in which the humus content is low.

The presence of decomposing organic matter in the soil is an important factor in making the mineral elements of plant food available. During decay certain acid substances, known collectively as humic acid, are produced, and these undoubtedly have a solvent action on the mineral matters of the soil, tending to make them more available to the plant. Perhaps quite as important a factor is the large amount of carbonic acid formed during the process of decomposition. This carbonic acid dissolved in the soil water is of prime importance in the production of soluble plant food, and it also has a beneficial effect on the physical condition of the soil, especially if the soil contains a large amount of clay.

Humus prevents extremes of soil temperature. A soil containing a sufficient supply of organic matter does not respond to changes of temperature so readily as one deficient in humus. The latter warms up somewhat more slowly and retains its heat for a longer period.

Experiments conducted in Minnesota and North Dakota have shown conclusively that as the humus content of the soil is decreased by constant cultivation and cropping (especially if planted continuously to one crop like wheat) the nitrogen content of the soil, the amount of moisture that it will contain, and the crop production are likewise decreased.

All the methods for making potential plant food available, which have been so far discussed, tend to decrease the amount of humus in the soil. Tillage, drainage, bare-fallowing increase the amount of food available to the crop because they present ideal conditions for the decomposition of the organic matter in the soil, and dependence on these methods alone will eventually result in injury through loss of humus. This fact is strikingly shown in the following table adapted from a Minnesota bulletin:

Loss of Nitrogen and Humus From Soils.

	Native Soil.	Cultivated 23 Years.
Total humus	3.97	2.59
Total nitrogen	.36	.19
Capacity to hold water	62.	54.
Phosphates with humus	.07	.03

The lesson to be learned from this table is that while intelligent use should be made of improved methods of tillage, etc., these should be supplemented by some means of maintaining the supply of humus. The method that first suggests itself is nature's own way of growing a crop to be afterwards incorporated with the soil. This is the process known as green manuring. "Plowing under green crops raised for that purpose is one of the oldest means of improving the fertility of the soil. It was advocated by Roman writers more than two thousand years ago, and from that time until now has formed a most important resource of the farmer, especially where the supply of barnyard manure is insufficient. Its advantages are many. The more striking are that it furnishes the surface soil with a supply of fertilizing materials needed by the crop, increases the humus and improves the physical qualities and tilth of the soil. As a humus former green manuring stands next to barnyard manure." (Farmer's Bulletin 16.)

The value of green manuring depends primarily on the fact that it increases the amount of humus in the soil, a point that has been shown to be of great importance. The crops used for this purpose may be of two kinds, viz., those which add nothing directly to the soil and those which increase its nitrogen supply. Of the first class the crops generally recommended are, buckwheat, spurry, mustard, rye, rape, etc. Plowing sod land may be said to be a species of green manuring and as such would be included in this class. These crops, while they add no element of plant food to the soil are beneficial because they gather food that would not be available to the less hardy plants, and on their decay leave it in forms suitable to the succeeding crop. As mere humus formers they are of great value.

The discovery that the leguminous plants can through the nodule forming bacteria fix the free nitrogen of the air, has thrown a new light on green manuring and the plants adapted to this purpose. The legumes have all the advantages of the other plants as humus formers and at the same time increase the amount of nitrogen in the soil. They are, as a rule, deeper rooted plants and are supposed to bring up mineral food from the subsoil and leave it where it will be within reach of the more shallow rooted plants. Of the legumes the crops most often recommended are red clover, cowpea, crimson clover, the lupines, soy bean, and the ordinary field bean, and field pea, red clover being probably the one most generally used. These plants have been found to produce good results even when the crop was harvested and the stubble only plowed under. At the Rothamsted Experiment Station it has been estimated that fifty pounds of nitrogen per acre is added to the soil in the roots and stubble of clover alone.

Where it is not advisable to devote an entire season to the growth of a crop for green manuring, beneficial results may often be obtained by growing "catch crops" between the profit crops. The use of cover crops on orchards as a protection to the land during the winter is a mode of green manuring. As far as possible leguminous plants should be used as green manures. One prominent agricultural investigator asserts that by good tillage and a judicious use of leguminous crops the fertility of the soil may be maintained indefinitely without the use of fertilizers of any kind. The writer feels that this point has yet to be demonstrated, but no one doubts that these plants are of great value in the conservation of fertility.

While green manuring is a valuable method of increasing the humus supply of the soil it is not unattended by danger. In a dry season, for instance, the growth of a crop to plow under may result in lowering the moisture content of the soil to a point that is detrimental to the succeeding crop. There is also danger in such a season that there may not be sufficient moisture in the soil to bring about the decomposition of the organic matter that is turned under, resulting in serious injury to the physical condition of the soil. If a crop is plowed under during a dry season the ground should be rolled or otherwise firmed so as to renew capillarity as far as possible.

Green manuring as a general practice is not to be recommended in any style of stock farming. The crops which are most valuable as green manures are also of great value as feeds, and it will be found more profitable to feed them to the stock and return the manure to the field, as will be shown later. On the whole it may be said that green manuring will prove desirable in any system of farming (including truck farming) where the crops are sold from the farm, and especially if all the crops produced are much alike in their food requirements. On the other hand, if the farmer is engaged in animal husbandry the crops are of such great value as feeds that turning them under must be considered a wasteful practice.

(39) **Rotation of Crops.**—It is the common experience of farmers living in parts of the world where the land has been cultivated for a long time, that the fertility of the soil is maintained for a much longer time by the growth of a variety of crops instead of producing one crop continuously. The adoption of a system of rotation of crops has been the outgrowth of accident rather than the result of an understanding of its underlying principles. The system of alternating years of bare-fallow and wheat may be said to be a two-year rotation and was the first to be adopted. History teaches us that this was later followed by a three-year rotation consisting of fallow, wheat, beans or oats; and still later, when the value of clover and fallow crops became evident, this rotation gave way to the now famous Norfolk rotation of turnips, barley, clover and wheat, the typical English rotation. The Norfolk four-year course represents the more common type of rotation the world over, consisting as it does of cereals alternating with hoed crops and leguminous crops.

There are many arguments to be advanced in favor of growing a variety of crops on the land. The different plants vary in their food requirements and in their ability to procure this food from the soil. Where one crop is grown continuously on the same field nearly all of the plant food that is available to it may become exhausted, while the soil would contain large quantities of food in forms that could be assimilated by plants of another class. Some crops evidently require the mineral matter to be in a readily soluble form, while others can use "tougher" forms of plant food. The early writers on agricultural chemistry supposed that the crop during its growth excreted substances that were injurious to itself, while they were at least harmless and perhaps beneficial to plants of a different class. This view is not now accepted, but it is believed that the failure to produce profitable results where one crop is grown continuously is due to the exhaustion of the forms of plant food available to that particular crop. Some crops make an especial drain on one element of plant food. By growing plants with different food requirements there is less likelihood of any one element becoming exhausted, and the different elements are more evenly used.

The various crops differ widely in their systems of root growth. Some plants like wheat are comparatively shallow rooted and must obtain their food from the surface soil. Others, as the clovers, are very deep rooted and are able to use food that would not be within reach of the more shallow rooted plants. The deep-rooted plants cannot only procure the low lying food, but probably bring a part of it to the surface, where it remains upon their decay for the use of the succeeding crop. It is well known that the shallow rooted plants do better when preceded by a deep rooted crop.

When a variety of plants are grown the soil receives different treatment for each crop, so that the faults of one year are likely to be corrected the next, and, for this reason, the soil is kept in much better physical condition. As a general rule the ground can be better prepared for the succeeding crop if a judicious rotation is practiced than if the same crop is grown continuously. The roots and stubble of clover and the grasses are also factors of some importance in improving the texture of the soil. Taken altogether the texture or tilth of the soil will be found to be much improved by rotation of crops.

Where a variety of crops is grown on the farm it results in economy of labor, for the work of caring for them is distributed throughout the season instead of all coming at one time. In this way it makes it possible to secure cheaper and better help than where only a few kinds of plants are produced.

Rotation also enables the farmer to control plant diseases and to head off the injurious insects. Most of the plant diseases are caused by bacteria or other fungi which live only on one genus of plants, or, at any rate, are more or less restricted in the number of crops that they can use as host plants. Where one crop is grown continuously, these disease-producing fungi are given every opportunity to be carried over from one year to another. Most of these germs are comparatively short lived, so that if three or four years of crops that are not suitable host plants intervene, these germs are likely to be destroyed. In the same way it may be said that the injurious insects are limited to certain plants for their food supply, and if these plants are not grown on the field for a number of years the insects may die from starvation. These remarks do not apply, of course, to those insects which have great migratory powers. There is no doubt, however, that both diseases and insects can be more easily suppressed if rotation is practiced.

Rotation may be useful in destroying weeds. "Certain classes of weeds infest certain kinds of crops much more than others; when this is the case, rotation may be made to do much to destroy them, by leaving the particular crop out of the rotation in which the weed or weeds appear. This is not difficult, since the ordinary crops of the farm are nearly equal in profit, if labor, use of the land, seed, and the amount of fertility carried to town where the crop is sold, are all considered. The farmer should study the undesirable plants quite as much as the desirable ones, that he may change or modify his practices so as to attack his enemies at their weakest points." (Roberts).

The effect of rotation on crop production is strikingly shown in the following table compiled from data furnished by the Rothamsted Experiment Station:

EFFECT OF ROTATION ON CROP PRODUCTION

Average of Eight Courses (32 Years.)

	BUSHELS PER ACRE	
	BARLEY	WHEAT
Grown continuously...	18	12
In rotation.......	32	26

The rotation was the Norfolk rotation, consisting of turnips, barley, clover and wheat, each grown one year, and the figures given are the average of eight crops each of barley and wheat, representing a period of thirty-two years. The experiments with wheat and barley grown continuously on the same plot for fifty years have been previously mentioned. For the sake of comparison, the table gives the averages for the same eight years in which these crops were grown in the rotation. All the crops were harvested and removed from the field, and as no manure of any kind was used, it will be seen that the increased production of barley and wheat is a result of rotation solely. No stronger argument in favor of rotation of crops is necessary.

Rotations are in use that cover periods of from two to seven or eight years. In planning a rotation the farmer must be guided by his own conditions and requirements in the way of crops. A few general rules may be laid down, however. Every rotation should include at least one cultivated or hoed crop, such as corn, potatoes, etc., in order to receive the benefits of such a crop in the way of destroying weeds, improving tilth, and setting free potential plant food. At least one leguminous crop should be included. The legumes are generally deep rooted crops, and in addition to increasing the nitrogen supply of the soil, bring up plant food from the subsoil and leave it where it will be available to the succeeding crop. These deep rooted plants render the subsoil more porous and hasten its disintegration. A crop that is exacting in its food requirements should follow one that is less exacting, or in general terms the crops should vary as much as possible in their food requirements, manner of growth, root system, and the season of the year in which they occupy the ground. Whatever fertilizers are used should be applied to the particular crop which will give the most profitable returns for its use.

(40) Resume.—In Part I. the reader was reminded that continuous cropping without the use of fertilizers finally results in practical exhaustion of the soil. The food requirements of the plant and the history of the formation of the soil were briefly considered, and the conclusion evolved was that to maintain the fertility of the soil two things were necessary: First, to make more of the potential food available; second, to add something to take the place of the materials removed in the crop. Part II. has been devoted to a discussion of the first proposition. Tillage, draining, irrigation, fallowing, green manuring and rotation are distinctly methods for changing potential plant food into available forms, and, with the exception of the nitrogen gathered by the legumes, add no plant food whatever to the soil. Although, as has been previously stated, it is claimed by some that by an intelligent use of these processes alone a profitable yield can be obtained indefinitely, it is the common experience that even with the use of the best methods of culture known in the past, it is impossible to maintain the fertility of the land without the use of some form of fertilizers. As it is obviously impossible to return the crop to the soil, the next thing that suggests itself is to feed the crop to farm animals and use their excrement as a fertilizer. The subject of barnyard manures is of sufficient importance to justify its discussion at some length as Part III. of this treatise.

PART III. Barnyard Manure.

(40) Importance of Barnyard Manure.—Barnyard manure is the oldest and is still undoubtedly the most popular of all fertilizers. It has stood the test of long experience, and has proven its position as one of the most important manures. The fact that the application of the excrement of animals to the soil results in increased crop production, is mentioned by the early Roman writers, and from that time to the present, the majority of farmers have placed their main reliance on this class of manures for maintaining the fertility of the soil.

"A well-kept manure heap may be safely taken as one of the surest indications of thrift and success in farming. Neglect of this resource causes losses which, though little appreciated, are vast in extent. Waste of manure is either so common as to breed indifference or so silent and hidden as to escape notice.

According to recent statistics there are in the United States in round numbers 19,500,000 horses, mules, etc., 61,000,000 cattle, 47,000,000 hogs and 51,600,000 sheep. Experiments indicate that if these animals were kept in stalls or pens throughout the year and the manure carefully saved, the approximate value of the fertilizing constituents of the manure produced by each horse or mule annually would be $27, by each head of cattle $19, by each hog $12, and by each sheep $2. The fertilizing value of the manure produced by the different classes of farm animals of the United States would, therefore, be for horses, mules, etc., $526,500,000; cattle, $159,000,000; hogs, $564,000,000; and sheep, $103,200,000, or a total of $2,352,700,000.

These estimates are based on the values usually assigned to phosphoric acid, potash and nitrogen in commercial fertilizers and are possibly somewhat too high from a practical standpoint. On the other hand, it must be borne in mind that no account is taken of the value of manure for improving the mechanical condition and drainage of soils, which as subsequent pages will show, is fully as important a consideration as its direct fertilizing value." (Farmers' Bulletin, 192).

If it is assumed that one-third of the value of the manure is annually lost by careless methods of management, and this estimate is undoubtedly conservative, the total loss from this source in the United States is about $750,900,000; a loss the more unfortunate because practically all of it could be prevented.

(41) **Composition of Manure from Different Animals.**—The manures produced by the various classes of animals differ greatly in their composition and in their physical properties. The following table gives the average percentage composition of the manures (including solid and liquid excrement) from the more common farm animals:

AVERAGE COMPOSITION OF FRESH MANURES.—(Wolff.)

	PER CENT OF			
	Water	Nitrogen	Phos. Acid	Potash
Sheep manure..	64.0	0.83	0.23	0.67
Horse " ..	70.0	0.58	0.28	0.53
Pig " ..	73.0	0.45	0.19	0.60
Cow " ..	77.0	0.44	0.16	0.40
Mixed Farm manures....	75.0	0.45	0.21	0.52

Assuming that the fertilizing constituents of manure are equal in value to those found in commercial fertilizers, the value of one ton of each of these manures is as follows: Sheep, \$3.39; horse, \$2.55; pig, \$2.14; cow, \$1.89; mixed, \$2.08. (Note.—This valuation is based on 15 cents per pound for nitrogen and 5 cents each for phosphoric acid and potash. This represents in round numbers the market price of these elements in commercial fertilizers at the present time. All the valuations given in the following pages will be on the same basis. The comparative value of nitrogen, phosphoric acid and potash in barnyard manure and commercial fertilizers will be discussed later).

Referring to the table it is seen that the difference in the value of the manures as given is due, to a large extent, to the variation in the amount of water present in the excrement of the different classes of animals. The moisture content also affects the physical properties of the manure. Manures containing large amounts of water are "cold manures"; that is they are manures which heat slowly because the amount of moisture present checks the fermentation. Sheep and horse manures are known as "hot manures," and the more rapid heating of these when compared with pig or cow manure is probably largely due to their lower water content. The difference in the kind and quality of the feeds given to the various animals also affects the quality of the manure, as will be shown later.

(42) **Amount and Value of Manure from Different Animals.**—The figures given in the previous section show the comparative fertilizing value of the different animal excrements and are, therefore, of importance to one who is purchasing manures. For the farmer who produces manure to use on his own land, it is more important to know the total amount and value of the manure produced in a year by the different classes of animals. In the quotation above from Farmers' Bulletin 192 the approximate value of the manure produced per head by the ordinary farm animals is given. A fairer way to present the matter is to calculate the manure to the same live weight of the different animals. The following table compiled from Cornell Bulletin 56 appears in Farmers' Bulletins 21 and 192:

AMOUNT AND VALUE OF MANURE PER 1,000 POUNDS OF LIVE WEIGHT OF DIFFERENT ANIMALS.

	Amount Per Day Pounds	Value Per Day Cents	Value Per Year
Sheep.......	34.1	7.2	\$26.09
Calves.....	67.8	6.7	24.45
Hogs.......	83.8	16.7	60.88
Cows........	74.1	8.0	28.27
Horses	48.8	7.6	27.74

This table shows that, with the exception of the hog, the manure produced from the same live weight of any of the animals is about equal in value. If the above figures are accepted, one must conclude that the hog is over twice as valuable as the other animals as a manure producer. This statement is absurd on the face of it, and the above table is misleading. As this table has been widely copied, appearing in several bulletins in this country and Canada as well as in a few text-books, it has unfortunately given rise to a widespread misconception of the value of hog manure. The fact is that these figures do not represent average conditions in the case of the hog as the animals used in the experiments from which the data were obtained were fed on an abnormal ration. Three lots of pigs were used to obtain these averages and all were fed on rations containing an excessive amount of protein to study the effect of high protein feeds on "the production of lean meat." In two cases about one-third of the dry feed in the ration consisted of "meat scrap obtained from the fertilizer manufacturers—and apparently composed of dried meat, blood and small pieces of bone. This meat scrap contained nearly 10 per cent of nitrogen." A nitrogen content of 10 per cent means that the meat scrap contained 62½ per cent of protein, and it is evident that the high value of the manure from 1,000 pounds live weight of hogs was due to the abnormal amount of protein in the ration, an amount that no one would think of using in practical feeding. In case of the other animals mentioned in the table, the rations were ordinary and the figures may be accepted as being approximately the average for good farm conditions.

The writer has calculated the value of the manure from 1,000 pounds live weight of pigs, using as a basis of calculation several rations recommended for practical use by recognized authorities on feeding. According to these calculations the average value of the manure is a trifle under $30 per year, or approximately the same as that produced by cows. In order that the table shall represent average conditions, this value should be substituted for that given for hogs. To sum up, it may be said that the average value of the manure produced by a given live weight of animals under farm conditions is practically the same irrespective of the kind of animal considered; and the sum of $25 may be taken as a conservative estimate of the value of the fresh manure from each 1,000 pounds of live weight. The use of this factor ($25 per 1,000 pounds) will enable the farmer to calculate approximately what the nitrogen, phosphoric acid and potash in the manure produced on his farm would cost if purchased in commercial fertilizers, granting that the manure is so managed as to prevent loss of its valuable constituents.

(43) Value of the Manure Determined by the Ration.—The total value of the manure produced by a given number of animals is dependent on the quality and quantity of the feeding stuff used in the ration. That the different materials used for feeding vary greatly in their fertilizing value is clearly shown by the following table:

FERTILIZING VALUE OF FEEDING STUFFS. (CORNELL BULLETIN.)

	Value of Nitrogen in one ton	Value of Phos. Acid in one ton	Value of Potash in one ton	Total Value per ton
Corn Meal	$ 4 53	$0 83	$0 31	$ 5 66
Corn Silage	78	14	32	1 24
Crimson Clover (Green)	1 29	16	44	1 89
Crimson Clover Hay	6 63	82	2 26	9 71
Red Clover Hay	5 70	54	1 31	7 55
Gluten Meal	15 09	39	05	15 53
Cotton Seed Meal	20 85	3 66	1 65	26 16
Linseed Meal	16 08	2 28	99	19 36
Meat Scrap	29 01	6 01	67	35 69
Wheat	7 08	96	45	8 49
Skim Milk	1 74	26	1 08	2 11
Oats	5 36	90	45	6 70
Timothy Hay	3 00	43	1 17	4 60
Wheat Bran	7 56	3 40	1 24	12 30
Wheat Straw	81	30	1 02	2 18
Turnips	48	14	34	96

The figures given in the above table represent the fertilizing values of the different feeds provided they are used directly as manures. It is evident that the richer the ration is in nitrogen, phosphoric acid and potash, the more valuable will be the manure produced by the animal. The next question to determine is what proportion of the fertilizing content of the food is recovered in the excrement.

Let the reader imagine that a matured animal (a steer for instance) is confined in such a manner that all of the excrement, both liquid and solid, can be preserved, and that the animal is kept on a maintenance ration. If now the total dry matter in the materials fed is determined, and likewise that voided in the excrement, it will be found that the dry matter in the excrement is just about one-half the amount that was present in the food consumed, the greater part of the other one-half having been given off from the lungs as carbonic acid gas.

If on the other hand the food is analyzed to determine the nitrogen, phosphoric acid and potash it contains, and the excreta are also examined, it will be found that the entire amount of these constituents is voided by the animal in the solid and liquid excrement. While the excreta, therefore, contain only half of the total dry matter which was present in the ration, it contains all of the constituents that are generally considered to have fertilizing value.

While these figures would hold good for a matured steer that was neither gaining or losing in weight they are not correct for young and growing animals. The latter retain a certain proportion of the nitrogen and phosphoric acid for use in building up their bodies. The amount thus retained depends primarily on the age of the animal, and also as will be readily imagined, on the rapidity of its growth. Recent experiments indicate that calves during the first three months of their lives retain in their bodies about one-third of the fertilizing value of the food consumed, or in other words, the excrement from such animals contains two-thirds of the fertilizing ingredients of the ration. For the first year of their existence they use in body growth an average of about one-fifth of the nitrogen, phosphoric acid and potash that was present in the food, and the amount gradually diminishes until practically none of these materials are retained. It may be noted here that where matured animals are gaining in weight during fattening there is no drain on the fertilizing value of the manure provided the gain in weight is all in fat. This is due to the fact that fat contains only carbon, hydrogen and oxygen, and hence its production does not remove any of those constituents which are considered in calculating the fertilizing value. Although the steer and calf have been used by way of illustration, the remarks regarding them hold true as well of the other classes of animals such as swine, sheep and horses, and the age of the animal has the same effect on the value of the manure.

In the case of the cow another factor is introduced, as a certain proportion of the nitrogen, phosphoric acid and potash is removed in the milk. Milk contains on an average about 0.53 per cent of nitrogen, 0.19 per cent of phosphoric acid, and 0.175 per cent of potash. A cow giving an annual yield of five thousand pounds, therefore, removes in the milk fertilizing materials amounting in value to $4.89. If the milk is sold, this amount of fertility is removed from the farm. If, on the other hand, butter only is sold, practically none is carried away, as all the valuable ingredients are found in the skim milk; the fertilizing value of three hundred pounds of butter, for instance, amounting to only 6½ cents. Even where the milk is removed, fully 85 per cent of the manurial value of the food is recovered.

It will thus be seen that a very large part of the elements of fertility contained in the ration fed is recovered in the excreta, and that the age of the animal is the principal factor in determining the amount that is removed. The fertility removed in the milk when it is sold from the farm is also of considerable importance and should not be ignored. Taking into account the ratio between matured and young stock, milch cows and non-milk-producing animals, as found on the average farm, it is conservative to assume that at least eighty (80) per cent of the nitrogen, phosphoric acid and potash present in the materials fed on the farm is voided by the animals in the solid and liquid excrement. This takes into consideration the amount removed in the milk, that retained by the young animals during their growing period, and, consequently, the fertility removed from the farm by the sale of the animals produced thereon. In order, then, to determine the fertilizing value of the excrement produced from a ton of any of the feeding stuffs mentioned in the table given above, it is only necessary to find 80 per cent of the fertilizing value therein stated. It will thus be readily seen that the composition of the feeding stuff really determines the value of the excrement, that produced from one ton of wheat straw, for instance, being worth only $1.74, while the excrement from one ton of corn meal, wheat bran, linseed meal or cottonseed meal would be worth $4.53, $9.84, $15.49 and $20.93 respectively.

By referring to the table it is seen that the most important factor in determining the fertilizing value of a feeding stuff or the manure produced from it, is the amount of nitrogen that it contains. This is due to the fact that nitrogen is usually present in larger proportions than phosphoric acid or potash and is much more costly when purchased. Nitrogen is also used by the animal body in much larger amounts than the other substances, and the difference in fertilizing value between the food and the excrement is largely due to the retention of nitrogen. It will be shown that the losses in manure fall more heavily on its nitrogen content than on the other elements, so it again becomes evident that the most expensive material to furnish is also the one most readily lost. This but confirms a previous statement that the problem of the profitable maintenance of fertility is largely a question of an economic method of supplying the plant with nitrogen.

While the total value of the excrement depends almost entirely on the composition of the ration, it does not follow that the value per ton of the manure is proportional to the fertilizing value of the substances fed. Cattle fed on highly nitrogenous rations drink more water than those kept on a ration low in nitrogen, and experiments have shown that the excrement contains a larger per cent of water in the former case than in the latter. The cattle fed on the narrow ration, therefore, will produce more tons of excrement at a greater total value, but the value per ton will not be very different from that resulting from a wider ration. The following table adapted from a Cornell bulletin gives results with two lots of pigs; Lot I having been kept on feeds extremely high in nitrogen, while Lot II were given a ration containing a much smaller proportion of nitrogenous materials.

EXCREMENT FROM 1000 POUNDS LIVE WEIGHT OF PIGS.

	Wt. per day, lbs.	Value per day	Value per ton
Lot 1.....	108.9	$0.2106	$3 86
Lot 2......	56.2	0.104	3 66

It is noteworthy that while the total value of the manure produced per thousand pounds of live animal in Lot I was twice that of Lot II, there is very little difference in the value per ton, due to the fact that the weight of excrement produced in the first case was nearly twice that in the latter.

(44) **Effect of Bedding on Value of Manure.**—The factors just discussed are those which affect the value of the excrement. The term barnyard manure as it is generally used includes the excreta and the litter or bedding used to absorb the urine. The following table gives the composition of some of the materials used for bedding.

FERTILIZING CONSTITUENTS IN ONE TON OF LITTER.

	Nitrogen lbs.	Phos. Acid lbs.	Potash lbs.
Wheat straw	9.6	4.4	12.6
Oat straw	9.2	5.6	35.4
Clover straw......	29.4	8.4	25.2
Sawdust..........	4.0	6.0	14.0
Peat	20.0	....	....

It is evident that the total fertilizing value of the manure is the sum of the values of the excrement and the bedding, and that the richer the bedding is in fertilizing constituents the more valuable will be the manure. The materials used for bedding are in most cases rather low in the elements of fertility so that the use of large amounts of bedding decreases the worth per ton of the manure, but in any case sufficient litter should be used to absorb all of the liquid excrement.

(45) Calculating the Amount of Manure from the Ration.—It is often of great interest and importance to the farmer to be able to calculate approximately the amount of manure that will be produced from the materials fed to his animals, as well as its value. Various estimates of the amount of manure produced by the different classes of animals have been made from time to time, but it will be much more satisfactory to use the ration as a basis for calculation. The total weight of manure may be easily calculated in this way, and the figures derived are remarkably close to the average results as determined by experiment.

It has been stated that one-half or 50 per cent of the dry matter present in the ration is recovered in the excrement. Experience has shown that the least amount of bedding that will absorb all of the urine excreted by the animal must contain dry matter equal to one-fourth (25 per cent) of the dry matter in the feeding stuffs used. Therefore if it is assumed that just sufficient bedding is used to absorb all of the liquid excrement, it will be seen that the manure (excrement plus bedding) contains three-fourths (75 per cent) as much dry matter as was contained in the ration. According to the table in (41) mixed farm manures contain on the average 75 per cent of water or only 25 per cent of dry matter, so that the 75 per cent of dry matter mentioned above as occurring in the manure, must be multiplied by four to find the total weight of manure. This gives a result of 300 per cent of the dry matter in the ration for the weight of the manure produced therefrom. It will thus be seen that to calculate the amount of manure resulting from the use of any given food materials it is only necessary to multiply the weight of the dry matter in the ration by three. This method of calculation can perhaps be made plainer by an example. Let it be assumed that a ration is used which contains one hundred pounds (100 lbs.) of dry matter. The excrement produced by feeding this ration would contain fifty pounds of dry matter. In order to absorb all of the urine voided by the animay straw, or some other bedding material, must be used in an amount large enough to supply twenty-five pounds of dry matter. Now as the manure is composed of the excrement plus the bedding, it follows that the manure contains seventy-five pounds of dry matter. Only 25 per cent of the manure is dry matter, so that the seventy-five pounds of dry matter in the example represents one-fourth of the total weight of the manure. The manure, therefore, weighs 300 pounds, which is just three times the dry matter that was present in the ration assumed.

This method of calculating the manure by multiplying the dry matter in the ration by three holds true, of course, only when the theoretical amount of bedding is used. In actual practice the farmer uses all of the bedding materials he has at hand, even though in excess of the amount required to absorb the urine; and it is generally considered to be advisable to do so, for the bedding materials decay much more readily when mixed with the excrement of animals. In the best farm practice, where the greatest possible use is made of all substances suitable for feeding, there is seldom an excess of bedding materials. In case more litter than the theoretical amount is used the method of calculation given above must be corrected by adding to the total the weight of the bedding in excess of 25 per cent of the dry matter in the ration. If in the example taken, for instance, instead of using twenty-five pounds of dry straw, fifty pounds had been used as bedding, the total weight of the manure would have been 325 pounds.

(46) Amount and Value of Manure From Fifty Cows.—The great value of barnyard manure as a farm resource is appreciated by very few farmers. Its importance is doubtless realized to a greater extent at the present time than ever before, but even now a large proportion of those engaged in agricultural pursuits seem to have little realization of the immense loss they are incurring by the waste of this important product of the farm. Indeed many farmers apparently look upon the manure as one of the necessary nuisances of a system of animal husbandry, and begrudge the time and labor required to remove it from the barn and feeding lot. Barns have even been known to be erected on the banks of swift running streams, with the express purpose of emptying the manure into the creek, in order to have it removed with the least possible expenditure of labor. While these cases are extreme, the reader has only to look around him as he travels through the country to see practices which fall only a few degrees short of this in the matter of wastefulness, due either to lack of knowledge of the value of the manure or to an indifference that is even more lamentable than ignorance.

In order that the great fertilizing value of the manure produced on the farm may be more definitely shown, as well as to make clearer the methods of calculation described in the previous sections, the figures are given here for the food consumed and the amount and value of the manure produced in one year by a herd of fifty dairy cows giving an average yield of fifteen pounds of milk daily. For the sake of simplifying the calculations and statements of results, it is assumed that the same ration is fed throughout the year. In actual practice, of course, the ration varies somewhat at different times of the year, but as the experienced feeder aims to keep approximately the same relation between concentrates and roughage, and, as nearly as may be, the same ratio between proteids and carbohydrates, the results of this calculation from a single ration will not be very different from those which would be derived from a variety of rations each having about the same nutritive value.

It is desired to make this estimate conservative, and for that reason no feeds are included in the ration that are unusually high in fertilizing constituents. The following ration will be used as a basis for the calculation:

Daily ration for a cow weighing 1,000 pounds and giving 15 pounds of milk per day:

Ten pounds of a mixture of one-third each of cornmeal, ground oats and bran; 35 pounds of corn silage; 15 pounds of clover hay (medium red).

This combination has been recommended by a prominent authority on the feeding of animals as a good ration for practical feeding, and one which will meet with the approval of conservative dairymen. At the same time the ration is well balanced and will conform reasonably well to the best feeding standards. A great many dairymen use a much higher feeding standard than is represented by this ration, and on the whole it may be said that the results of this calculation will be lower than the average for good dairy conditions. It will be assumed that just the amount of wheat straw which would theoretically be necessary to absorb the liquid excrement is used as bedding.

The following table gives the dry matter and fertilizing constituents in 1,000 pounds of the different materials.

DRY MATTER AND FERTILIZING CONSTITUENTS IN 1000 POUNDS.

	Dry Matter lbs.	Nitrogen lbs.	Phos. Acid lbs.	Potash lbs.
Cornmeal..	871.	15.8	6.3	4.0
Oats.......	889.	18.6	7.7	5.9
Bran.......	883.	26.7	28.9	16 1
Silage.....	220.	2.8	1.1	3.7
Clover.....	887.	20.7	3.8	22.0
Straw......	875.	4.8	2 2	6.3

(Note.—Tables giving the amount of water and fertilizing constituents in each 1,000 pounds of all the ordinary substances used in feeding, or which are raised on the farm, can be found in a number of different books, among which may be mentioned Henry's "Feeds and Feeding," Woll's "Handbook for Farmers and Dairymen," Robert's "Fertility of the Land," and "Yearbook of the U. S. Department of Agriculture").

The ration mentioned above represents the amount of the different substances fed to each cow per day. This amount must be multiplied by 50 and then by 365 to determine the total amount fed per year. From the totals thus obtained and by the use of the table just given it is possible to calculate the dry matter and fertilizing constituents of the entire amount of food given to the fifty cows during the year. These results are compiled in the following table:

TABLE SHOWING TOTAL AMOUNT OF MATERIALS FED WITH DRY MATTER AND FERTILIZING CONSTITUENTS.

	Am't Fed Pounds	Dry Matter Pounds	Nitrogen Pounds	Phos. Acid Pounds	Potash Pounds
Cornmeal............	60830.	52982.9	967.11	383.23	243.32
Oats	60830.	54077.8	1141.34	468.39	358.90
Bran	60830.	53712.9	1624.16	1757.98	979.36
Silage	638750.	140525.0	1788.50	702.63	2363.38
Clover	274250.	239968.7	5676.88	1042.15	6033.50
TOTALS	1095490.	541267.3	11197.99	4354 38	9978.46

While the totals given in the table show the amounts of fertilizing constituents in the feeding stuffs used during the year, it will be remembered that only 80 per cent of this amount is recovered in the excrement. The solid and liquid excrement combined, therefore, contain of nitrogen 8,958.47 pounds, phosphoric acid 3,483.50 pounds, and potash 7,982.77 pounds.

The manure, however, contains the fertilizing constituents of the bedding in addition to that found in the excrement. It has been stated that the least amount of bedding that will absorb the urine must contain dry matter equivalent to one-fourth the dry matter in the ration. The dry matter in the bedding used in this example, therefore, must amount to 135,316.8 pounds. To furnish this quantity of dry matter it will be necessary to use at least 154,647.7 pounds of wheat straw. If the amounts of nitrogen, phosphoric acid and potash in this weight of straw are added to that in the excrement the results will express the quantities of these ingredients found in the manure. The following table gives these data:

FERTILIZING CONSTITUENTS OF THE MANURE.

	Nitrogen Pounds	Phos. Acid Pounds	Potash Pounds
In excrement	8958.47	3483.50	7982.77
In bedding..	742.61	340.22	974 28
Totals.....	9701.08	3823.72	8957.05

The prevaling prices of fertilizing materials at the present time, as given by the Eastern experiment stations, are such that the purchaser pays at the rate of 15 cents per pound for nitrogen, and 5 cents each for phosphoric acid and potash. These prices hold only when crude materials are bought and much higher prices are paid for mixed fertilizers. To determine the value of the manure produced by the fifty cows it is only necessary to multiply the totals in the last table by the trade prices of the constituents. These calculations are given below:

VALUE OF MANURE FROM 50 COWS.

Value of nitrogen............	$1,455 16
Value of phosphoric acid.....	191 19
Value of potash..............	447 85
Total value of manure...	$2,094 20

This means that the fresh manure from the fifty cows would contain amounts of nitrogen, phosphoric acid and potash that would cost the farmer at least $2,094.22 if purchased in commercial fertilizers. How nearly the actual agricultural value of the manure will approach the trade value depends on a number of conditions, such as the crop to be fed, the physical condition and tilth of the soil, the climatic conditions, and above all the intelligence displayed in its care and use. The same statements apply, however, to commercial fertilizers, the trade price not necessarily being any indication of the agricultural value of the material, and there is no doubt that the farmer who receives the best returns from commercial fertilizers is also the one who will be best repaid for the use of barnyard manure. Whatever the reader's opinion may be of the actual value of manure, the figures evolved in this calculation should impress him with the fact that his manure heap is a valuable resource, and that he cannot afford to waste so valuable a substance even if it is but a by-product of the farm.

It will be interesting to carry these calculations a little farther and determine the total amount of manure produced and the value per ton. It has been shown that the weight of the manure is three times the weight of the dry matter in the ration. The total dry matter fed during the year was found to be 541,267.3 pounds, so the manure would weigh 1,623,801.9 pounds, or 811.9 tons. The total value of the manure divided by the number of tons gives $2.58 as the value of a ton of the manure.

As was stated in the beginning of this section, this ration is considered a conservative one. The writer has made a few calculations from rations in use by practical dairymen that have run from five to six hundred dollars higher per year for fifty cows than does the one used in this example.

The easiest way for the farmer to calculate the value of the manure produced per year on his farm is to add together the amounts of fertilizing constituents in all the foods fed to the various animals; take 80 per cent. of this and add to it the fertilizing constituents of the bedding, and multiply the total by the trade prices per pound given above. If the reader will take the trouble to do this for his own farm he will find the results extremely interesting, and will be well repaid for his labor in the better understanding that he will have of his farm resources.

(47) **Relation of Manure to Maintenance of Fertility.**—The discovery of the fact that fully eighty per cent. of the fertilizing constituents of the crop can be recovered in the manure, has thrown a new light on the subject of the maintenance of fertility. A number of the most prominent authorities on agricultural chemistry believe (and the belief seems perfectly plausible in view of the facts already discussed) that in a system of strictly animal husbandry, where nothing is sold from the farm except animals or animal products, the fertility of the soil may be maintained indefinitely without the purchase of fertilizers, provided the manure is properly utilized. This assumes, of course, that as nearly as possible the full value of the fresh manure is realized and that the losses, which are to be discussed later, are avoided. Not only may the fertility be maintained in this way, but it may actually be increased, as has been demonstrated by a number of farmers.

It has been shown that where the crop is allowed to remain on the ground to decay and become a part of the soil, the fertility of the land increases from year to year. The fact was also brought out that the soil contains large quantities of potential plant food, especially of the mineral elements, and that each year a certain portion of this potential food is becoming available. The question that suggests itself is whether the food rendered available each year is sufficient to make up for the twenty per cent. loss in feeding the crops to animals. There seems to be no reason to doubt that this is so in case of the mineral elements even if not true of nitrogen. The twenty per cent. loss in feeding falls nearly altogether in the nitrogen, while very little of the phosphoric acid and potash are lost; so that it is easy to realize that the supply of these two elements can be maintained by the use of the manure and a good system of tillage. The experiments at Rothamsted indicate that the growth of a crop of clover adds from fifty to seventy-five pounds of nitrogen per acre to the soil, and consequently this suggests a method of replacing the nitrogen lost through feeding. Taking all things into consideration it is evident that under the conditions mentioned above it is possible to keep a farm fertile indefinitely through the use of the barnyard manure produced on it, supplemented by good tillage and the growth of leguminous crops. This statement holds true only where no crop is sold. In case the crop is sold the entire amount of fertilizing ingredients that it contains is removed from the farm. Where the farmer depends for his profit on the sale of animals and animal products, however, there is no doubt that the fertility can be maintained in the manner described.

(48) **How to Increase the Value of the Manure.**—It often occurs that the farmer finds it necessary, for one reason or another, to supply more plant food to the soil than can be obtained from the manure produced from the

crops raised on his farm. Under these circumstances if he is engaged in animal husbandry he will find that the most economical way to increase the plant food is by purchasing feeding stuffs rich in the fertilizing constituents, feeding them to his animals and using the manure as a fertilizer. The most successful stockmen find it profitable to reinforce the feeds raised on the farm with one or more of the various mill products and other by-products that are sold as cattle feeds. A glance at the table in (43) will immediately suggest how easily the value of the manure might be increased at the same time that the ration was being materially improved. It will be readily seen that the purchase of a relatively small quantity of some of the concentrated feeding stuffs would more than replace the twenty per cent. of fertilizing value of the crops which is lost during feeding. The farmer who buys large quantities of concentrates is increasing the fertility of his land rapidly, provided he is taking proper care of the manure.

In purchasing feeding stuffs one should always consider their fertilizing value as well as the feeding value, for while the substance is bought primarily for its feeding value it is sometimes possible to buy two different materials, which will serve practically the same use as feeds and yet vary greatly in their values as fertilizers. Right here the reader should be warned against the reports of experiments where the value of the manure is considered in calculating the profit from feeding. A feeding experiment that does not show a profit in the increase alone, without taking the manure into account, cannot be considered very successful. The business farmer expects to make a profit on all the feeding stuffs used by increase in weight of his animals, in dairy products or in some other salable product and, if he is not doing that, it is time for him to change his methods. As long as the feeder can buy feeding stuffs and sell his products at a profit on the investment it is good business policy for him to do so, but his profit should be a tangible one and not exist only in the manure heap. In other words the manure is distinctly a by-product of the farm and costs the farmer practically nothing, but the fact that it is a by-product does not make it less valuable. Good business policy demands that the manure heap be as well cared for as if it represented an actual cash outlay equal to that which would be required to purchase its fertilizing equivalent in commercial fertilizers. Even where a number of animals sufficient to consume all of the crops raised on the farm are at hand it is often advisable to sell some of the products and use the money thus obtained for the purchase of other feeding stuffs. There is scarcely a farm on which such an exchange could not be made to advantage, both from the feeding standpoint and in order to increase the value of the manure. A study of the market prices of the various farm products and concentrates in any year will readily show how such exchanges could be made at a profit to the farmer. To illustrate what is meant by this statement the following simple example used recently by the writer in one of his classes is given.

At the time mentioned it was possible to buy on the local market seven tons of clover hay for the price of five tons of timothy hay, and five tons of corn could have been exchanged for six tons of bran. The problem was to determine the increase in fertilizing value due to such an exchange. Calculating the value of the different materials in the manner already described the results may be briefly stated as follows:

Fertilizing value of 7 tons of clover.....	$52.85
Fertilizing value of 6 tons of bran	73.80
Total	$126.65
Fertilizing value of 5 tons of timothy...	$23.00
Fertilizing value of 5 tons of corn	28.30
Total	$51.30
Gain due to exchange	$75.35

By a simple exchange of products without any cash outlay the fertilizing value of the ration would have been increased $75.35 and consequently the manure produced would have been worth $60.28 more than that resulting from the use of the corn and timothy hay. The increase in value of the manure does not tell all of the story, for the total weight of food has been increased nearly one-third. Its actual feeding value has increased more than one-third, due to the larger amount of protein in the ration. It is well known that cattle require less weight per head of a narrow ration than of one that is more carbonaceous.

This example is cited merely as a suggestion of the possibilities of exchange. A little careful consideration will show that such exchanges may be made of great practical value.

The value of the manure is affected by the quantity of food given the animal as well as by the quality. Other things being equal, the manure from animals fed liberally will be more valuable than that from those that are fed insufficiently. This is mainly due to the fact that the latter use a larger proportion of the nitrogen of the food and hence the per cent. returned in the manure is smaller. Liberal feeding, then, produces richer manure.

(49) Relative Value of Liquid and Solid Excrement.—The values given for manures refer only to fresh manures that have been handled so as to prevent loss of any kind. The greatest loss that is likely to occur is due to the waste of the liquid excrement through the use of insufficient bedding to absorb it. The urine is really the most valuable part of the excrement and unless plenty of bedding is used the value of the manure will fall far below that given in the previous discussions. Apparently but few people realize the importance of using plenty of litter, for it is not unusual to see barns constructed in such a way as to cause the urine to run off as rapidly as possible. Doubtless the reader has before now seen holes bored in the barn floor to keep the floor dry by draining off the liquid excrement. The following table gives the composition of the solid and liquid excrements:

	Nitrogen		Phos. Acid		Soda and Potash	
	Sol.	Liq.	Sol.	Liq.	Sol.	Liq.
Horses....	0.50	1.20	0.35	trace	0.30	1.50
Cows......	0.30	0.80	0.25	"	0.10	1.40
Swine.....	0.60	0.30	0.45	0.125	0.50	0.2
Sheep.....	0.75	1.40	0.60	0.05	0.30	2.0

The table shows that, considered pound for pound, the liquid excrement is more valuable than the solid, except in the case of the swine. As the relative weights of solid and liquid excrement produced by the animals are not given it does not show the real proportional value of the liquid and solid excrement produced from a given ration. Several experiments have been made to determine this point and there is a wide variation in the results. It is perfectly safe to say, however, that of the total fertilizing materials found in the manure sixty per cent. of the nitrogen, fifty per cent. of the potash and practically none of the phosphoric acid are found in the urine. The solid part then contains only forty per cent. of the nitrogen, half of the potash and nearly all of the phosphoric acid. It will thus be seen that a little over half of the total value of the manure is in the urine. In the example mentioned in (46) if the liquid excrement had been allowed to run away the value of the manure would have been under $1,000.00 instead of $2,049.00 as calculated.

This last statement does not properly show the comparative value of the solid and liquid parts of the manure. The plant food in the urine is in a form that is soluble in water and consequently much more readily available to the plants than that in the solid excrement. The solid excrement consists of the undigested portion of the food and must undergo thorough decay before its fertilizing constituents become available to the plants, so that while only about half of the actual plant food is in the urine, the value of the urine is much greater than the dung owing to the better condition of its plant food. The difference is due largely to the more available form in which the nitrogen exists in the urine.

That the difference in value of solid and liquid excrement is not wholly theoretical is shown very nicely by a New Jersey experiment. In this experiment two plots were treated with manure, in one case the solid excrement only was used, while in the other the mixed solid and liquid excrements were used. Each plot received enough of the manure to supply exactly the same amount of nitrogen, and the other elements were added in excess. The results are stated in per cent. of gain over a check plot that received no manure and are given below:

PER CENT. GAIN IN YIELD FROM MANURE.

	Solid Excrement Only.	Solid and Liquid.
First year........	15.2	52.7
Second year......	69.7	116.9
Third year.......	47.9	80.6
Average......	44.3	83.4

It will be seen that the yield from the same amount of nitrogen was very much larger from the mixed manure than from the solid excrement alone. It is evident that the first and perhaps most important requirement to obtain the full value of the excrement is to provide plenty of material to absorb all of the urine and prevent any of it being wasted. It may be said here that where bedding material is scarce it can be made to go farther by running it through the cutter. Straw cut into one inch lengths, for instance, will absorb about three times as much urine as long straw.

(50) Losses in Manure.—The great possibilities of barnyard manure as a means of supplying nitrogen, phosphoric acid and potash to the soil have been discussed at some length. While values equal to those mentioned may be realized by any farmer by the exercise of reasonable care, the fact remains that few even approximate these results with their present practices. Barnyard manure is a perishable material and must be handled with care and intelligence to obtain its maximum value. As manure is managed on the majority of farms today, it is doubtful if more than half its worth is realized.

Before discussing the methods of preservation of manure it will be well to indicate some of the sources of loss. One of the principal causes of loss in value in manure is the faulty construction of stables and the use of insufficient bedding. Stable floors should be so tightly constructed that it is impossible for the liquid excrement to drain away. In spite of the fact that so much has been written about the fertilizing value of the urine of animals, there seems to be little attempt on the part of most farmers to preserve all of the liquid excrement. It has been shown that more than one-half the total value of the excrement is in the urine, and the man who does not strive to prevent its loss has not yet realized the great value of this substance. It is not enough to have tight floors, but bedding should be used in such quantities that the manure can be easily removed from the barn without loss of the liquid excrement; that is, the urine should be so thoroughly absorbed that there will be no drip in handling the manure.

Manure is never so valuable as when perfectly fresh. The very best methods of handling and care, if the manure is stored, cannot prevent more or less loss of the valuable constituents. For this reason it is advisable when possible to apply the manure to the soil as fast as it is made, a point that will be discussed at some length later.

Next to improper absorption of the urine the greatest loss in manure comes from leaching by rains. As ordinarily handled the manure each day is thrown out into the open yard to lie for months, subject to washing by the summer or winter rains. In many cases it is even deposited directly under the eaves of a large barn, so as to make the washing process the more complete. It seems absurd to go to the trouble of absorbing all the liquid excrement by means of bedding and then allow it to be washed out of the manure by the rains, and yet that is what very often occurs. The losses in manure due to leaching by rains in the open yard are much greater than most people imagine. Many experiments have been carried on to illustrate these losses, but the limits of this paper will permit the presenting in detail of only one or two of them.

At the New Jersey Experiment Station four samples of manure were exposed to the weather for varying periods and the loss of fertilizing constituents determined. The results are summarized in the following table:

Losses in Manure.

Period	Nitrogen Per cent.	Phosphoric Acid Per cent.	Potash Per cent.
131 Days..	57.	62.	72.
70 " ..	44.	16.	28.
76 " ..	39.	63.	56.
50 " ..	69.	59.	72.
Average.	51.0	51.1	61.1

It will be seen that the average loss amounted to more than half the value of the manure during rather short periods, the longest time being a trifle over four months. On many farms the manure is exposed to the elements for a much longer period than that given in the table.

In 1890 experiments were conducted at Cornell with manure exposed to the weather for a period of five months (from April to September), with the following results:

	Value per ton at beginning	Loss Per Ton	Loss Per Ct.
Horse manure.	$2.80	1.74	62.0
Cow manure..	2.29	.69	30.0

Tests at the Canada Experiment Farm with horse manure exposed to the weather for six months showed a loss of one-third of the nitrogen, one-sixth of the phosphoric acid and one-third of the potash, while a corresponding sample that was protected from the weather lost only one-fifth of its nitrogen and none of the phosphoric acid or potash.

Examples similar to these might be given indefinitely from American and European experiments did space permit. It is only necessary to state here that all of these experiments show great losses in the valuable constituents of the manure from exposure to the elements, the decrease in value amounting to from 30 to 70 per cent for periods of three to twelve months. These losses vary with the climatic conditions and with the quality of the rations. During heavy rains, especially if occurring in warm weather, the losses will be much greater than in dry or cold weather. The relative decrease in value is larger for manures produced from rations of high nutritive value. In other words the more valuable the manure the greater will be the per cent of loss from leaching. It is conservative to say that manure exposed to the weather for six months loses fully half its value. It is not the liquid excrement alone that is washed away by the rains, for the solid excrement contains a certain amount of soluble plant food which is removed by leaching. In addition to this there are chemical changes taking place in the manure which are converting some of the constituents, which were originally insoluble, into forms that are soluble in water, and these may be carried away by the rains. Below are given the results of experiments at New Jersey to determine the losses due to leaching when the solid excrement alone was considered:

LOSSES IN SOLID EXCREMENT.

PERIOD	Nitrogen Per cent.	Phosphoric Acid Per cent.	Potash Per cent.
131 Days..	46.	73.	80.
70 " ..	34.	27.	10.
76 " ..	25.	54.	48.
50 " .	45.	42.	42.
Average.	37.6	51.9	47.1

The figures given in the above tables representing the percentage loss of fertilizing constituents from the manure, do not tell the whole story. The nitrogen in the portion removed by leaching is more valuable per pound than that which remains because it is in a form more immediately available to the crop. This fact is strikingly shown in an experiment conducted at the New Jersey Station in which two plots were treated with amounts of fresh and leached manures that would give exactly the same amount of nitrogen. The results stated in per cent of gain over a plot receiving no manure are given below:

PER CENT. GAIN IN YIELD from MANURE

	Fresh Manure	Leached Manure
First Year	52.7	41.5
Second Year.......	180.4	96.8
Third Year........	117.5	89.6
Average....	116.9	76.0

On perhaps a majority of the farms in America the cattle are fed during the winter in open lots, the manure not being hauled away until the following summer or fall, if indeed it is removed at all. This method of feeding presents ideal conditions for excessive losses from leaching, and it is safe to say that more than half the fertilizing value of the manure is lost where this practice is pursued. In the "corn belt" of Ohio, for instance, large numbers of cattle are fed during the winter and it is not unusual to see a large feeding lot covered to a considerable depth with manure which is spread out and exposed to the weather in such a way that the maximum effects of leaching must take place. There is no doubt that, considered from the fertility point of view alone, the farm would be better off if the corn were sold from the farm and the stover all plowed under. To illustrate what is meant by this statement, the writer quotes from a letter of inquiry recently received by him and his reply to the same. The query, "The method of cattle feeding followed by many farmers in this country is to feed in an open lot which frequently has not even a strawstack for wind protection, all being exposed to the rain. When they have their cattle on full feed they think they feed about one-half bushel of corn per day, the most of them allowing the stover to go with the corn to be wasted—since a steer on full feed will not eat so much stover. Assuming a yield of fifty bushels of corn per acre and about 3,500 pounds of corn stover per acre fed to cattle, how, in detail, would the manure which was hauled from this feed lot in the following July compare in chemical constituents with the corn stover if left on the field?"

Answer—"Your acre of corn stover (3,500 pounds) would contain 36.40 pounds of nitrogen, 49.9 of potash and 10.15 of phosphoric acid. Putting the cost of nitrogen at 15 cents per pound and potash and phosphoric acid at 5 cents per pound each (just about trade values for this year), the value of the stover as a fertilizer would amount to 8.42 dollars per acre. The soil would get all of this if the stover was not removed from the field.

"Fifty bushels (3,400 pounds) of ear corn contains 47.94 pounds of nitrogen, 15.98 pounds of potash and 19.38 pounds of phosphoric acid, which at above prices would give 8.96 dollars for the fertilizing value of one acre of ear corn.

"From this it follows that the total fertilizing value of the crop is 17.38 dollars, i. e., if the entire crop was plowed under it would add to the soil amounts of nitrogen, potash and phosphoric acid that would cost 17.38 dollars if purchased in commercial fertilizers, or, of course, would remove the same amount from the soil if the entire crop was harvested.

"In feeding a crop we estimate that under ideal conditions about 80 per cent of the fertilizing ingredients can be recovered—the other 20 per cent being utilized to build up animal tissue, etc. This figure varies with the class of animals fed, i. e., the more mature the animals the less the loss, while with young and growing animals the loss is greater. The above figure pretty well represents average conditions, however. This means that under ideal conditions we could produce manure equal to 13.90 dollars per acre from the corn crop.

"A number of experiments have been conducted to show the losses in manures under just such conditions as you describe, and they have nearly all been carried on for about the length of time mentioned by you (about six months). These experiments show losses in fertilizing value in the manure amounting to from 40 to 60 per cent of the total original value, the average being about 50 per cent. The manure produced from one acre of corn is worth at the time of hauling out only half the ideal value given above, or 6.95 dollars, leaving a balance in favor of the stover alone (if left standing in the field) of 1.47 dollars, not to say anything of the labor of hauling the two ways. This refers to the fertility side of the question alone and takes no acount of the feeding value. On general principles it may be said that any crop or portion of a crop that cannot be used to feed had better be left in the field."

There is another source of loss in stored manure that may be quite as wasteful as leaching, i. e., what is known as "hot fermentation." Manure is very easily decomposed and there is no doubt that decomposition begins almost as soon as the excrement is voided by the animal. The first evidence of decomposition or fermentation is the odor of ammonia that is noticeable in the barn, especially in the morning, if the stable has been closed during the night. This is due to rapid decomposition of urea, a nitrogenous substance found in the urine. Ammonia contains nitrogen, and when its odor is perceptible it is a sign that nitrogen is being given off into the air and that the manure, therefore, is undergoing a loss of this valuable constituent. The early decomposition of the urea will not be so likely to occur if plenty of absorbing material is used.

The fermentation of manure is due to different forms of bacteria. Some of these germs can exist only in the presence of oxygen and are called "aerobic" bacteria, while others do not require free oxygen and are designated as "anaerobic" bacteria. It is the aerobic organisms that cause the hot fermentation which is the cause of great loss of value in manure. It is well known that if manure is thrown loosely into a heap, especially if it contains large quantites of horse or sheep excrement, it soon becomes very hot and dry, "fire-fanged," as it is popularly termed. During this process large losses of nitrogen are occurring. Experiments conducted to show the loss due to fermentation alone indicate that from 30 to 80 per cent of the nitrogen is removed, but that the phosphoric acid and potash are not affected. In the case of the fire-fanged material, in one experiment it was found that all of the nitrogen was lost. As the value of manure depends for the most part on the nitrogen content, it follows that more than half its worth may be lost by hot fermentation.

If the manure heap is so compact that the air cannot penetrate it the aerobic bacteria are unable to live and hence hot fermentation is not possible. The presence of a large quantity of water also checks this kind of decomposition, and for that reason the excrement of cows and pigs is not so liable to hot fermentation as is that of horses and sheep.

Where the manure is in a compact mass the fermentations that take place are due to the anaerobic organisms. These bacteria cause decompositions in the manure which convert the insoluble plant food in the excrement into soluble forms, but do so with little loss of the fertilizing constituents provided the heap is protected from leaching rains. Even under the best of conditions it is not possible to entirely eliminate losses in stored manure, although if properly preserved the loss may be limited to about 10 per cent of the nitrogen and none of the other two constituents. This loss, however, is insignificant in comparison with the losses which result from not saving the urine, from leaching due to rains, or from allowing the manure to undergo hot fermentations, all of which waste may be controlled to a great extent, as will be shown under the next heading.

(51) Preservation of Manure.—The great value of the manure produced on the farm, and the losses that may occur in it, have been discussed at some length. The next point to be considered is the best method of caring for manure so as to prevent these losses as far as possible. Much that will be said under this heading has undoubtedly been already suggested to the reader by his perusal of the previous sections, but the subject is of sufficient importance to justify devoting some space to it, even though repetition becomes necessary.

Attention has been called to the fact that over one-half of the value of the manure is in the liquid excrement, and it is desired to emphasize the statement that the first consideration in caring for manure is to have that part of the barn floor upon which the excrement falls so tight that none of the liquid can seep through. The manure trough behind the cattle, especially, should be made absolutely tight by the use of pitch, cement or some other material that is impervious to water. In addition to this, care should be used to supply litter in quantities large enough to absorb the urine so thoroughly that the manure may be removed without loss from dripping. If the farmer possesses a feed cutter, he will be well repaid for cutting up all of the bedding materials, not only because this increases the absorptive power, but because the manure is so much more easily handled. Prominent stockmen have asserted that the greater ease with which manure containing short bedding can be handled and spread, well repays the cost and trouble of cutting all the litter, to say nothing of the saving in bedding materials, and the latter is an important item on a farm that is stocked to its full capacity.

Most of the nitrogen present in the urine exists in the compound known as urea. This is very readily decomposed by bacteria and changed into a compound of ammonia and carbonic acid known as "carbonate of ammonia." This substance is volatile, and is sometimes given off into the air in such quantities as to be readily detected by the nose (i. e., by the odor of ammonia.) This kind of decomposition takes place more readily in horse and sheep manures than in that from cattle or swine, as anyone can testify who has taken care of these animals when confined in closed barns. No doubt the reader has gone into the horse barn on a winter morning when there was so much ammonia in the air that it "made the eyes water."

When the odor of ammonia is perceptible it means that nitrogen is being given off from the manure, and the loss from this source may be an item of considerable importance. This loss may be prevented to some extent by the use of gypsum or land-plaster. The addition of this substance to a solution of carbonate of ammonia brings about a chemical change that converts the ammonia into a compound that is not volatile, and hence does not pass off into the air; and at the same time the gypsum increases the value of the manure in other ways, as will be seen later. In using gypsum, scatter it on the floor immediately after the barn is cleaned and before the fresh bedding is spread. About one pound per animal each day is the amount most commonly used, although more will do no harm. It will probably pay better to apply all the land-plaster used on the farm with the manure, than to sow it directly on the ground.

Kainite, muriate of potash and acid phosphate, or superphosphate, are often recommended as preservatives for manure and to prevent the loss of nitrogen. These substances are objectionable for the reason that they are injurious to the hoofs of the animals. If used at all they should be scattered on the floor and carefully covered with bedding. Another objection to using superphosphate to "fix" the ammonia is that part of the soluble phosphoric acid is made insoluble by mixing it with manure, and as the superphosphate is purchased solely for its soluble phosphoric acid, this change is undesirable. Some experiments have indicated that nothing is so efficacious in preventing the loss of nitrogen from the manure as a liberal application of dry earth to the stable floor, especially if the soil used contains a large amount of humus. In some sections of the country it is considered good practice to collect and dry out muck soil for use in the stable in connection with the bedding. There is no doubt that this prevents the loss of ammonia if properly used. Dry earth should not be used in large quantities, however, for if sufficient is added to make the manure very dry it will cause loss of nitrogen instead of preventing it.

Mention has been made of the fact that manure is never so valuable as when perfectly fresh, for it is impossible even under the best system of management, to entirely prevent loss of its fertilizing ingredients. For this reason the plan of hauling the manure from the barn directly to the field is to be recommended whenever there is a field available and the weather is suitable. This method of handling the manure has many points that commend it to the American farmer. In the first place it is the most economical of time and labor, as the manure has to be handled but once, and if the barns are conveniently constructed, can be removed to the field with little more labor than is required to place it in the heap if it is stored. Where the manure is allowed to collect for long periods, it becomes almost impossible to find the time and help necessary to haul it to the field, and the temptation to neglect it entirely is almost irresistable. Again, almost the total value of the manure is realized when it is removed directly to the field and spread over the surface of the ground. To be sure, the rains falling on this manure will leach out the soluble portion, but now it will be carried into the soil where it is needed. The soluble constituents of the manure are "fixed" by the soil so that there is no danger of their being lost. If the manure is spread in a thin layer it will not heat, so there will be no fear of hot fermentation, and it has been demonstrated that where manure simply dries out when spread on the ground there is no loss of valuable constituents.

It is not always possible to remove the manure to the field immediately, for there may be none ready to receive it, or the weather may be such as to make it undesirable to haul over the ground. In that case it becomes necessary to store the manure for a time, and the question is, how can this be done with the least loss, for it is impossible to entirely prevent loss in stored manures.

In section 50 it was shown that the two sources of loss in fertilizing value in the manure after it is removed from the barn are, leaching due to rains, and hot fermentation. Obviously if the maximum value of the manure is to be retained, these two injurious processes must be prevented. The effect of leaching rains may be overcome in two ways, by providing water-tight receptacles so that the liquid cannot run away, or by keeping the manure under cover so as to protect it from the rains. The first of these two methods is in general use in some sections of Europe. Pits or cisterns of cement or other impervious material are built in which to store the manure, and in some cases a pump is provided so that the liquid may be pumped up and allowed to again run over the solid portion to hasten and control its decay. While this process results in the production of manure of excellent quality, it has little to recommend it to the American farmer, for it requires too much time and labor to prepare it, and is not easy to apply to the field. Protection of the manure from leaching rains by keeping it under cover is more practical and should be in general use, for an inexpensive shed or lean-to is all that is required. Where it is possible to provide the shed with a floor of some water-tight material it is of course desirable to do so, as that prevents danger of loss of any liquid excrement that might not be properly absorbed by the bedding.

The whole secret of preventing hot fermentation may be summed up in these few words: "Keep the manure heap compact and moist." It has been shown that the heating of manure is caused by a class of bacteria which require free oxygen for the performance of their functions. Unless these bacteria are provided with sufficient air it is impossible for them to live, and consequently hot fermentation cannot occur. In building the manure pile, therefore, great care should be taken to have the heap well compacted by tramping or other means. Each daily addition to the pile should be firmly packed into place and the sides and top of the heap should be smooth and firm in order to exclude as much air as possible. If the pile is made in this way the aerobic bacteria soon use all the air that is enclosed in it, and the manure never becomes very hot. The presence of an abundance of moisture tends to prevent hot fermentation, due first to the cooling effect of the moisture itself, and to the fact that the moisture prevents the entrance of air. The manure heap should be carefully watched and water added to it occasionally if it shows any tendency to become too dry. Keeping the pile compact and damp in this way will stop the injurious hot fermentation, but does not interfere with the decay due to anaerobic bacteria. The latter is beneficial because it decomposes the organic matter of the manure in such a way that the plant food becomes more available, and the manure is greatly improved in its mechanical condition. The first step in the preservation of manure should be the mixing of the different kinds produced on the farm, for in this way the rapid fermentation that would take place in the dryer horse and sheep manure is checked by the more moist cow and pig excrement. When it is possible to do so, turn the manure occasionally, for this will cause it to decompose more readily and evenly. When it is necessary to store the manure for some time it is a good plan to cover the heap with an inch or two of earth. This prevents the escape of any ammonia that may be formed, as the earth has the power of fixing and retaining the ammonia.

Roberts and other writers recommend the use of covered barnyards for the preservation of manure. These are simply sheds with good roofs but no sides, and large enough to allow the cattle some room to move about. The bottom is excavated a few inches and made tight by puddling and pounding the clay or by use of grout. The manure as it is removed from the barn is spread evenly on the floor of the covered yard, is tramped into a compact mass by the cattle and is kept moist by the liquid excrement. The manure produced in this way is of excellent quality, can be easily handled when its removal is necessary and experiments indicate that the losses are reduced to a minimum. The advantages of such a covered yard as a place in which the cattle may take mild exercise in severe weather will be apparent to most farmers.

A method of preserving manure that is in use in some parts of Europe is what is known as the "deep stall method." The stalls in which the cattle stand are excavated for some depth below the general level of the barn floor, and every day the manure is spread evenly over the stall and a liberal amount of bedding added. The mixture of excrement and bedding is firmly packed by the feet of the cattle and is not removed until the end of the winter, the surface of the manure being by this time above the level of the floor. The manure produced in this way is of excellent quality and suffers very little loss in fertilizing value. This method will hardly commend itself to the farmers of this country for sanitary reasons, especially if they are engaged in dairy husbandry.

The plan followed by many agriculturalists of throwing horse and cattle manure into a basement room and allowing it to be worked over by the hogs is perhaps as good a method as could be devised when considered from the preservation of manure standpoint. The working over and tramping of the manure by the swine accompanied by the addition of their own moist excrement, controls the fermentation so as to prevent undue heating, and very little fertilizing value is lost from manure produced in this way if the number of pigs is sufficient to thoroughly work it over.

Occasionally it becomes absolutely necessary to store the manure when no cover of any kind is at hand. In case it must be left in the open the heap should be made so high that even the hardest rains will not soak entirely through it. The sides of the pile should be kept as nearly perpendicular as possible, and the top should dip slightly toward the center, and great care be exercised to make the heap compact.

(52) **Composting Manures.**—Any method of storing manure requires considerable labor, and for that reason is to be avoided in general farming whenever it is possible to use it in the fresh condition. In market gardening, on the other hand, such quantities of manure are used that it is necessary to have it thoroughly rotted before applying, as otherwise the crop would suffer from the heating effect that the large amount of raw manure would have on the soil. While the manure may be rotted by keeping it in a moist compact heap as described in the previous section, it must be remembered that the manure commonly used by market gardeners is the horse manure from the city stables. This heats so rapidly that special care is necessary to prevent hot fermentation, and the pile must be frequently moistened. Many market gardeners prefer to compost the manure with earth or muck. This is done by making a foundation of about six inches of dirt and on top of this placing alternate layers of soil and manure, moistening the mass as the heap grows. The sides and top should be nicely smoothed off and the mass covered with a thin layer of earth to prevent loss of nitrogen. After about two months the pile should be turned over, the materials thoroughly mixed and more water added if necessary to keep the compost moist.

A compost in great favor with greenhouse men is one made of manure and sod, these materials being piled in alternate layers as described above. This gives the fibrous compost so desirable for bench and pot work. Any of the refuse organic materials of the farm or garden may be used in composts. Weeds, refuse parts of plants, dead animals, kitchen wastes, etc., may be added to the manure-earth mixture, or composted separately, for handled in this way they decompose rapidly and without offensive odors. The presence of the earth decreases the loss of ammonia where highly nitrogenous materials are used.

Some market gardeners throw the horse manure as it comes from the city stables into the pig pens to be first worked over by the pigs and then composted with the earth, and this plan is no doubt a wise one.

In using composts a good practice is to add bone meal and one of the potash salts to the heap. In this way the plant food in the bone meal is made more available to the plants and the compost is made more valuable.

It occasionally happens that one wishes to produce a stock of well-rotted manure in a very short time. This can be done by mixing the manure with a small quantity of freshly slaked lime. In this way the manure is made to decay very rapidly, but as the decomposition is probably attended by more loss of nitrogen than usually occurs in composts, it is not to be recommended for general use.

(53) **Applying Manure.**—Nature applies all her fertilizers to the surface of the ground. Many farmers have come to the conclusion that Nature's method is the best, and whenever possible are using manure as a top dressing. The tendency is for the elements of fertility to gradually pass down in the soil, especially the compounds containing nitrogen. For this reason it is best to apply the fertilizer to the surface so that the soluble food as it descends comes in contact with plant roots, and is not carried to such a depth as to be beyond their reach. Ma-

nure to be used in this way must be so fine as not to interfere seriously with the subsequent tillage of the ground. This condition of fineness generally exists if the manure is well rotted, but even fresh manure may be utilized as a top dressing if cut straw, or other fine material, has been used for bedding. It is well to apply the manure directly after plowing, and to thoroughly incorporate it with the soil, by use of the harrow or cultivator, preparatory to planting the field.

Two general methods for the application of manure are in common use; one is to throw it into heaps where it is allowed to remain some time before being spread; the other to broadcast it directly from the wagon. The first method is objectionable for several reasons. In the first place it increases the work necessary to spread the manure, as it must be twice handled, and it takes no more labor to spread it from the wagon than from the heap on the ground. When piled in this way the manure is very often allowed to stand for some days at great risk of injurious fermentations such as described in (50). The leachings from these heaps make the spots directly beneath them more fertile than the rest of the field and, hence, produce a rank growth at those places. No doubt the reader has often seen a field where he could detect every spot on which the manure heap had been placed by the greener and more luxuriant growth of the crop. This uneven growth is undesirable, because in the case of grains it increases the danger of lodging in the more fertile spots, and in any case it results in unevenness in the maturity of the crop. A crop that has a large supply of plant food for instance, has a longer period of growth than one with a meager supply, and consequently is later in maturing. If, therefore, the field is very uneven in fertility a part of the crop will be ready to harvest some time before the rest has matured. If the manure is spread directly from the wagon not only is the labor lessened but the danger of unevenness in growth is to some extent avoided. There is no likelihood of loss in the value of the manure when it is spread in a thin layer on the ground as has already been stated, (51). Manure spreaders are now being offered for sale of such efficiency that they are likely to come into general use. Whatever method is used to spread the manure it will readily be seen that the finer the material the easier it will be to distribute it evenly. Where very coarse manure is used some farmers find it advantageous to supplement the spreading from the wagon by the use of a drag that will break up the larger lumps and distribute it more evenly. A reason in favor of top dressing over other methods of applying manure is, that the organic matter added to the surface soil in this way acts as a mulch, and tends to prevent the evaporation of water from the soil.

Where the manure is so coarse as to interfere with tillage it becomes necessary to plow it under, and in this case some discretion should be used to prevent its being covered to too great a depth. Especially in clay soils, where the air does not readily enter, it is easily possible to bury the manure so deeply as to prevent decay. In the case of heavy soils the manure should probably never be covered to a greater depth than four inches, while in sandy soils the depth might be much greater. In very dry seasons much harm may be done to the soil by plowing under large quantities of coarse manure, as there may not be sufficient moisture in the soil to bring about the decomposition of the organic matter, and the undecayed material may cause serious injury to the physical condition of the soil as was noted in the discussion of green manures (38). A practice that is highly recommended is to apply the manure, especially that of the summer and early fall, to sod land that is to be plowed and planted the following spring. In this way of utilizing manure the soluble part, as it is washed out by the rains, is used by the growing crop, and thus the losses due to leaching are avoided and, as the stubble or sod is turned under, the entire amount of plant food is in position to be used by the succeeding crop. The permanent pastures should not be neglected in manuring and will well repay liberal applications. It is well to use the drag mentioned above on the pastures, so as to spread the droppings of the cattle evenly over the surface.

Few questions have been more discussed by the agricultural press than the relative merits of fresh and rotted manures, and the apparently inconsistent results reported by different farmers are probably due more to various kinds of soil on which the manure was used, than to any difference in the values of the manures themselves. Considered from the standpoint of the soil alone it will be found that on heavy soils containing large amounts of clay more benefit will be derived from raw manures than from those that are well rotted. The fresh manure warms these naturally cold soils, makes them more porous, and the fermentations that take place during its decay tend to make the soil more mellow, and to set free the "locked up" plant food. Rotted manure has the same effect but in a less marked degree than that which is fresh. On light or sandy lands on the other hand those manures that are well decomposed will be found more beneficial. Such soils are likely to suffer from the heating and drying effect of raw manure, and to have their porosity increased to an undesirable extent. The manure used on these soils should be thoroughly decayed, and will thus be found to improve the mechanical condition of the soil, and to materially increase its moisture retaining power.

Raw manures induce rank growth and for that reason are objectionable for use on the small grains, where the product desired is the grain, and not the yield of leaf and stem. If manure is used directly on these crops it should be thoroughly decomposed. Corn, millet and the hay crops, on the other hand, are usually benefitted by liberal applications of fresh manure. Corn especially is a gross feeder, and apparently is not injured by the heaviest application of raw manure, in fact, it may be said that when the farmer is in doubt as to where to apply the manure he should use it on the corn. Manures that are at all fresh are injurious to sugar beets and tobacco, in the former case producing a large beet that is low in sugar content, and in the latter a coarse and undesirable leaf. It is also a well-known fact that raw manure is likely to make wheat lodge.

Instead of using manure directly on the grain, beets or tobacco it is customary, in some parts of the country, to apply it liberally to corn, and plant the field to the above mentioned crops the following year. Using it this way there is no danger of inducing rank growth.

In a few instances manures are wasted by being used too liberally. For ordinary farm crops it probably is never profitable to use more than ten to fourteen tons per acre, and on general principles it may be stated that somewhat frequent light applications will pay better than very large ones given at long intervals. On the other hand the amount of manure produced on the average farm is so small, when compared with the land to be fertilized, that it would be utterly impossible to spread it over all the farm each year; for this reason, it is a good plan to apply the manure to one crop in a rotation, thus covering only a fraction of the farm each year. The following rotation which is used by a well known dairyman is an example that will explain the last statement; corn 1 year, grain 1 year, clover and timothy 2 or 3 years. The manure is applied the last year the field is in sod. A second rotation in common use is as follows: corn (manured), grain, clover, grain. Chemical fertilizers as well are often used on one or both grain crops.

(54) **Usefulness of Manure.**— Some difference of opinion exists among farmers as to the relative value of barnyard manure and commercial fertilizers for crop production, but it is worthy of note that those who are most diligent in caring for the manure are the ones who have most faith in its worth as a fertilizer. The fact that barnyard manure has been used so universally by agriculturalists, and for so many centuries is one of the strongest arguments in its favor. That the popular estimate of its value is established by scientific experiment is well shown by investigations carried on at Rothamsted. On certain plots, as has been mentioned, crops have been grown continuously with no fertilizer of any kind added; on other plots barnyard manure has been used every year, and on still others various combinations of commercial fertilizers have been tested. The following table gives the yields of barley and wheat from the unmanured plots, the plots dressed with barnyard manure, and the highest results obtained from the use of any combina-

tion of commercial fertilizing materials. The tests extend over forty years, but to shorten the table the results are given here in averages for five eight-year periods. (Fractions have been omitted).

	BARLEY Bushels per Acre			WHEAT Bushels per Acre		
	No Manure	Barnyard Manure	Commercial Fertilizers	No Manure	Barnyard Manure	Commercial Fertilizers
1st 8 yrs.	24	44	48	16	34	36
2nd 8 "	18	52	51	13	35	39
3rd 8 "	14	49	45	12	35	36
4th 8 "	14	52	42	10	28	32
5th 8 "	11	44	41	12	39	38
Average (40 yrs.)	16	48	45	13	34	36

It will be seen that while both the fertilized plots gave much larger yields than the one receiving no addition of plant food, there is practically no difference between the plots dressed with barnyard manure and the best commercial fertilizers. This test is hardly fair to the barnyard manure, as the quantities of commercial fertilizers applied were far in excess of anything used in general practice; the amount of nitrogen added to the wheat, for instance, being equivalent to that contained in 800 pounds of nitrate of soda, which would cost practically as much as the wheat would bring on the market. In all probability, if these experiments had been conducted in this country the showing would have been much more favorable to barnyard manure. It has been explained that the materials in the manure must undergo nitrification before the nitrogen becomes available to plants, and this process takes place so much more rapidly in this country than in England, that it is easy to believe better returns might be obtained from barnyard manure under American conditions.

Barnyard manure differs from other fertilizers in its lasting effect when applied to the soil. At Rothamsted in connection with the above experiment one plot was manured annually for twenty years, and then received no manure for the next twenty years. In the table below are given the yields of barley in averages for five-year periods on the plot which was never manured, and the plot that had been manured the previous twenty years. The figures given for the second plot represent the effect of the residual manure as no fertilizer was added during the period covered by the table.

	Unmanured every year	Effect of Residual Manure
First 5 years........	13	39
Second 5 years......	14	29
Third 5 years......	14	30
Fourth 5 years......	12	23
Average (20 yrs.)...	13.25	30

The table shows that the effect of the manure was perceptible in the yield for at least twenty years after the last application. It is more than likely that the more rapid rate of nitrification in this country might materially shorten the period in which the lasting effect of the manure would be observable, and no doubt the influence of the residual manure would have disappeared in a shorter time than twenty years.

The value of barnyard manure cannot be estimated from the content of nitrogen, phosphoric acid and potash alone. Manure is probably as valuable on account of its effect on the mechanical condition of the soil as for the plant food that it contains. As a humus former it has no equal among fertilizers, and the great value of humus in improving the tilth of the soil and increasing its power to hold water has been shown in an earlier section (38). The writer believes that the farmer would be well repaid for applying the barnyard manure for its physical action alone, even though it contained none of the elements of plant food.

(55). Effect of Style of Farming on Fertility.—The facts brought out by this discussion of the subject of barnyard manures must have made it apparent that the losses in fertility are much greater in any system of farming where the crops are sold from the farm, than where some form of animal husbandry is followed, especially if no commercial fertilizers are used. To bring this point more concretely before the reader the following table adapted from a Minnesota bulletin is given here. In compiling the table it was assumed that each farm consisted of 160 acres. In the first case nothing but grain was raised and all sold from the farm, in the second the

EFFECT OF TYPES OF FARMING ON FERTILITY.

Kind of Farming	Gain or Loss in Fertility		
	Nitrogen Pounds	Phosp'ic Acid Pounds	Potash Pounds
All Grain.......	—5600	—2500	—4200
Grain and Stock	—2600	—1000	—1000
Stock..	— 900	+ 50	— 60
Dairy...........	— 800	+ 75	— 85

farm was about equally divided between grain and stock raising, and in the third and fourth the farms were devoted to stock raising and dairying respectively. In the last two cases a small amount of potatoes and grain were exchanged for mill products, but it was assumed that no other concentrates or fertilizers were used.

Even this table does not show the advantages in favor of the last two styles of farming for, if the results obtained at Rothamsted from the growth of clover are accepted, there was a gain of nitrogen in the stubble in these two cases that would much more than counterbalance the losses shown in the table. No better illustration of the effect of the system of farming on the fertility of the soil could be desired.

PART IV. Commercial Fertilizers.

(56) **General Considerations.** — It was shown in Part III. that under a system of animal husbandry it is possible to maintain the fertility of the soil by means of the barnyard manure used in connection with leguminous crops, provided the best methods of tillage, etc. are used, and all the materials raised are fed on the farm. Where a part or all of the crops produced are sold from the farm, it sooner or later becomes necessary to supply plant food derived from outside sources. This is especially true in truck farming where the crops raised are such as remove large quantities of plant food. The needed fertility is supplied to some extent by the manure produced in the city stables, and is best so supplied where possible, but this source of fertilizing material is obviously inadequate to furnish the required amount of plant food.

The constantly growing demand for something that will increase the crop production has given rise to the fertilizer industry which is rapidly assuming gigantic proportions. At the present time over fifty millions of dollars are used annually in the purchase of fertilizers in the United States, and it is probably no exaggeration to say that fully half of this is money thrown away. This is no argument against the use of commercial fertilizers, but simply means that they should be used with judgment and not used at all until actual investigation has shown them to be necessary.

"One must distinguish between lack of plant food in the soil and other conditions which prevent good crops, for lack of food is not the only cause that makes crops suffer. In some soils there is insufficient porosity which causes the development of the roots to be checked. Lack of moisture, caking of soil, retention of stagnant water, deficiency of humus, lime, etc., unfavorable weather and other conditions may interfere with the healthy growth of plants and thus cause diminished crops, even when the plant has within reach all the food it needs. Under such circumstances the unfavorable conditions must be removed to secure good crops, which, according to the demands of special cases may be done by irrigating, draining, harrowing, hoeing, marling, mucking, etc. It may often happen that the soil contains an abundance of plant food, most of which is still unavailable. Under such circumstances an effort should be made to bring this food into an available condition as rapidly as the plants can use it, and this may be done by an improved system of tillage, together with the application of such indirect fertilizers as have the power to make insoluble plant food available." (Van Slyke).

Too frequently fertilizers are made to take the place of tillage when they should be used to supplement it. That is, fertilizers are most lilkely to produce profitable results when conjoined with superior physical conditions of the soil. On general principles it may be said that the man who would obtain the best yield without fertilizers of any kind is the one most likely to realize a profit from their use.

"The fact that fertilizers may now be easily secured, and the ease of application, have encouraged a careless use, rather than a thoughtful expenditure of an equivalent amount of energy in the proper preparation of the soil. Of course it does not follow that no returns are secured from plant food applied under unfavorable conditions, though full returns cannot be secured under such circumstances. Good plant food is wasted, and the profit possible to be derived is largely reduced." (Voorhees).

(57) What are Commercial Fertilizers?—When it was first discovered that certain of the elements found in the soil were necessary to plant growth, it naturally occured to the agricultural investigators that it might be possible to renew the fertility of worn out soils by supplying these elements artificially. In the first experiments conducted along this line all of the elements which the plant derives from the soil were supplied. As the investigations progressed it was discovered that increased production resulted in most instances from the addition of only three of these substances, i. e., nitrogen, phosphoric acid and potash. In other words it was determined that except in rare cases all the other elements existed in the soil in quanities sufficient to supply the needs of the plant even when the available nitrogen, phosporic acid and potash were practically exhausted. For this reason it is generally considered unnecessary to supply any of the elements of plant food except the three named above, and these substances have come to be known as the "essential ingredients of a fertilizer," and the only ones that give the fertilizer a commercial value.

From what has been said it will be seen that any material that supplies one or more of these "essential ingredients" might be used as a commercial fertilizer provided it could be purchased at a price that would make its use profitable. As a matter of fact the number of substances that are available for this purpose is somewhat limited, owing to the prohibitive prices which the others bring on the market.

Many persons seem to think that there is something mysterious about the manufacture of fertilizers, and some of the makers encourage this belief by pretending that they have some secret process of manufacture, that enables them to produce a better product than their competitors, and far better than the farmer can mix himself. The truth is that there are a limited number of basic materials from which all the different brands of fertilizers are made and these basic substances are articles of commerce and can be purchased by anyone. The so called "complete fertilizers" consist of two or more of these substances mixed together, in the proportion to give the required per cent of nitrogen, phosphoric acid and potash in the finished product. Some of these materials are commonly purchased unmixed, while others are rarely seen by the farmer except as one of the ingredients of a complete fertilizer. Some of these basic materials contain only one of the essential ingredients of a fertilizer, while others contain two, but usually one is in such excess that the substance is used chiefly to furnish that one element. It is possible, therefore, to separate the basic fertilizers into three classes; viz:

(1) Materials used chiefly as sources of nitrogen.

(2) Materials used chiefly as sources of phosphoric acid.

(3) Materials used chiefly as sources of potash.

In order to discuss intelligently the subject of commercial fertilizers it will be necessary to briefly consider the substances included in these different classes.

(58) Nitrogenous Fertilizers. — The larger number of this class are composed of various kinds of refuse animal matter fram the packing houses, soap and glue factories, etc. Only those in common use will be discussed here.

DRIED BLOOD. As its name signifies this is the blood from the slaughter house which has been rapidly dried by artificial heat, and when ready for sale is in the form of a powder. Two grades of dried blood are found on the market, known as the red and black blood. The red blood is more carefully dried and is not charred as is likely to occur with the more rapid drying that produces the black blood. The red blood contains from 13 to 14 per cent of nitrogen, while the black is much less constant in composition, and contains from 6 to 12 per cent.

MEAT MEAL, AZOTIN, AMMONITE. These are synonomous terms used to designate a meat product derived principally from the rendering establishments, where the different portions of dead animals are utilized. When relatively pure it contains from 13 to 14 per cent of nitrogen.

HOOF MEAL. The principal source of this product is the glue factory, and consists of the dried hoof or portions thereof ground to a fine powder. It is fairly uniform in composition and contains about 12 per cent of nitrogen.

HORN MEAL is produced at the packing houses and in the factories where combs, buttons, etc., are manufactured. The chips and shavings are ground to a fine meal and sold as a fertilizer. It is quite uniform in composition, containing from 10 to 12 per cent of nitrogen—though in a very unavailable form.

TANKAGE consists of the dried animal wastes from the large slaughtering establishments. It is variable in composition owing to the fact that the proportions of the different ingredients of which it is composed may vary widely in different samples. As commonly made it may include offal, small bones, tendons, waste flesh, hair, etc. These materials are rendered for the extraction of the fat, and the residue is dried and ground to a meal of more or less fineness. Tankage contains phosphoric acid as well as nitrogen, and the percentage of the two vary. As the nitrogen decreases the phosphoric acid increases and vice versa. The variation of these two ingredients is so great that in trade it is always sold on the basis of its composition. Because it contains very considerable amounts of phosphoric acid its commercial value is not based wholly on its nitrogen content as is the case with dried blood and dried meat. Tankage contains from 4 to 9 per cent of nitrogen and from 3 to 12 per cent of phosphoric acid.

DRIED FISH OR FISH GUANO. Most of the fish fertilizers are made from the menhaden, a fish that is caught in large numbers along the Atlantic coast. The fish are steamed and pressed to extract the oil and the remaining "pomace" is dried and ground. This material contains from 8 to 11 per cent of nitrogen and 3 to 5 per cent of phosphoric acid. Some of the fish fertilizers consist of the residues of the canning factories, but those are not so valuable as those derived from the menhaden.

LEATHER MEAL consists of the smaller scraps and chips from the leather industry that are collected and ground into a meal which is sometimes used in the manufacture of fertilizers. Leather is fairly rich in nitrogen but, taking into consideration that the one object in making leather is to render it resistant to the conditions which promote decay, it will be seen that is not a desirable substance to use as a fertilizer.

COTTONSEED MEAL AND LINSEED MEAL were formerly used as nitrogenous manures, but their value as feeds is now so well recognized that they are no longer available as fertilizers.

PERUVIAN AND OTHER GUANOS. These are composed of the accumulated droppings of fish eating birds, more or less mixed with the dead bodies of these birds. The most important source of this material was a group of islands lying off the coast of Peru, and its high value was due to its being produced in a rainless region. Guano was formerly abundant, and was so much appreciated as a fertilizer that many substances in no way resembling the true guanos were called by that name. At the present time practically no guano of good quality is imported and any product bearing that name should be looked upon with suspicion and purchased only upon analysis.

SULPHATE OF AMMONIA. is a by-product of the manufacture of coal gas, animal charcoal and coke. It resembles common salt somewhat in appearance and is the richest in nitrogen of all fertilizing materials, containing from 20 to 23 per cent. At the present time the high price of the sulphate interferes with its extensive use, although it gives excellent results on soils that contain plenty of lime. It should never be used on soils deficient in lime nor in connection with the ordinary potash fertilizers which contain chlorine.

NITRATE OF SODA OR CHILI SALTPETER. This is a crystalline substance, somewhat resembling coarse salt in appearance, and is entirely soluble in water. It all comes from large deposits in Chili, which supply over one million tons of nitrate per year to be used as a fertilizer. Chili saltpeter contains from 15 to 16 per cent of nitrogen in a form that is immediately available to the plant, and for this reason it is the most desirable nitrogenous fertilizer to use where immediate results are desired. It is not fixed by the soil and consequently should be supplied only as the crop can use it, and never applied to the ground when it is bare. As it is so easily washed from the soil it is considered best to use it in two or three applications instead of applying all at one time.

(59) **Relative Availability of Nitrogenous Fertilizers.**—The per cent of nitrogen present in the different fertilizing materials, as given in the previous section, does not properly indicate their relative fertilizing value. Mention has repeatedly been made of the fact that the plant can make use of the nitrogen only when it is present in the soil in the form of nitrates. Nitrate of soda is the only fertilizer on the list that contains nitrogen in the nitrate condition, and consequently is the only one that adds nitrogen to the soil in a form that is available to the plant without further change. All the other materials must undergo the process of nitrification and have their nitrogen converted into nitrates before it can be used by the crop. It must be apparent, then, that the value of a nitrogenous fertilizer depends upon both its content of nitrogen and the ease with which it is nitrified.

Of the list given above sulphate of ammonia is the most easily converted into nitrates, provided the soil is abundantly supplied with lime. Next in order comes dried blood. So many other uses are being discovered for dried blood, however, that the time is probably not far distant when it can no longer be used as a fertilizer.

The nitrogen in dried fish, tankage, hoof meal and bone meal are readily changed by nitrification and rank next to blood meal. Horn meal on the other hand decomposes very slowly, and the nitrification of leather is so slow as to make it practically worthless as a fertilizer.

Experiments up to date indicate that if nitrate of soda is rated at a 100 per cent the availability of the other materials would be as follows:

Nitrate of soda	100
Blood and cottonseed meal	70
Fish, hoof meal	65
Bone and tankage	60
Leather and wool waste	2 to 30

"If, for example, the increased yield of oats due to the application of nitrate of soda is 1,000 pounds, the yield from blood would be 700 pounds, from hoof meal 650 pounds and leather 20 to 200 pounds."

These statements indicate how little an analysis of a fertilizer which gives only the per cent of nitrogen or ammonia tells of the real value as a supplier of nitrogen, and show very clearly that to arrive at any conclusion regarding the value of a nitrogenous fertilizer one should know the source or condition of the nitrogen as well as the per cent.

Two or three suggestions for the selection of nitrogen fertilizers may be deduced from this discussion. For those crops which begin their growth early in the spring the best results will follow the use of Chili Saltpeter, as the soil is likely to be poor in nitrates and the process of nitrification is slow at that time. Such crops as have very short periods of growth will respond best to nitrogen in nitrates. Corn, on the other hand, and the other crops which make their growth after the season is well advanced can use the slower acting fertilizers, as can also those crops which occupy the ground permanently. Some agriculturists prefer to use a fertilizer containing nitrogen in three forms for the crops that grow during the greater part of the season; a little nitrate of soda for immediate use, sulphate of ammonia to supply nitrogen a little later, and tankage to carry the plant to maturity, all these materials being mixed and applied at one time..

(60) Potash Fertilizers.—It has been shown that most soils contain much more potash than nitrogen or phosphoric acid. (28.) The greater part of the potash in the soil is in very insoluble and unavailable forms, and although there are large quantities present, the plant may be able to use so little of it that a good crop is impossible, as has been shown by the increased yield from the use of potash on clay soils that had a high content of this element of fertility.

"It has been attested that potash is of relatively less importance than either nitrogen or phosphoric acid, inasmuch as good soils are naturally richer in this element, and because a less amount is removed in general farming than of either nitrogen or phosphoric acid, as the potash is located to a less extent in the grain than in the straw, which is retained on the farm. It is, however, a very necessary constituent of fertilizers, being absolutely essential for those intended for light, sandy soils and for peaty meadow lands, as well as for certain potash-consuming crops, as potatoes, tobacco and roots, since these soils are very deficient in this element, and the plants mentioned require it in larger proportion than do others. In fact, it is believed by many careful observers,—and the belief has been substantiated in large part by experiments already conducted,—that the average commercial fertilizer does not contain a sufficient amount of this element. It is a particularly useful element in the building up of worn-out soils, because contributing materially to the growth of the nitrogen-gathering legumes, an important crop for this particular purpose." (Voorhess.)

The statement so often made by fertilizer manufacturers that potash is not necessary in a commercial fertilizer, because it is present in such quantities in the soil, does not take into consideration the fact that it is only the available plant food that is of importance to the present crop, and that the larger part of the food in the soil may be in unavailable or potential forms.

WOOD ASHES at one time was the sole source of potash for fertilizing purposes, but at present ashes supply but a very small proportion of this element of plant food. The potash in wood ashes is in one of the best forms for use as a fertilizer, but the supply is so limited and the price usually demanded so high that ashes can no longer be considered an important source of potash. Wood ashes vary greatly in composition, and ash from soft wood containing less potash than that from the har woods; the content of potash ranging from 2 to 8 per cent.

Potash as found in wood ashes is in a form that is very soluble in water so that ashes that are exposed to the weather may have practically all of the potash leached out of them; leached ashes as a rule contain less than 2 per cent of potash. As it is not possible to distinguish between leached and unleached ashes by mere physical examination, it is evident that this material should be purchased only from guaranteed analysis.

In addition to potash ashes contain from 25 to 30 per cent of lime and in many cases, no doubt, the beneficial results obtained from ashes were due as much to the lime in them as to the potash. All ashes produced on the farm should be carefully preserved and utilized, but they can seldom be purchased to advantage.

STASSFURT SALTS. At the present time practically all of the potash used in fertilizers comes from the Stassfurt Mines in Germany. These mines contain immense deposits of potash and are owned by a syndicate that controls the price and output of potash the world over. A number of different minerals containing varying per cents of potash are produced from the mines, and many of them are used in Germany. Only three or four of these products are in use in this country, and these are the only ones that will be discussed here.

KAINIT. This is one of the crude salts which has been ground to a powder. It looks somewhat like common salt but is darker in color and contains about 12.5 per cent of potash, in the form of sulphate, mixed with the sulphate and chloride of magnesia. This substance has been used because it is chaper per ton than the next two substances to be mentioned, but even at the lower price per ton, the actual potash costs more in kainite than in the concentrated salts.

MURIATE OF POTASH is manufactured from the crude minerals of the mines by concentration, and contains about 50 per cent of potash, all of which is combined with chlorine in the form known by the chemists as potassium chloride. At the present price per ton, the muriate supplies potash at a cheaper price per pound than any of the other materials.

SULPHATE OF POTASH is another concentrated product of the Stassfurt industry. What is known as high grade sulphate contains about 53 per cent of potash in the form of sulphate (i. e. combined with sulphuric acid). The actual potash in this compound costs a trifle more per pound than in the muriate. A lower grade sulphate, containing about 26 per cent of potash, mixed with sulphate of magnesia, is sold under the name of "double manure salt." Although the price per ton of this material is much less than the muriate or high grade sulphate, the cost of the actual potash is a little more.

(61) Comparison of Potash Fertilizers.—All of the materials mentioned contain potash in forms that are soluble in water so that there is no such marked difference in availability as was noted in the case of the nitrogen fertilizers, but there is a difference in their effect on certain crops and soils, due to the substances with which the potash is combined. The form in which th epotash occurs in wood ashes is probably the best of all, especially for use on light soils and those which are rich in humus or are inclined to be sour; but at the prices demanaed for wood ashes at the present time the potash costs more per pound than in any of the German salts.

The chlorine in the muriate has been found to be injurious to certain crops, among which may be mentioned potatoes, tobacco and sugar beets. Nearly all crops are harmed by the muriate if it is applied in large quantities immediately before or after seeding. This injury may be prevented by sowing the muriate in the fall, as the potash will become fixed by the soil and the chlorine will be leached out. When the chlorine is removed in the soil water it carries with it part of the lime, so that the soil in fields which are continuously manured with muriate may become sour through removal of the lime. This may be prevented, of course, by occasional applications of lime. The same remarks apply to the use of kainite. As the muriate is the cheapest form of potash it is the compound that is used nearly altogether in mixed commercial fertilizers. So far as has been determined no injurious effect results from the use of sulphate of potash, and some experiments indicate that larger yields per pound of potash are obtained from the sulphate than from any of the other salts. It is the only potash salt that can be safely used on pototoes, sugar beets or tobacco. Although the potash in the sulphate costs a trifle more per pound it probably will not prove the dearer in the long run, if the necessity for liming where the muriate is used is taken into consideration; so that for continued use the sulphate is undoubtedly to be preferred.

(62) Phosphatic Fertilizers.—Phosphoric acid is present in the soil in much smaller quantities than potash, and experience shows that it is much more likely to become exhausted. In fact there are sections of the country where no other fertilizers than those furnishing phosphoric acid are used, while these are bought in large quantities. All this class of fertilizers contain their phosphoric acid in the form of phosphates i. e., the phosphoric acid is combined with some basic substance which is generally lime. The phosphates may be subdivided into two general classes—the "natural" and the "manufactured phosphates."

(63) Natural Phosphates. — There are two general sources of phosphates—the bones of dead animals and certain phosphate, containing minerals which will be briefly considered.

RAW BONE MEAL is made by grinding raw bones into a powder, and the finer it is the more valuable the product. This substance contains about 22 per cent of phosphoric acid and 4 per cent of nitrogen. Raw bones contain a small quantity of fat as well, and as this prevents the rapid decay of the bone the phosphoric acid and nitrogen in it are somewhat slowly available to the crop.

STEAMED BONE MEAL. Most of the bone meal sold at the present time is made from bones that have been previously steamed to remove the fat and a part of the nitrogen compounds. The fat is used in making soap, and the nitrogen in glue and gelatins. Steamed bone contains from 28 to 30 per cent of phosphoric acid and about one and one-half per cent of nitrogen. The steamed bone can be ground to a much finer powder, and the removal of the fat causes them to decay more rapidly so that they must be considered a more valuable source of phosphoric acid than the raw bones.

TANKAGE was considered under nitrogenous fertilizers, and is an important source of phosphoric acid in the so called "animal fertilizers." When the product contains a very large proportion of bone it is sometimes designated as "bone tankage," and may contain from 17 to 18 per cent of phosphoric acid.

BONE BLACK OR ANIMAL CHARCOAL is made by heating bone in airtight vessels until all volatile matter is driven off, and is used in the refineries to purify sugar. After it has become "spent" or useless to the refiner it is sold for use as a fertilizer. Bone black contains from 32 to 36 per cent of phosphoric acid.

MINERAL PHOSPHATES. In a number of places rock deposits are found that contain varying percentages of phosphate of lime. These phosphates are usually named after the place where they are obtained, as "Carolina phosphates," "Florida phosphates," and "Tennessee phosphates." These rocks contain from 18 to 32 per cent of phosphoric acid and differ from the bone products in that they are purely mineral substances and contain no organic matter. Ground into a fine powder they are sometimes sold under the name of "floats," but the rock phosphates are used only to a limited extent in the crude condition.

(64) Superphosphates or Manufactured Phosphates.—The phosphoric acid in all of the natural phosphates described is combined with lime in a form that is extremely insoluble in water. In order to make the phosphate soluble it is sometimes treated with sulphuric acid, which unites with part of the lime, leaving a phosphate which contains only one-third as much lime as the natural phosphate and which is soluble in water. The lime and sulphuric acid make a compound which is the same as that found in gypsum or land plaster. This combination of soluble phosphate and gypsum, made by treating the natural phosphates with acid, is called by the various names of superphosphate, soluble phosphate, acid phosphate, acidulated rock, etc. For its manufacture the rock phosphates are generally employed both because they are cheaper and because the organic matter in the bones interferes with the use of sufficient acid to make all the phosphate soluble. A good sample of superphosphate or acidulated rock contains about 16 per cent of phosphoric acid in a form that is soluble in water.

Sometimes when insufficient acid has been used a part of the soluble phosphate will change into a form intermediate in solubility between the natural phosphate and the acid phosphate, and the phosphate is said to have undergone "reversion" and the new compound is called "reverted phosphate." The latter product is supposed to be more available to the plant than the insoluble or natural phosphate, hence the soluble and reverted phosphoric acid taken together are known as the "available phosphoric acid."

In some instances bone meal is treated with a limited amount of sulphuric acid, and the product is called "acidulated bone." This substance contains a much smaller proportion of its phosphoric acid in the soluble form than does the rock superphosphate. When soluble phosphates are added to the soil they soon combine with the mineral matter and are converted first into the reverted phosphate and finally into the insoluble form such as is found naturally in the soil. In this was the phosphoric acid is "fixed" and there is no danger of its being lost by leaching.

(65) Relative Value of Phosphate Fertilizers.—The soluble phosphate, present in the acidulated goods, is generally considered the most valuable form of phosphoric acid for use as a fertilizer. At first sight it seems useless to go to the expense of making the phosphate soluble when it is again rendered insoluble by the soil before the plant can make use of it. The real object in making it soluble is to aid in its distribution in the soil. When an insoluble phosphate is applied it remains where it falls except for the slight distribution it receives by cultivation. In the case of the soluble phosphate, on the other hand, the phosphate dissolves in the soil water and is widely distributed before it becomes fixed by the soil. In the former case the roots must go to the phosphate, while in the latter the phosphate is carried to the roots. It follows from what has been said that after the soluble phosphate is distributed throughout the soil the individual particles must be very much smaller than is the case with the insoluble phosphate, and the importance of fineness of division has been clearly shown. (See 34).

There are some soils on which superphosphates cannot be used without injury, and these are usually soils that are deficient in lime; the superphosphate in such cases having a tendency to make the soils acid. Indeed it is asserted that even soils containing an abundance of lime in the beginning may be made acid by the continued use of superphosphate if no lime is added.

When the natural phosphates alone are considered there is no doubt that the preference should be given to those derived from bones. The organic matter present in the bones decays when it is incorporated with the soil, and this process doubtless causes the phosphate to become more readily available to the plant, while the rock phosphate, on the contrary, is very slowly decomposed. At the present price of steamed bone meal it is probably one of the cheapest substances with which to supply phosphoric acid where everything is taken into consideration.

The use of ground rock phosphate or "floats" has not met with general favor, and it probably does not give good results when used alone. Investigations carried on at the Ohio Experiment Station indicate that when added to manure, "floats" have a high fertilizing value, in fact the increase due to adding the ground rock phosphate to stall manure was quite as large as that obtained from the addition of superphosphate. It would seem from these experiments that the comparatively inexpensive floats might, partially at least, replace superphospnates if used in connection with manure, and it is recommended in Bulletin 134 that the ground rock be used "as an absorbent in the stables, thus securing an intimate mixture with the manure in its fresh condition."

(66) **Complete Fertilizers.**—Mention was made of the fact that the basic materials described in the foregoing sections contain only one, or at most two, of the essential elements of fertility. Nearly all of the commercial fertilizers used by the farmers in this country are purchased in the form known as "complete fertilizers." A "complete fertilizer" in the sense in which the word is used in trade is one that contains nitrogen, phosphoric acid and potash and in proportions that are supopsed to be suited to the requirements of farm practices. Practically all of these fertilizers are made by mixing two or more of the basic materials heretofore described, the different ingredients being so combined as to give the desired per cent of nitrogen, phosphoric acid and potash. In case the basic materials alone yield a product that is richer in the essential ingredients than is desired by the manufacturer, sufficient sand, gypsum, dry earth, or other inert matter is added to bring the per cent of these ingredients down to the desired point. These fertilizers are indiscriminately rcommended for general use and all sorts of startling claims are made for them by the various manufacturers. They are offered as universal fertilizers irrespective of the well-known fact that soils differ widely in their characteristics, and that the crops vary in their food requirements. To be sure such a fertilizer, if sufficiently rich in nitrogen, phosphoric acid and potash, might be made to produce a large yield on any kind of a soil if used in large quantities, but such a use of a fertilizer would result in adding some of the elements at least in quantities far in excess of the need of the crop. "Economy requires that fertilizers should be adapted to the soil and the crop, and that we apply only what is needed. Farming is not sufficiently profitable to make it expedient to go on applying elements of plant food in excess of what is useful. In view of these considerations it is evident that the general fertilizers can suit only those who are brain lazy—those who do not care to study and think. No thinking farmer can be satisfied to blindly and thoughtlessly continue the 'hit or miss' system of using general fertilizers." (Brooks).

(67) **Special Fertilizers.**—A large number of so-called special fertilizers are now offered by the manufacturers, which are supposed to be adapted to the particular needs of a special crop or class of crops. Each fertilizer generally bears the name of the particular crop for which it is designed. Such fertilizers are offered for all of the prominent crops, and there are

found on the market "corn specials," "tobacco specials," "potato specials," "truckers' favorite," etc., etc., every manufacturer offering a number of such products.

If such fertilizers were compounded with any regard to the requirements of the particular crop for which they were advocated, their use would be a distinct advance over the use of the general complete fertilizers. Unfortunately their chief charm is in their attractive names, and their composition is in no way in accord with what scientific investigation has shown to be necessary for the crop. That these mixtures are not based on any scientific knowledge of the needs of the plant is shown by the fact that the "specials" offered for the same crop by the different manufacturers vary as widely in composition as do the fertilizers offered for different classes of crops. Yet these several makers are all claiming to have the best fertilizers for that particular crop.

Even were this idea of special fertilizers for each crop carried out consistently, it does not take into account the fact that soils are very different in their fertilizer requirements for the same crop, and that a given crop, for instance, may fail in one place for lack of nitrogen, while the failure in another case may result from an insufficient supply of phosphoric acid or potash.

"The use of these special fertilizers hinders progress. The system is in some respects similar to that of quack medicines. The farmer calls for a specific just as the ignorant or unwise patient calls for a quack medicine, and just as the intelligent physician, who studies the individual peculiarities and condition of the patient, can select and use medicine with better results than can be obtained with any so-called specific, so the intelligent farmer who will study the peculiarities and condition of his soils and the special needs of his crops can do better than the one who blindly uses some special fertilizer which is recommended to him." (Brooks).

(68) **High and Low-Grade Fertilizers.**—As the basic materials show great variation in the amounts of fertilizing ingredients they contain, it will readily be seen that products made by mixing these materials will contain very different percentages of nitrogen, phosphoric acid and potash. If dried blood, steamed bone meal and muriate of potash were used, for instance, the fertilizer would have a high content of the three essential elements, while if low grade tankage and wood ashes or kainite were employed, the product would have a much lower percentage of the three named substances. The use of a filler as well makes it possible to have an almost endless variety in the composition of fertilizers, and hundreds of different brands are offered in the market. It is customary to designate those having large amounts of plant food as "high-grade goods" and those low in plant food as "low grade." While no hard and fast line can be drawn between high and low-grade goods, it may be said that any complete fertilizer that contains less than two per cent of nitrogen should be considered low grade.

The terms "high grade" and "low grade" are used by some writers to distinguish the condition of the plant food in the fertilizer and not the amount. Leather meal, therefore, would be classed as low grade because the nitrogen in it is in an unavailable form, although the amount is relatively high. It may be stated as a general rule that the fertilizers containing the largest amounts of plant food usually have it in the most desirable condition while the materials containing the "toughest" forms of plant food are used to make the cheaper fertilizers.

(69) **The Expensiveness of Cheap Fertilizers.**—A large part of the commercial fertilizers used by the farmers at the present time is purchased in the form of cheap mixed or complete fertilizers. The low price per ton is attractive and, as a "fertilizer is a fertilizer" to many people, irrespective of its composition, this class of goods is sold more readily than those higher in price, although the plant food in the cheap fertilizers actually cost more per pound. This fact is very clearly set forth in a recent bulletin of the New York Experiment Station, from which the table following has been adapted. The analyses of all the fertilizers sold in the State have been compiled along with the retail prices and from these data the price per pound paid for nitrogen, phosphoric acid and potash in the different grades of goods has been calculated. The fertilizers have been divided into four

classes as follows: Low grade, having a commercial valuation of less than sixteen dollars per ton; medium grade from sixteen to twenty dollars; medium high grade, twenty to twenty-five dollars; high grade, over twenty-five. For the sake of comparison a few of the basic materials are included in the table:

AVERAGE COST OF ONE POUND OF PLANT FOOD TO CONSUMERS.

	Nitrogen cents	Phos. Acid cents	Potash cents
Low Grade Complete Fertilizers.	26.3	8.0	6.8
Med. Grade Complete Fertilizers.	23.2	7.0	6.0
Med. High Grade Com. Fertilizers.	21.0	6.4	5.4
High Grade Complete Fertilizers.	19.6	6.0	5.0
Dried Blood.......	18.5	....	....
Bone Meal........	14.9	3.96	....
Nitrate of Soda...	13.9	....	....
Acid Phosphate..	....	5.1	....
Sulphate Potash.	....	....	5.0
Muriate Potash ..	....	....	4.6

It will be seen that the price per pound of plant food is very much less in the high-grade goods than in the low grade. If the fertilizer is to be shipped any distance there is another point in favor of the high-grade goods, for it costs no more for freight on a ton of a high-priced fertilizer than on a ton of a low-priced one, while the former may contain twice as much plant food as the latter.

(70) **Home Mixed Fertilizers.**—The above table not only shows that plant food is cheaper in high-grade fertilizers than in low grade, but also that the essential elements can be purchased more cheaply in the basic materials than in any mixed fertilizer. This is due to the fact that the manufacturer must be paid for mixing, bagging, etc., and Voorhees has shown by careful investigations that the average charges of the manufacturer for this work amounts to $8.50 per ton.

In other words, the plant food in one ton of a mixed fertilizer can be purchased by the farmer for from six to ten dollars less in unmixed materials. This fact suggests the thought that it might be possible for the farmer to buy the basic materials and prepare his own mixed fertilizers. The matter of home mixtures has been carefully studied by a number of experiment stations and it has been shown conclusively that the materials can be evenly mixed on the farm, that the mechanical condition is good and that the results obtained from their use are entirely satisfactory. It would not be advisable to try to make the superphosphate on the farm, but the plain acid phosphate can be purchased to mix with the other materials. There are some obvious advantages other than cheapness in home mixing over the purchase of mixed fertilizers. The usual analysis of a mixed fertilizer gives no clew as to the condition or source of the nitrogen, and it is difficult to determine its availability, while in the home-made mixture the condition of the nitrogen should always be known. Home mixing permits the uniting of the different elements in the proportions which have been found to best meet the requirements of the crop and the soil on which it is to be raised, something that is not easily managed with factory mixed fertilizers. By buying the basic materials separately it is possible to apply the different elements at different times, a point that is sometimes of great advantage in feeding a crop, especially if it is one that needs large quantities of nitrogen. In fact the only advantage that can consistently be claimed for the mixed goods is that they are more generally distributed in the market than the basic materials, and can, therefore, be more easily purchased in such amounts and at such times as are convenient.

The following directions for home mixing are taken from a bulletin of the Rhode Island Experiment Station and are given after a careful investigation of the value of home mixtures:

"In fertilizer factories where the business is conducted on a large scale, machines are employed which are so constructed as to mix considerable quantities at a time, and do it rapidly. The conditions existing upon the majority of farms are such that an elaborate arrangement, even for mixing small quantities at a time, will not be brought into use, and a tight barn floor and square pointed shovel will be the only requisites at disposal. Under such circumstances after weighing out the quantities to be mixed they should be spread upon the floor in layers one upon the other. Then beginning at one side and working across, the whole should be shoveled over; this may be leveled somewhat and the operation repeated until the mixing is satisfactory. In addition to the shovel and the barn floor a large screen such as is used in screening gravel or coal ashes, may be employed with decided advantage; the material at the first mixing can be thrown upon the screen, and by this means lumps may be separated and more easily broken up and the thoroughness of the mixing will be increased. It may be desirable to employ the screen as an aid to the mixing even in the subsequent shoveling over, to which the material is subjected. Owing to possible losses of nitrogen and frequently to undesirable changes in the form of the phosphoric acid, it is usually not advisable to mix the material long before using."

(71). Fertilizer Laws and Guarantees.—It is impossible for the farmer to determine the kind and proportion of the different materials entering into the composition of a fertilizer by its appearance, weight, smell or any other physical examination. Formerly all commercial fertilizers were sold without any guarantee of their composition, and the injustice done to the purchaser under such a system has resulted in the passage of laws in most of the states in the Union which require the manufacturer or dealer to state the actual amounts of the different constituents contained in these products. The manufacturers are compelled to guarantee the per cent of nitrogen (or ammonia), available phosphoric acid and potash, that each brand contains and usually the composition must be stated on each bag or parcel of the fertilizer that is offered for sale. The enforcement of this law, and the chemical examination of the fertilizers to determine if they agree with the guarantee, are entrusted to the experiment stations in some states, while in others they are in the hands of the Board of Agriculture. The results of the analyses of the various brands are published in bulletins for free distribution and should be generally consulted by the farmers using fertilizers. One result of the fertilizer laws has been to greatly reduce the number of brands offered for sale, and the decrease has fallen in a great measure on the low-grade goods, as the worthlessness of a large number of such brands has been exposed by chemical analysis.

(72) Buying Commercial Fertilizers.—In buying fertilizers, as in the purchase of other commodities it is desirable to get the highest possible return for the money invested. It has been pointed out that more plant food can be obtained for the money in the unmixed basic materials than in any kind of mixed fertilizers, but in spite of this fact there are undoubtedly large numbers of persons who will continue to buy mixed goods for years to come. The attention of such persons is again called to data given in section (69). Whatever form of fertilizer is used it should be purchased only on the basis of its analysis as shown by the bulletin from the control laboratory, or, in case this is impossible, on the basis of the lowest amounts of nitrogen (or ammonia), phosphoric acid and potash which it is guaranteed to contain. In many states the bulletins referred to give, in addition to the analysis, the "calculated trade value" or "commercial valuation." This in most instances represents what would be the actual cost of the amount of the three valuable ingredients of the fertilizer if they were purchased for their average retail trade price. Where such a table is available the farmer will do well to consult it before making his purchase, and in general terms it may be said that he should never pay for a mixed fertilizer very much in excess of the price per ton given in the commercial valuation. In case such a table is not at hand, the commercial valuation can be determined by finding the number of pounds of each essential ingredient as shown by the guaranteed analysis, multiplying these by their trade values per pound previously given (see note under 41) and adding together the amounts so determined. It should be stated here that the fertilizer guarantees generally contain many more statements than are required by law, and some of these are apparently added to confuse the buyer. In studying a guarantee of a mixed fertilizer it should constantly be kept in mind that the only statements of interest to the purchaser are the per cents of nitrogen (or amomnia), available phosphoric acid and potash, and that all others should be ignored. The law requires these to be given, so they can always be found in the guarantee. Some states require the per cent of nitrogen to be stated, while others allow it to be given as ammonia, which is about four-fifths nitrogen. The potash is sometimes stated as "actual potash," but in any case the buyer must not allow himself to be confused by statements of equivalents of bone phosphate, sulphate of potash, etc., but must shut his eyes to everything except the lowest guaranteed per cent of the three essential ingredients. A simple method which will give very nearly the commercial valuation of a fertilizer is to multiply the per cent of nitrogen by three, add the product to the per cents of available phosphoric acid and potash and the result will be the commercial value of a ton of the fertilizer in dollars and cents.

Example: Supose a fertilizer is guaranteed to contain 2.4% of nitrogen, 10.5% of available phosphoric acid and 4.0% of potash. Multiplying 2.4 by 3 gives 7.2. To this add 10.5 and 4.0 and the result is 21.7, which means that the commercial valuation is $21.70 per ton. In case the analysis states ammonia instead of nitrogen, the ammonia should be multiplied by 2½ and added to the available phosphoric acid and potash. The valuation determined in this way should be compared with the selling price of the fertilizer and the difference should never exceed five dollars per ton. Taking the precaution to compare the commercial valuation and the selling price it is always wise to purchase high-grade fertilizers. Money can generally be saved by co-operative buying, for the price per ton is generally less in quantities and the freight charges are reduced.

(73) Trade .Values Not Agricultural Values.—The values for commercial fertilizers and manure which have been discussed are trade values and do not necessarily bear any relation to the agricultural value of these substances. Trade values are determined by the law of supply and demand, and many of the materials used in commercial fertilizers are required by other industries as well, so it is not the agricultural demand alone that sets the price. The agricultural value of a fertilizer is measured by the value of the increased crop produced by its use and is, therefore, a variable factor depending upon the availability of its constituents and the character of the crop to be raised. It is possible to have circumstances under which a fertilizer with a comparatively low commercial valuation may have a high agricultural value.

(74) Using Commercial Fertilizers.—From what has already been said it will be evident to the reader that the fertilizer to be used depends on the soil and on the crop to be raised. A complete study of the use of commercial fertilizers would call for separate treatment of each crop and its requirements, but such a discussion would demand much more space than is consistent with the original conception of this series of articles. This treatise was intended to deal with the principles underlying farm practice rather than with the practice itself, and for that reason only general principles will be taken up in this connection.

Commercial fertilizers have been on the market for a sufficient length of time to have been widely used, and as might have been surmised, there have been developed a number of different plans or sytems for their use which vary somewhat in the principles on which they are based, and which will be briefly discussed.

"The one which has perhaps received the most attention, doubtless largely because one of the first presented, and in a very attractive manner, is the system advocated by the celebrated French scientist, George Ville. This system, while not to be depended upon absolutely, suggests lines of practice which, under proper restrictions, may be of very great service. In brief, this method assumes that plants may be, so far as their fertilization is concerned, divided into three distinct groups. One group is specifically benefited by nitrogenous fertilization, the second by phosphatic, and the third by potassic. That is, in each class or group, one element more than any other rules or dominates the growth of that group, and hence each particular element should be applied in excess to the class of plants for which it is a dominant igredient. In this system it is asserted that nitrogen is the dominant ingredient for wheat, rye, oats, barley, meadow grass and beet crops. Phosphoric acid is the dominant fertilizer ingredient for turnips, Swedes, Indian corn (maize), sorghum and sugar cane; and potash is the dominant or ruling element for peas, beans, clover, vetches, flax and potatoes. It must not be understood that this system advocates only single elements, for the others are quite as important up to a certain point, beyond which they do not exercise a controlling influence in the manures for the crops of the three classes. This special or dominating element is used in greater proportion than the others, and if soils are in a high state of cultivation, or have been manured with natural products, as stable manure, they may be used singly to force a maximum growth of the crop. Thus, a specific fertilization is arranged for the various rotations, the crop receiving that which is the most useful. There is no doubt that there is a good scientific basis for this system, and that it will work well, particularly where there is a reasonable abundance of all the plant food constituents, and where the mechanical and physical qualities of soil are good, though its best use is in "intensive" systems of practice. It cannot be depended upon to give good results where the land is naturally poor, or run down, and where the physical character also needs improvement.

"Another system which has been urged, notably by German scientists, is based upon the fact that the mineral constituents, phosphoric acid and potash, form fixed compounds in the soil, and are, therefore, not likely to be leached out, provided the land is continuously cropped. They remain in the soil until used by growing plants, while the nitrogen, on the other hand, since it forms no fixed compounds and is perfectly soluble when in a form useful to plants, is liable to loss from leaching. Furthermore, the mineral elements are relatively cheap, while the nitrogen is relatively expensive, and the economical use of this expensive element, nitrogen, is dependent to a large degree upon the abundance of the mineral elements in the soil. It is, threfore, advocated that for all crops and for all soils that are in a good state of cultivation, a reasonable excess of phosphoric acid and potash shall be applied, sufficient to more than satisfy the maximum needs of any crop, and that the nitrogen be applied in active forms, as nitrate or ammonia, and in such quantities and at such times as will insure the minimum loss of the element and the maximum development of the plant. The supply of the mineral elements may be drawn from the cheaper materials, as ground bone, tankage, ground phosphates and iron phosphates, as their tendency is to improve in character; potash may come from the crude salts. Nitrogen should be applied as nitrate of soda, because in this form it is immediately useful, and thus may be applied in fractional amounts, and at such times as to best meet the needs of the plant at its different stages of growth, with a reasonable certainty of a maximum use by the plants. Thus no unknown conditions of availability are involved, and when the nitrogen is so applied, the danger of loss by leaching, which would exist if it were all applied at one time, is obviated." (Voorhees).

Still another system is based on the food requirements of the plant as shown by the analysis of the plant itself. The amount of plant food removed from each acre of ground is calculated from the analysis of the plant and a corresponding amount is returned to the soil. Different formulas are, therefore, recommended for each crop, and in these the nitrogen, phosphoric acid and potash are combined in the same proportions in which they are found in the plant. Experience shows that it is necessary to add amounts of these fertilizers to the soil that will supply more plant food than is removed by the crop if the maximum results are desired. This system may result in a large yield, but cannot be considered an economical method of feeding the plant, as one or more of the elements is likely to be applied in excess of the requirements of the crop. It does not take into consideration, for instance, the fact that a plant which contains a large amount of one element of plant food may possess unusually great power of procuring that element from the soil. The principle underlying this system, of course, is the idea that to maintain the fertility of the soil unimpaired an amount of plant food equivalent to that removed by the crop must be returned to the land. To this extent the system is similar to the use of barnyard manure, but is not so effective.

Another system used in ordinary or "extensive" farming is to apply all the fertilizer to the "money crop" in a rotation. This method is used especially where only one crop in a rotation is sold, the others being fed on the farm. A liberal supply of food is used to give the maximum yield which the climate and season will permit. The amount of food applied is in excess of the requirements of the crop and the residue is depended upon to help nourish the succeeding crops, or at least the one immediately succeeding the money crop. This system has some valuable features and is probably the one most in use in this country at the present time.

Too frequently fertilizers are used by what certain writers have called the "hit or miss" system. No special thought is given to the requirements of the crop or the composition of the fertilizer, but if the farmer feels that he can afford it and the agent is a glib talker, the sale is made. If the buyer happens to "hit" the food requirements of his crop a profit is secured and he is correspondingly happy, while if he makes a "miss" he feels assured that there is no value in commercial fertilizers.

All of these systems, with the exception of the last one mentioned, have their good features and have proven remunerative in the hands of many of their advocates. They all have, however, one weak point in common, i. e., they do not take into consideration the fact that different soils contain varying amounts and proportions of plant food and that while a certain soil may be lacking in potash, for instance, it may contain amounts of nitrogen and phosphoric acid sufficient for a maximum yield. Such a soil would obviously be benefited by an application of potash, while nitrogen and phosphoric acid would produce no effect. Experiments have shown that on ordinary soils it seldom happens that all three of the elements of fertility are required at one time. Unfortunately there is no easy way of determining accurately the fertilizer requirements of a soil for a particular crop. Van Slyke has formulated the following general rules which may be of value where no accurate data is at hand.

"It is impossible to give any fixed rules which will cover all cases and enable a farmer to tell without any experiment on his part what food constituents his soil lacks. In a general way, the crops themselves may give some valuable suggestions.

(a) As a rule, lack of nitrogen is indicated, when plants are pale-green, or when there is small growth of leaf or stalk, other conditions being favorable.

(b) A bright, deep-green color, with a vigorous growth of leaf or stalk, is, in case of most crops, a sign that nitrogen is not lacking, but does not necessarily indicate that more nitrogen could not be used to advantage.

(c) An excessive growth of leaf or stalk, accompanied by an imperfect bud, flower, and fruit development, indicates too much nitrogen for the potash and phosphoric acid present.

(d) When such crops as corn, cabbage, grass, potatoes, etc., have a luxuriant, healthful growth, an abundance of potash in the soil is indicated; also, when fleshy fruits of fine flavor and texture can be successfully grown.

(e) When a soil produces good, early maturing crops of grain, with plump and heavy kernels, phosphoric acid will not generally be found deficient in the soil.

"Such general indications may often be most helpful, and crops should be studied carefully with these facts in mind.

"In order to ascertain with greater certainty what food elements are lacking in the soil, the surest way is for each farmer to do some experimenting on his own soil and crops. Apply different kinds of fertilizing materials in different combinations, using for example, potash compounds alone in one place, phosphoric acid compounds in another, nitrogenous materials in another. Then different combinations can be made on other portions of the crop. Some portions of the field can be left without application of any kind. The results can then be studied in the yield of crop. It is generally found that the application of phosphoric acid gives excellent results on fields which have long been cropped with grain without keeping up the supply of plant food. In other places, it is found that best results are obtained with application of potash compounds. And many cases require a liberal supply of all three forms of plant food. In carrying on such field tests several difficulties may be met. The season may frequently be such as to interfere seriously with the favorable action of the fertilizing materials applied. Thus a serious drouth may counteract all other conditions and prevent a satisfactory yield. The difference of mechanical condition of the soil on the same farm or even in the same field may prevent a fair comparison of the action of different kinds of fertilizing materials and elements. But, notwithstanding such difficulties, valuable suggestions will be gained from an experimental study of one's soils through the behavior of the crops."

This method of determining the fertilizing material which must be added to the soil is, in the opinion of the writer, the only rational system and the only one that can be depended upon for consistent results.

(75) Commercial Fertilizers Not All-Sufficient.—Absolute dependence should not be placed on commercial fertilizers alone to maintain the fertility of the soil. Their continued application without the use of any other method of improving the soil will eventually result in serious injury to its physical condition. Commercial fertilizers add litlte or no humus to the soil, and to obtain the best results it is absolutely necessary to provide humus, either by plowing under green crops or by the use of barnyard manure. Numerous experiments have shown that commercial fertilizers give much better returns when used in connection with barnyard manure than if used alone, and they are coming to be used in this manner more and more as the subject is more thoroughly investigated.

It may be said here that commercial fertilizers are not merely "stimulants" as is frequently imagined, but that they actually supply plant food, and if rationally used will leave the soil more fertile than before their use instead of decreasing its fertility as would be likely to happen if a mere stimulant were used. Commercial fertilizers have an important place in the rural economy, but they should not be used to do the work that can be betetr accomplished by properly husbanding the home resources.

(76) Soil Amendments.—There are various substances that are beneficial to the land under some conditions although they add neither humus nor important quantities of plant food. Such substances have been called "soil amendments' and the benefit from their use arises from the fact that they produce certain changes in the soil which directly or indirectly promote plant growth. Some of them contain small amounts of plant food, but their value is chiefly due to their secondary effect on the soil and not that they add nitrogen, phosphoric acid or potash. LIME is probably the most important substance of this class and its use as a manure antedates the Christian era. Although lime has been employed as a fertilizer for so long a time it is only in recent years that its action has been explained, and at the present time there remain for investigation many questions concerning the action of lime on the soil.

In a few instances lime has a direct manurial value, for occasionally a soil is found which is so lacking in this substance that the crops are unable to obtain sufficient lime for a maximum yield. Such soils are rare, and in nearly every instance the good results from the use of lime are due to its indirect effect. The effects of lime may be considered to be of three kinds, i. e., mechanical, chemical and biological.

Lime has a very marked effect on the mechanical condition of the soil. When added to sandy soil it tends to make it more compact by partially cementing together the particles of sand and makes the soil capable of retaining larger quantities of water. When used on clay lands, on the other hand, lime makes the soil more mellow. A clay soil containing very little lime is made fine with greatest difficulty; it adheres to the implements used when wet, and cracks when allowed to dry. A soil rich in lime crumbles more easily, is readily brought into good tilth and does not adhere to any appreciable extent to the implements. The addition of lime to a soil containing much clay makes the soil more friable, and makes it possible for the rains to percolate more easily through the soil, and overcomes the danger of "puddling." The puddling of clay soils is due to the fact that the clay is composed of very small granules which fit so closely together that the water cannot pass between. When lime is added to the soil a number of these small particles become cemented together to form a much larger granule and as the granules increase in size the spaces between them also become larger.

Any one can easily satisfy himself in regard to this valuable effect of lime on stiff clay by taking a sample of such clay and working it thoroughly and then allowing it to dry, when it becomes as hard as a brick. If to another portion of the clay a little lime is added (say one-half of one per cent) and this is moistened, mixed thoroughly and allowed to dry, it will be found that a mere touch will cause it to crumble to pieces. There are other materials that have a somewhat similar effect on clay, but none are so efficient as lime. This granulated condition of clay soils, so easily accomplished by liming, is not easily destroyed, but will last for some years.

Lime is useful in making potential plant food available. Much of the potash of the soil, for instance, is locked up in insoluble compounds and is not available to the plant. Lime may decompose these compounds and thereby convert the potash into forms that the crop can use. Experiments have proven that when lime is applied to a soil originally poor in this constituent, the plants grown are not only richer in lime but also in potash. The use of lime then may for a time have a similar effect to that of potash containing manures, but it must be remembered that the lime does not supply potash, it merely makes that present in the soil available, and if the store of potash originally present is small it will probably need liberal potash manuring at an earlier date because of liming.

Caustic lime acts energetically on organic matter and its beneficial action on peaty or other soils containing large quantities of undecomposed vegetable matter may be partly due to this fact.

Recent investigations have shown that many soils fail to produce good crops because they are acid or "sour." Formerly it was supposed that only low lying or marshy land ever became sour, but experiments conducted by the American experiment stations have demonstrated that there are large areas of uplands which an acid condition of the soil exists. Acidity of the soil is injurious to nearly all of the cultivated crops, so that good returns cannot be expected from sour lands. Where such a condition exists the liberal use of lime is the proper remedy. Acidity may result from a number of causes such as the presence of stagnant water, turning under of large quantities of organic matter, constant use of commercial fertilizers, etc., but whatever the cause, lime is the practical neutralizer. An acid conditon of the soil can sometimes be foretold by observation of the character of the plant growth thereon. Where such plants as the common sorrel, beard grass, rushes and mosses grow to the exclusion of the more desirable plants it is a pretty sure indication that the soil is acid, for the plants named are not injured by acidity while the others are.

Probably the best method of testing the soil for acidity is what is known as the litmus paper test. The test is applied as follows: a little of the surface soil is scratched aside and the piece of litmus paper pressed onto the moist soil beneath. If the paper turns a reddish color it shows that the soil is sour. To obtain good results only the best "neutral" litmus paper should be used. The statements so often seen in the agricultural press about making this test are frequently misleading, for most of the litmus paper on sale in the retail stores is worthless for this purpose, and those who contemplate making the test should be sure to obtain a good sample of neutral litmus paper. An amount of acid that would entirely prevent the growth of clover, for instance, might not change the color of the common litmus paper at all. The clovers and other legumes seem to be especially sensitive to acid, and in many cases the failure of clover has been shown to be due to the acidity of the soil. In such cases the application of lime resulted in a good crop of clover.

Lime is valuable because it promotes the growth of the desirable bacteria in the soil. It has been shown that one of the most important changes in the soil due to bacterial action is the process of nitrification (14). The nitrifying bacteria cannot thrive in a soil that is deficient in lime. These bacteria are injured by acidity, so it is necessary to keep the soil "sweet' to promote their action. On the other hand, the injurious process of denitrification (15) takes place more readily in sour soils, so that lime in promoting the desirable process overcomes the undesirable.

The bacteria which grow in the nodules found on the roots of the legumes and which "fix" the nitrogen of the air will not perform their functions in an acid soil, therefore lime in keeping the soil sweet promotes the gathering of nitrogen by the leguminous plants. In general it may be said that all the desirable fermentations in the soil are accelerated by the presence of lime.

It is generally recommended that freshly slaked "burnt" lime be used on heavy clay lands, while air-slaked or "mild" (carbonate of lime) or marl be applied on sandy soils. As the lime is gradually carried downward in the soil it should always be applied to the surface, and, if possible, thoroughly incorporated with the upper few inches of the soil. From one-half to one and one-half tons per acre applied once in five or six years is usually sufficient. As in the case of commercial fertilizers the best way to determine if lime is necessary is by the plot test, using some crop which is especially benefited by lime. It has been said that "lime makes the father rich and the son poor," and this is undoubtedly true if lime is used alone. Lime adds no plant food to the soil, but simply brings about conditions that enable the crop to use large quantities of the store of food already present in the soil, so that if used alone it only makes the exhaustion of the soil take place more rapidly. It has, however, a legitimate place in agriculture, and if used in connection with green crops, barnyard manure and commercial fertilizers will produce only beneficial results. Large quantities of lime should not be applied immediately before a crop of potatoes, as it has a tendency to cause the production of scabby tubers.

MARL is mild lime (carbonate of lime) in the form of a fine powder, and is found in some parts of the country in large deposits. It has the same effect on the soil that air-slaked lime has and is a very convenient form in which to apply to sandy soils. Some of the European marls contain appreciable quantities of potash and phosphoric acid as well, but the American marls are of value only for the lime they contain.

GYPSUM or land plaster is a compound of lime with sulphuric acid (sulphate of lime) and has been used for many years as a fertilizer. For a long time the action of land plaster was little understood, but it is now generally believed that its beneficial action is due to the fact that the plaster sets free the unavailable potash of the soil, and for this purpose it is more useful than lime. It is of value to those crops that are benefited by the use of potash manures and, as will be surmised, plaster gives good results only on soils containing large amounts of potential potash. For this reason it gives best returns when used on clay soils and practically no beneficial results when used on sandy soils. The best method of using it is probably to add it to manrue as has been suggested (51). When gypsum has been used continually it has been found that after a time it fails to produce satisfactory results. In the latter case it is probable that the crop would be benefited by an application of some potash manure.

SALT was among the first substances to be used as a manure, but in spite of the antiquity of its use the value of salt as a fertilizer is still in dispute. It is certain that injury has resulted from the application of salt quite as often as benefit, and in fact it may be said that there are no experiments of any note which indicate that salt has any beneficial effect on plant growth. Large quantities of salt are poisonous to plants, as everyone knows, due undoubtedly to the chlorine that he salt contains. It was formerly supposed that such plants as asparagus were benefited by the application of salt, but investigations have not shown any increase in yield from its use. It is well known that salt checks fermentations of all kinds, so that it probably decreases the rate of nitrification which is seldom desirable. It is said that adding salt to the soil will make the straw of wheat stiffer, but this effect is very likely due to the fact that the salt on acount of its poisonous action makes the straw shorter and the greater stiffness is due to reduced length. Many so-called "agricultural salts" are on the market, but they certainly do not possess any virtues not found in common salt, and it is doubtful if there is any manurial value in salt of any kind.