FARM MANURES

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ILLUSTRATED

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PREFACE

Thirty years ago Orange Judd Company published a little book, written by Joseph Harris, entitled "Talks on Manures," a book which was the most thoroughly practical discussion of the problems relating to the maintenance of soil fertility which had appeared up to that date. Written in a most entertaining style, and from the standpoint of the practical farmer, it has been of incalculable benefit to the agriculture of our country. The book is still abundantly worth reading, and ought to be in the library of every English-speaking farmer.

At the time when this book was written there was, in all the world, just one institution in which the soil had been studied by the method of systematic field experiment for a sufficient length of time to afford data of any scientific value, and Mr. Harris made extensive use of these data—the Rothamsted experiments—in the preparation of his book. It is true that the experiment station at Moeckern had been established at about the same time as the one at Rothamsted; but the German investigations had been directed almost altogether along the line of laboratory research.

The materials, therefore, for "Talks on Manures" were necessarily derived from the experience of practical farmers, and while such experience is not to be despised, but, on the contrary, must be welcomed as an indispensable check upon the deductions from scientific investigation, yet it lacks the accuracy which can only result from long-continued work under a systematic method in which the scales and measuring rod are in constant use.

Since the publication of Mr. Harris's book, agricultural experiment stations have been established in practically every civilized country in the world, and these institutions are now accumulating a body of knowledge which, while still falling far short of completeness, is yet affording a much clearer conception of the nature of the problems under consideration than was possible to the most advanced students of agriculture a generation ago, and it would seem to be time that some of the results of this work should be arranged in a more convenient form for ready reference than is afforded by the various bulletins and other publications in which they have been published, and this is the reason for the publication of this book.

In the preparation of this volume no attempt has been made to treat the subject exhaustively. A few paragraphs have been introduced on the origin and nature of the soil, which seem to be essential to a clear understanding of the effects produced by manure; but it is hoped that these will serve to whet the appetite for a more thorough treatment of the subject, as given by King, Hilgard, Hopkins, Hall, Van Slyke and Merrill.

It has been necessary to quote some experiments with commercial fertilizers, in order to arrive at a standard of value for manure, but the comprehensive treatment of this phase of the subject has been left to others.

Even in the branch of the general subject of fertility maintenance which is treated in the following pages—the production and management of farm manures—no attempt has been made to include all the data available. It has seemed better to limit the discussion for the present to such points as have been most definitely established by long-continued investigation.

The book is offered with a deep consciousness of its many defects, both in arrangement and treatment, but it is hoped that it may add a little to the definiteness of our knowledge; that it may encourage a larger production and aid in a wiser treatment and use of farm manures by the practical farmer, and that it may serve as a stimulus to more extended and more exact research by the scientific investigator.

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CHAPTER I

THE SOIL

The Origin of the Soil

The earth a cooling globe—Some astronomers believe that the solid earth of today was at one time a red-hot, molten mass; that the water which now fills oceans, lakes and rivers existed then only in the elemental gases surrounding this fiery ball; that the surface of the globe slowly cooled until a thin crust of solid rock was formed; that with further cooling the hydrogen of the enveloping gases combined with oxygen to form the vapor of water; that in time the cooling had progressed sufficiently for this vapor to condense into a shallow, boiling sea, covering the entire surface of the globe; that the steam from this hot sea rested upon it in a pall so dense as to shut out the light of the sun, and "darkness was upon the face of the deep."

As the crust of the earth cooled, the mist became less dense; in time the light of the sun penetrated sufficiently to establish the difference between day and night; then the land began to rise from the sea; the "firmament" appeared "in the midst of the waters, and divided the waters which were under the firmament from the waters which were above the firmament."

With the gradual cooling of the crust of the earth and its consequent contraction, it began to wrinkle, as the skin of an apple does in drying; the waters were gathered together into seas, and the dry land arose between them in low-lying continents, raised but slightly above the surrounding, shallow seas; these continents later were traversed by great mountain chains as the crust was forced upward by the increasing internal contraction.

The sides of these primeval mountains were almost constantly drenched with torrential rains, falling from the saturated atmosphere, slowly scouring away the surface of the rock and carrying the detritus to lower levels. Lichens began to grow upon the rocks, each plant loosening a few grains of the rocky material. In time frost came to the assistance of rain and plant roots, and thus by forces whose work was almost imperceptible, but which had eons of time for its performance, the surface of the uplifted mountains was slowly ground to powder.

Other agencies also assisted in the work of soil formation. The waters of the primeval seas were charged, as they are now, with lime and other mineral substances dissolved from the rocks, and in these waters corals and other lime-using forms of aquatic life began their work of rock building. Great beds of limestone accumulated on the bottom of shallow seas, formed by the growth and death of countless myriads of shell-bearing organisms. With the continued crumpling of the earth's crust, these limestones were sometimes brought to the surface and even thrown up into mountains, to be subjected to disintegrating agencies by which their surfaces were reduced to powder, which was here left in level beds on table lands or plateaus, and then carried down and rearranged in admixture with the detritus from noncalcareous rocks, giving rise to deposits of all gradations, from those rich in lime to those in which this substance is found in very small proportion.

The solvent action of water containing traces of carbonic acid, as do all waters exposed to the air and soil, has been a potent factor in the dissolution of the rocks, of limestones especially, and the redisposition of their particles in other forms. The growth of the higher plants, whose roots also exert a solvent action, as may be seen by tracing the marks of such roots upon the face of the rocks; the action of earthworms and other earth-burrowing forms of animal life, in bringing to the surface materials from lower depths, and in actually grinding and pulverizing these materials—these have all contributed to the slow pulverization of the rocky earth crust and its conversion into the basis of arable soil.

Moving ice has also played an important part in this work. We have evidence that at one time a large part of the North Temperate zone was covered with a sheet of ice, hundreds and even thousands of feet in thickness which, under the ever accumulat-

Transition from rock to arable soil. At the surface a thin layer of soil has been formed. Below this the rock is being gradually disintegrated, the tree roots hastening the work.

ing weight of arctic snows, moved slowly southward to meet the sun, by which its southern extremity was melted away, forming great, southward flowing rivers; or, where it terminated in the open seas, breaking off into icebergs, just as the Alaska glaciers and the sheet of ice which covers Greenland in places to the depth of 2,000 feet, are doing today.

This southward moving ice carried with it masses of rock material, broken from the mountain sides along which it passed, or plowed up before it in its irresistible course. These materials were deposited at its southern extremity, sometimes forming large ridges or "moraines" of sand and gravel where the glacier's foot had remained for some time, these being spread out in sheets of greater or less thickness as the increasing heat of the sun drove it back to the north.

Glacial action has been a most important factor in the formation of the soils of the northern part of the United States. By it mountains have been cut down and valleys have been filled, the glacial drift sometimes reaching a thickness of hundreds of feet, and the soil materials have been worked over and rearranged by the floods springing from the glacier's foot, so that glacial soils are generally among the richest in their supply of the mineral elements of plant nutrition, although the physical condition of these soils is often such as to call for the exercise of the highest skill of the farmer in drainage, cultivation and crop rotation, in order to realize their full capacity in crop production.

The mineral basis of the soil has been formed through such agencies as those suggested above. It consists merely of pulverized rock. And that such agencies are sufficient to produce the effect observed cannot be doubted by one who carefully studies their workings, bearing in mind that they have certainly been at work for tens of thousands, probably hundreds of thousands, or even millions, of years. But this mineral basis, of itself, does not constitute a soil; that term implies a mixture of such a basis with a larger or smaller proportion of decomposed organic matter.

We may grind together a feldspar containing potash; a dolomite containing lime and magnesia; an apatite containing phosphates, and so on until we have a combination including all the mineral elements which are formed in the plant; we may add to these powdered leather, rich in nitrogen; we may dilute the mixture with pulverized quartz until we have a proportion of these elements to each other and to the entire mass similar to that which we find in the most fertile soils, and we may add distilled water until we have brought our artificial soil into the most perfect moisture condition for plant growth; but when we attempt to grow plants in this soil they will lead but a stunted and miserable existence.

We are familiar with the fact that the herbivorous animals are able to thrive upon food materials upon which the carnivorous organism would starve, and to convert these materials into the most nourishing food for the carnivores; but we are only just now learning that, just as the herbivores stand between the carnivores and the plant, and the plant stands between animal life and the soil, so a fourth class of organisms is employed within the soil in working over the minerals there and preparing them for the use of higher vegetation, and that the mediation of these organisms, between the plants we cultivate and the minerals, is as essential as that of the animal which converts these plants into its tissues is to the flesh eater.

The beginning of life occurred as soon as the temperature of the primeval seas was reduced to such a point as to permit its existence. Before the pall of cloud had lifted, the sands of the seashores, no doubt, became inhabited with single-celled, colorless plants, such as the bacteria which are now revealed to us by the microscope as existing in the soil below where light penetrates, and which feed directly upon the soil minerals and the free nitrogen of the air which circulates in the upper layers of the soil, combining these elements in their tissues and leaving them in this combined form as the first step towards their final destiny as human food.

Millenniums passed before the sun's light began to penetrate the cloud, during which the ever-falling rain washed from the slowly rising shores much of the material combined by these organisms, carrying it into the sea to become there the nutrient substance for the hosts of living things, from the minutest single cell to the leviathan, with which the sea began to be inhabited; but a part of each minute addition to the stock of elementary combination became fixed in the film of moisture surrounding each particle of sand, so that, while the addition to the stock of potential plant food in the land was but a very minute fraction of that carried into the sea, yet there was a steady increase, especially in those portions which had risen above the washing of the waves.

Green plants made their appearance with the first dawning of light; probably such plants as the lower forms of algæ which we find today growing in moist and shaded places, and which also, then as now, were able to feed directly upon the original minerals of the soil and upon atmospheric nitrogen.

With increasing light came the higher forms of plant life, first feeding upon the soil food prepared for them by the bacteria and algæ, but after their span of life was ended returning their substance to the soil and by their slow decomposition gradually reducing the proportion carried to the sea.

Year after year, century after century, eon after eon, this work went on, each advancing age leaving a little larger the accumulation of organic remains in the soil.

Worms have also contributed materially to soil formation. The cast of a single earthworm, as thrown up between a pair of paving bricks, seems a very insignificant thing; but when such casts are multiplied by millions, they are no longer insignificant, but become a potent factor among the agencies concerned in soil building. For these casts are the product of a commingling of mineral particles with vegetable matter; these mineral particles are ground to a much finer condition in the digestive organs of the worms, and are thoroughly mixed with vegetable matter and digestive fluids.

The countless myriads of insects which have their short existence on or in the soil and in the vegetation above it have also contributed materially to the condition which makes the soil a feeding place for the plants we cultivate, through their decay upon it. And the same is true of other forms of animal life which, after their period of existence is over, return their tissues to the elements from which they came—earth to earth and air to air.*

Humus—A heap of bright, yellow straw is built in the barnyard; the farm animals are given access to it and consume a part of it, trampling the remainder under foot; gradually the heap disappears, and there is left in its stead a comparatively very small quantity of dark material, brown at the surface and still showing the structure of the straw, but black and formless at the bottom. Had the straw been spread upon the land and plowed under, the same transition into a structureless, black substance would have taken place.

If, now, we separate this black substance, as may be done by chemical processes, and subject it to analysis, we shall find it containing the mineral substances of the original straw, such as may not have

* See Darwin's "The Formation of Vegetable Mould."

been washed out by rain, together with a considerable but variable percentage of nitrogen, which has become fixed in a comparatively stable form.

This black substance is humus. It is the product of the decay of organic matter—vegetable and animal—but it is not correct to apply the term humus to such matter during the process of decay. The humus of the soil is its storehouse of available plant food, both mineral and nitrogenous; plant food that has been wrested from the rocks and the atmosphere by infinitesimal agencies working through eons of time, and stored for the use of humanity; plant food which we may so utilize as to return it to the soil undiminished or even increased in quantity, or which we may so waste as to leave to those who follow us a sadly diminished heritage.

The skeleton of the soil consists of grains of sand or minute fragments of the rocks from which the soil has been derived. (The larger fragments, or gravel, are not, properly speaking, parts of the soil.) This mineral skeleton may consist of particles so coarse as to be easily discernible, or of atoms of silt or clay so minute that they can only be separately distinguished by the aid of the microscope; but in either case it is upon these separate particles that the forces impinge which control the growth of vegetation. Practically all soils contain particles of different degrees of fineness, the space between the larger ones being occupied by smaller ones of silt and clay and by fragments of decaying vegetation. Whether the soil be classed as sandy, loamy or clayey depends upon the relative proportion and character of the coarser and finer particles.

Whatever the size of the particles, it is upon their surfaces only that the various forces act which prepare the food for the plant—the soil water, in which that food is dissolved; the air which furnishes oxygen for the conversion of the insoluble mineral matter into soluble oxides; and the soil organisms, whose growth transforms the inert soil nitrogen into active nitrates, and the mineral elements into available forms.

The size of the soil particles is an important factor in determining the rate at which the plant food is made available. F. H. King has shown that the surface area is in inverse proportion to the size of the particles. For example, a marble, 1 inch in diameter, would have a superficial area of 3.1416 inches, and a cubic foot of such marbles would have a total area of 37.7 square feet, while a cubic foot of soil grains .001 inch in diameter, would have an area of 37,700 square feet, or nearly an acre. Hence, a fine-grained soil exposes a very much larger surface to solvent action than a coarse-grained one, so long as the size and condition of the particles are such that they move freely upon each other and allow water to penetrate their interstices, as sands and silts. In clays, however, the soil particles are so fine that the water cannot circulate freely; hence a clay may be rich in the mineral elements of fertility. and yet its physical condition may be such that its plant food will be yielded up to the growing crop with extreme slowness; while a sandy soil, though showing under analysis smaller quantities of the elements essential to crop production, may yet give larger yields.

When, however, the texture of the clay is altered, by manuring or by the turning under of vegetation, it often becomes more productive than the naturally looser soils.

On the other hand, in a coarse, sandy soil the particles are separated by such large interstices as to permit too easy a passage for the rain water, and it passes below the reach of the plant roots before it becomes sufficiently saturated with the mineral elements required for plant nutrition.

For both classes of soils the remedy is the same, the incorporation of vegetable matter. Such matter loosens the clays by separating their particles, and makes the sands more compact by filling their interstices with finer material, while its decay not only furnishes plant food directly, but also serves indirectly to bring the soil and atmospheric elements into combinations available for plant sustenance.

The cycle of life—A dead animal, lying exposed in summer weather, is soon attacked by flies, whose maggots devour the carcass, converting the carbon, oxygen and nitrogen of its dead tissues into their own living substance. A dead plant, covered with a few inches of soil, is attacked by millions of microscopic plants (bacteria), which consume its tissues, recombining the carbon, oxygen and nitrogen of those tissues into the protoplasm which fills their cells.

The maggots are transformed into flies and these, if not devoured by other animals, live out their cycle of existence and then are consumed by molds and these in turn by bacteria. Bacteria also may be consumed by other organisms (amœbæ), as has quite recently been shown at the Rothamsted experiment station, or they may reach their natural life limit—a matter of a few hours, probably—when their cells will be decomposed with the formation of oxides of nitrogen and carbon (nitric and carbonic acids), the nitric acid to be absorbed by the soil water and carried to the roots of growing vegetation, if there be such vegetation in the vicinity, otherwise to be carried into the drainage or separated into its elements; the carbon dioxide to escape into the free air, there to be captured again by the foliage of green-leaved plants.

In some such way as this the never-ending cycle of life moves on; the aztobacter seizing upon the surfaces of the soil particles and combining their phosphorus, potassium and calcium with atmospheric nitrogen; this combination to be passed on to the higher plants, which add to it the carbon dioxide of the air; these plants to be consumed by the herbivores and their tissues to be converted into bone and nerve and milk and muscle; the herbivores to serve as the food of the carnivores, and these in turn to feed the worm, and the worm the bacteria, the cycle thus returning to the plane from which it started.

Geological Classification of Soils

The geologist classifies soils in four principal groups, according to their origin, namely: Sedentary or residual soils, or those which have been formed where they now lie by the decomposition of the underlying rock; alluvial soils, or those which have been transported by rivers and deposited upon their flood plains—soils to which the farmer applies the name "bottom lands"; glacial or drift soils, or those which owe their origin to the action of moving ice, by which agency a part or all of their material has been transported for long distances and deposited at the foot of continental glaciers; and æolian or loess soils, which have been formed from dust blown by the wind.

Residual soils vary greatly in quality, owing to the character of the rocks from which they have been derived. Thus the soil of the famous "Blue Grass" region of Kentucky is due to the weathering of the underlying limestone, while in other places sandstones, shales and granites have given origin to soils of very different character. In fact, it is a matter of general observation that soils formed wholly or in part from limestone are, as a rule, much more productive and more durable than those derived from noncalcareous rocks, although it sometimes happens that a limestone soil has been so improvidently managed that its natural superiority has vanished.

Alluvial soils—The superior fertility of alluvial or bottom lands has been recognized since man began to till the soil, and the cause of this superiority is easily understood by one who observes the turbid streams which course down every hillside in times of freshet, carrying down the wealth of the highlands and spreading it over the flood plains of the rivers. It is no unusual thing to see such deposits reach a thickness varying from a quarter to half an inch, after an ordinary spring flood of today, and our floods are evidently much smaller than those of former days, as shown by the greater width of the earlier flood plains, which include the second and third bottoms, so called, or the river terraces. Only a tenth of an inch annually would mean ten inches in a century or a hundred inches in a thousand years, but in geologic time "A thousand years are but as yesterday when it is past, and as a watch in the night."

Drift soils are variable in character, consisting sometimes of the weathered surfaces of beds of gravel containing a great deal of limestone, forming soils naturally underdrained and rivaling the best limestone soils in productiveness, while sometimes they are found lying on heavy sheets of bowlder clay, rich in the mineral elements which enter into the food of the plant, but requiring drainage and aeration to bring this potential food into an available condition. Sometimes the drift is so modified by the rock upon which it lies as to possess the chief characteristics of a residual soil.

Loess soils have been formed under climatic conditions approaching aridity. It may seem a mystery to the farmer in humid climates that soils even a hundred feet in thickness should have been formed from fine particles of dust, blown by the wind, but the mystery will disappear after he has spent a dry summer on the treeless plains of the semi-arid regions, and watched the clouds of black dust which follow the plowman, filling eyes, nose, ears and mouth, and covering face and hands with such a coating as only coal heavers carry in the humid climates.

A considerable part of the deep, black soils of the rolling prairie region between the Mississippi and the mountains is of this character. Loess is not always black, but is sometimes of much lighter colors, containing a larger proportion of clay; as, for example, the bluffs of the lower Mississippi. The loess soils are very fine grained, and are usually well stored with the elements of fertility.

Sand dunes are another example of æolian soils, but they are much coarser grained, and contain comparatively little matter of vegetable origin. They are as conspicuous for their poverty as the loess soils are for fertility.

Agricultural Classification of Soils

From the earliest ages farmers have based their classification of soils upon the fineness of the particles into which the mineral constituents may be divided, the relative proportion between the mineral and organic constituents, and the degree of decomposition which these latter have undergone. Thus we have sandy soils, in which the mineral particles are relatively large, and clays, in which they are impalpably small, with an intermediate class called silts. When a considerable proportion of organic matter is found in the soil, we call it a loam, and we use the terms "sandy loam," "silty loam" and "clay loam" to indicate the condition of the predominant mineral constituents. The organic matter may constitute so large a proportion of the soil as to change its color to black, giving us black sands, silts and sometimes clays; a still greater proportion of organic matter produces muck soils, and these pass into peats, which are composed so largely of partly decayed vegetation that they burn readily when dried, and may be used for fuel.

The Inhabitants of the Soil

The modern science of bacteriology has demonstrated that the soil is inhabited by numerous species of micro-organisms, which play a very important part in the conversion of its stores of plant food into available form, and in the fixation of atmospheric nitrogen. These organisms are single-celled plants, extremely minute in size, colorless when they live below the surface, or green in the case of some low forms of algæ found at the surface of the soil.

The first forms of life—Such organisms, growing in the sandy beaches of the primeval seas, were probably the first forms of life upon the earth. In these sands they would find the mineral elements essential to their growth, and they would necessarily have the power, possessed by similar organisms to-day, of fixing the free nitrogen of the air circulating between the particles of sand. In the slow grinding of the rocks into sand and silt they are constantly washed by waves or rain, so that their soluble portions are extracted and removed. A beach sand or freshly ground rock makes but a barren soil, and the washing of the rock powder increases its barrenness; hence the play of other than physical and chemical forces is required before the barren rock is converted into productive soil. The first of these forces is undoubtedly bacterial growth, which serves as the forerunner to the growth of higher organisms. Not only is it probable that certain bacteria are able to assimilate mineral as well as nitrogenous matters which the higher plants cannot appropriate, but their minute size enables them to penetrate interstices between soil particles which are closed to the roots of higher plants. For example, it has been shown that the particles of clay are not larger than one five-thousandth of an inch in diameter; but some of the soil bacteria are not more than one-sixth as large as these clay particles, and hence are indefinitely smaller than the smallest plant roots.

Nitrification—Another function performed by soil bacteria is the breaking down of dead vegetable matter in the soil and the conversion of its nitrogen into nitric acid. This work has been shown to be due to the action of organisms which grow upon such matter, appropriating its carbon and causing the combination of its nitrogen with oxygen, forming nitric acid.

For centuries saltpeter, which is nitrate of potash, was made by mixing loam with manure and ashes, allowing the material to lie in heaps for two or three years, shoveling it over occasionally and watering with liquid from the barnyard, but protecting it from excess of rain, and finally leaching it out and evaporating the lye.

In 1862 Pasteur suggested that the combination of nitrogen with oxygen and potassium which takes place in the formation of saltpeter is due to the action of bacteria, and in 1877 Schloesing and Muntz confirmed this view, their work being supported by later investigations by Winogradsky, Warington and others.

These investigations have shown that nitrification takes place only in summer weather, that it may be suspended by heating the material to 212 degrees Fahr., or by treating it with powerful antiseptics, and that in material which has been sterilized by these methods nitrification may again be set up by inoculating with fresh material, thus proving that the agent of nitrification is a living germ.

Conditions essential to nitrification—In order that nitrification may take place there must be organic matter in the soil—that is, material carrying nitrogen; there must be summer temperature; there must be a moderate degree of moisture, but excessive moisture is as unfavorable to the work of these organisms as it is to that of some higher plants; finally, there must be lime or some other similar alkaline base, with which the freshly formed nitric acid may combine, forming a neutral salt; otherwise the increasing amount of nitric acid will in time have a toxic action upon the organisms forming it and thus stop their work.

The corn crop makes its growth in midsummer just when the conditions are most favorable for nitrification. It thrives best in soils heavily charged with organic matter, and the cultural methods employed with this crop are such as are calculated to stimulate this process. This explains the fact that a crop of corn will extract from the soil twice as much nitrogen as an equivalent crop of wheat.

The products of nitrification are known as nitrates. In the old niter bed the chief product was nitrate of potash; in ordinary soils it is nitrate of lime, although nitrates of other alkalies, such as potash and soda, are no doubt formed to a limited extent. These nitrates are soluble salts, and in humid countries if they are not utilized by growing plants they will be washed out of the soil by the rains of the fall and spring. For this reason there is a great waste of fertility from bare corn-stubble land, for the corn is killed by the first frosts, at a time when nitrification is still active.

When winter wheat follows corn this waste is prevented, the wheat utilizing the nitrates which have accumulated after the corn has ceased growing. The same object may be accomplished by sowing rye in the corn at the last working, the rye to be turned under in the spring. A leguminous crop would be more desirable for this purpose, as it would not only utilize the ready-formed nitrates in the soil, but would add more nitrogen, as will be shown farther on; the practical difficulty, however, is to find a frost-resisting legume having seeds sufficiently large to resist the drouths which frequently occur during the months of August and September. The hairy vetch is one of the most promising plants for this purpose, and may be sown with rye.

Symbiosis—A third class of soil-improving bacteria is that which forms the nodules found on the roots of the clovers, beans, peas and other plants of the order Leguminosæ. From the earliest history of agriculture the observation has been recorded that the growing of clover leaves the soil in better condition for subsequent crops.

When the physiology of plants and the chemistry of their nutrition began to be understood it was assumed that these plants were able to absorb and assimilate the free nitrogen of the atmosphere through their foliage, just as all plants utilize the carbonic acid of the air in the building of their carbonaceous tissues.

This theory, however, was completely overthrown by a series of epoch-marking experiments made by

Lawes, Gilbert and Pugh at the Rothamsted experiment station, from 1857 to 1860, by which it was shown that, when the atmosphere was made the only possible source of nitrogen to growing clover plants, their growth was limited to the amount of nitrogen carried in the soil.

This work was taken up about 25 years later by Hellriegel and Wilfarth, who found that leguminous plants grown in a soil devoid of nitrogen would make a normal growth when watered with leachings from an old loam, but when this normal growth occurred the roots were found to be the homes of bacteria.*

At least three general classes of soil organisms, therefore, are concerned in the accumulation and preparation of nitrogenous material for the sustenance of the higher plants. These are (1) the organisms which exist independently in the soil, obtaining their mineral food directly from the surface of the soil particles, and their carbon and nitrogen from the air circulating between these particles; (2) the nitrifying organisms which live upon the dead organic matter in the soil, appropriating its carbon, nitrogen and oxygen; and (3) the organisms which inhabit the nodules of the legumes, obtaining their mineral and carbonaceous food from the juices of their host plants and their nitrogen from the air.

* For history of the experiments by which the agency of bacteria in enabling clover to assimilate free nitrogen was discovered, see Experiment Station Record, vol. II, p. 686. For that of the discovery that nitrification is due to the action of bacteria, see Bul. No. 8 of the Office of Experiment Stations, U. S. Department of Agriculture; and for investigations on the direct assimilation of free nitrogen by soil bacteria, see Bul. No. 66 of the Delaware Experiment Station.

The microbes of the nodules are, therefore, parasitic in their first attack, and the plant suffers; but in a short time a secondary form makes its appearance within the nodules, much larger in size than the bacteria, and apparently due to accumulation of nitrogenous material resulting from the death of the bacteria, and which serves to supply the host plant with nitrogen.

We have as yet no very definite knowledge as to the amount of nitrogen which may be added to the soil by either the first or third of these classes of organisms—the second class adds none, merely working over the supply already in the soil—but the very great increase of crop produced by nitrogenous fertilizers in the long-continued experiments at Rothamsted indicates that the addition of nitrogen by the first class is quite small; while in the experiments of the Ohio experiment station the growth of a heavy crop of clover apparently furnishes little more than enough nitrogen to satisfy the demands of the one crop immediately following the clover.

CHAPTER II

The Composition of the Plant

The living plant is chiefly water—When freshly cut grass is allowed to lie for a few hours in the sunshine of a summer day it loses from two-thirds to three-fourths of its original weight. This loss consists simply of water, which is vaporized by the heat and dissipated into the atmosphere. The water thus lost is, in fact, the liquid in which are dissolved the nutrient materials required for the growth of the plant, and which are carried upward through its tissues and left behind as the water itself passes out into the atmosphere. For the water does not leave the cut grass any more rapidly that it has been leaving the standing grass; and the cutting of the grass has merely cut off the supply of water from below, which has heretofore kept the tissues turgid. An acre of growing grass or similar crop is therefore sending into the atmosphere in summer weather several tons of water daily. It is estimated that on the average 300 pounds or more of water passes up through the plant for every pound of dry matter added to its substance.

The dry substance—If, now, the air-dry hay thus made be placed in a ventilated oven, heated to the temperature of boiling water, and kept at that temperature for a few hours, it will be found to have suffered an additional loss, amounting to from 10 to 15 per cent of its air-dry weight. This loss also consists of water—hygroscopic water. Since the atmosphere itself always contains more or less moisture, it is easily understood that no substance exposed to the air can be absolutely dry. When we compare the absolutely dry plant with the green one, we find that from 75 per cent to more than 90 per cent of the original green weight has disappeared. The residue left is chemically known as dry matter or dry substance.

Carbon—If this dry substance be subjected to a red heat for some time, in a vessel so arranged that the gases of combustion may escape but that no air can enter, it will be found to have been converted into charcoal, a substance which may retain the form and structure of the original material, but which has less than one-third of its dry weight, and which consists of the element carbon, together with the mineral elements found in the plant.

Ash—Finally, if this charcoal be heated at red heat with free access of air, it also will disappear, leaving only a small residue of ash, amounting usually to not more than two per cent of the original weight of the living plant. This ash contains all of the material which the plant has obtained from the earthy matter of the soil. It is true that the water which has carried this earthy matter through the growing tissues of the plant was contained in the soil, but not as a necessary part of it. It is also true that the nitrogen, which constitutes an important percentage of the plant tissues, is also carried into the higher plants through their roots; but the ultimate source of the supply of both water and nitrogen is the atmosphere and not the soil.

Ash elements essential—We find, therefore, that of the total substance of the living plant, approximately 98 per cent has been derived from the atmosphere, and only about two per cent from the soil; but this small proportion of mineral substance which the soil contributes is as essential to the growth of the plant as is the somewhat larger proportion of similar substances to that of the animal. In both orders of beings the ash elements compose the skeleton, which serves to co-ordinate and give form to the more evanescent substances derived from, and returning on dissolution to, the atmosphere. It is not only "earth to earth and dust to dust," but air to air as well.

Components of the ash—Of the elementary substances found in plants, 12 are obtained from the soil—namely, nitrogen, phosphorus, potassium, calcium, magnesium, sodium, iron, sulphur, chlorine manganese, aluminum and silicon. Three others—namely, carbon, oxygen and hydrogen—are obtained directly from the atmosphere, being absorbed by the foliage, or taken in through the roots as water. Of these 15 elements only the four first named require consideration under ordinary conditions.

Oxygen and nitrogen are mixed together in the atmosphere in the proportion of one part oxygen to four of nitrogen; but while it has been proven that the plant may absorb and use the oxygen of this mixture, through the stomata or breathing pores on the underside of its leaves, it can only use the nitrogen after that has been chemically combined with oxygen in nitric acid.

Chemical combination—It is important to understand the difference between simple mixture and chemical combination. Water, for example, is a chemical combination of oxygen with hydrogen, the two gases being combined in the proportion of one volume of oxygen to two of hydrogen. Nitric acid is a combination of the two principal gases of the atmosphere, in the proportion of one volume of nitrogen to three of oxygen. In a simple mixture the component parts retain their original characteristics, but a chemical compound possesses properties wholly different from those of its components. Thus oxygen is a supporter of combustion; so active is it in this respect that a piece of iron wire, heated to a red heat and introduced into a jar of pure oxygen gas, will burn with the evolution of intense light and heat. Hydrogen is also a combustible gas, being one of the constituents of illuminating gas; but when oxygen and hydrogen are combined in water, we have the universal extinguisher of combustion. In like manner, the air we breathe, which is a mixture of oxygen and nitrogen, when its components are combined in certain proportions, becomes nitric acid, one of the most corrosive of acids.

Of the mineral elements above named, iron and sulphur are the only ones which exist in the earth in uncombined form; all others, except chlorine, being combined with oxygen, or with this and some other element, in the forms in which we know them. Thus potassium combined with oxygen is known as potash; sodium with oxygen as soda; calcium with oxygen as lime; magnesium with oxygen as magnesia; iron with oxygen as iron oxide, or rust; silicon with oxygen as silica, or quartz; sulphur with oxygen, as sulphuric acid, and phosphorus with oxygen as phosphoric acid. Chlorine unites with various elements, forming chlorides, the most familiar example of which is sodium chloride, or common salt.

The ultimate source of all the mineral elements is the rocky crust of the earth, in which they are held, not in their elementary condition, nor often in the simple compounds above mentioned, but in more complex combinations. Thus phosphoric and sulphuric acids are found only in combination with other substances, chiefly with lime and iron, giving the various phosphates, sulphates and sulphides; potash and soda are found in feldspar, one of the constituents of granite, as well as in deposits of salt. The world's chief supply of commercial potash comes from mines in Germany, where it is found combined with chlorine, as muriate (chloride) of potash, or with sulphur in kainit and sulphate of potash. Beds of common salt are widely distributed. Lime is united with carbon in limestones, and these generally contain also more or less magnesia; iron is a constituent of hornblende and mica; sulphur is combined with lime in gypsum, with iron in pyrites (a mineral often mistaken for gold), with soda in glauber salts, and with magnesia in Epsom salts.

The nitrogen of the soil has been derived from the nitric acid and ammonia brought down by rain, and from the work of nitrogen-fixing bacteria in the soil, agencies which, acting through countless ages, have slowly accumulated and stored in the soil, chiefly in the form of the remains of former vegetation known as humus, a few thousand pounds of nitrogen per acre.

These are a few of the many different forms in which the elements of plant food exist in the soil. It is evident that if these elements are to serve the purpose of plant nutrition for an indefinite period they must be stored in such form that they can be dissolved by the soil water, and yet this solution must take place only so fast as they can be utilized by growing plants; otherwise they would be carried into the drainage and thence to the sea, and the land would eventually become sterile. And in fact the maintenance of a successful husbandry depends upon so adjusting the cropping, fertilizing and general management of the soil that it shall meet the demands of the crops grown upon it, and yet shall not suffer waste.

Atmospheric elements—The plant constituents derived from air and water are four—oxygen, nitrogen, carbon and hydrogen. The air we breathe is a simple mixture of oxygen and nitrogen, in the proportion of about one part of oxygen to four of nitrogen. In this colorless gas is disseminated watery vapor, also colorless and invisible when the sky is clear, but under certain conditions condensing into clouds from which it falls as rain or snow. The air also contains a relatively small quantity of a combination of carbon and oxygen—the carbonic acid gas of the older chemistry, carbon dioxide of the newer. From this carbon dioxide of the atmosphere has been derived the entire carbon supply of the earth, not only that found in the tissues of vegetation, but also that stored in the world's beds of coal and its strata of limestone.

Carbon absorbed through the foliage—The foliage of the plant is constantly bathed with an atmosphere carrying carbon dioxide; this is absorbed by the leaves, decomposed by the plant, and combined with the elements of water, with nitrogen, and with the ash elements held in solution in the stream of water passing upward through the plant, and out of these materials are elaborated the starches, sugars, fats and proteid matters by which animal life is sustained.

Fixation of nitrogen—The earlier chemists assumed that nitrogen also was absorbed by the plant through its foliage from the inexhaustible supply in the atmosphere, but this has been definitely proved to be wrong, so far as the plants we cultivate are concerned. We now know that nitrogen must first enter into combination before it can be utilized by the plant. Nitrogen is combined in small quantity with the elements of water during thunderstorms, producing nitric acid and ammonia, which are washed into the soil. The quantity produced in this way, however, is too small to be of material importance in agriculture. The investigations of the Rothamsted experiment station have shown that the total quantity of nitrogen reaching the soil annually in this way, including a small portion which falls in the particles of dust in the air in the form of organic nitrogen, amounts to about five pounds per acre, and that it comes chiefly in the form of ammonia.

The plant's food must be combined—The higher plants do not assimilate their food in the elementary form, but the mineral elements as well as the nitrogen must first enter into combination. Nitrogen is believed to be utilized by such plants only in the combination with oxygen known as nitric acid, the combination of nitrogen with hydrogen in ammonia being oxidized to nitric acid before it can be assimilated. Phosphorus is combined with oxygen in phosphoric acid, but this is further combined, usually with lime, before being absorbed by the plant. Potassium combined with oxygen is known as potash, but this combination does not exist as such in the soil, except in very small quantitv resulting from the slow oxidation of feldspar and other rocks of which it is a constituent. Calcium and oxygen are combined in lime, and lime again combines with water and carbonic acid on exposure to the air, producing calcium carbonate, in which form it exists in ordinary limestones. Other combinations of lime, less frequently found, are the deposits of phosphate of lime found in some of the southern states and in a few other limited regions, and those of sulphate of lime, or gypsum. In the first of these the carbonic acid is replaced by phosphoric acid, and in the second by sulphuric acid.

Evaporation removes from the plant nothing but water, hence the substances which the water has carried upward in solution are left behind when it is evaporated from the foliage, to be recombined in the tissues of the plant, with the carbon dioxide which has been absorbed through its foliage, and out of the combinations thus formed are built the innumerable vegetable compounds, with their varying properties.

These compounds have been arranged in five general groups or classes, according to their composition or physical structure—namely, crude fiber, nitrogen-free extract, ether extract, proteids and ash.

Crude fiber is found in all parts of the plant and gives to it its form and structure. It is composed of carbon, combined with the elements of water. It may be comparatively soft and succulent, as in vegetables and young growth, or hard and woody. In the ordinary feeding stuffs it furnishes more or less digestible substance.

Nitrogen-free extract—This group includes the starches, sugars and similar bodies, which are composed of the same three elements as the crude fiber. In analysis the separation of the two groups is governed largely by the strength of the solvent used. Usually a much larger proportion of the substances belonging to this group is digestible than of the crude fiber, but that portion which is digestible is assumed to have the same nutritive value in the two groups. The term "carbohydrates" is frequently used to designate the digestible part of the two groups.

Ether extract—This group includes the oils, wax, resins and similar substances soluble in ether. In grains and seeds this extract is chiefly oil, and the term "fats" is frequently used to designate the group. The chief function of the fats and carbohydrates is the production of heat and work. For this purpose a pound of digestible ether extract is estimated to be about as effective as 2.4 pounds of digestible carbohydrates.

The proteids—This group is composed of bodies which contain nitrogen and sulphur in addition to the three elements mentioned above. Egg albumen is a familiar proteid, and the earlier chemists gave the name albuminoids to the class. Later the term protein compounds was used to designate it, but with progress in chemical knowledge the word proteid has been substituted as being more inclusive, while the group has been subdivided into smaller ones—the albumins, globulins, albuminates, etc. Proteids are also found in the animal organism, and it is believed that these are derived with very little change from those of the plant. Since nitrogen is as indispensable to animal as to plant life, and since the animal is entirely unable to utilize the elementary substances, as also the simpler compounds which serve the plant, such as carbon dioxide and nitric acid, it is evident that the proteids occupy a very important place among animal nutrients. The proteids not only serve for the upbuilding of nitrogenous tissues in the animal organism, but they may also be converted into fat, the nitrogen and sulphur being eliminated.

The ash—While the mineral elements are grouped in a class by themselves in the process of chemical analysis, it must not be understood that they exist as a separate class in the plant. On the contrary, the ash elements are essential constituents of every living cell, whether plant or animal. Starch and sugar may exist as independent granules within the cells, but the protoplasm with which these granules are surrounded, and which Huxley has called "The physical basis of life," is built upon the ash elements, insignificant though they seem in relative prominence.

Growth controlled by the ash elements—Notwithstanding the fact that the ash elements constitute an extremely small portion of the total volume of the plant, yet if any one of them should be completely absent from the soil, no growth would take place, and the one which is present in smallest available quantity, relative to the plant's demand for it, will be the controlling factor in regulating growth.

CHAPTER III

The Feeding of the Plant

Condition of plant food in the soil—As has been shown above, the mineral elements which are found in the ash of the plant constitute a very small proportion of the total weight of the living plant, yet they are as indispensable to its life and growth as is the skeleton to the life and growth of the animal. Of these elements, as well as of the water which is required to dissolve them and carry them into the tissues of the plant, the soil is the storehouse, and as both must be stored together it is evident that the condition of the mineral elements must be such as to limit their solubility to the annual needs of the vegetation occupying the land, otherwise they would have been leached out and carried to the sea ages ago. This point may be illustrated by the following examples:

Soil potassium—Orthoclase feldspar is one of the constituents of granite, and is one of the chief sources of clay; this feldspar contains nearly 14 per cent of potassium, or three times as much as wood ashes; but this potassium is held in such firm combination that feldspar has never yet been made an economic source of the potash used in human industry;* but, instead, the world depends for the larger

* The Institution of Industrial Research of Washington, D. C., claims to have discovered a process by which the potash of feldspar may be made available on a commercial basis. July, 1912.

part of its supply of this substance, used in such a multiplicity of ways, upon the Stassfurt mines of Germany. An acre of land, taken to the depth of 7 inches, may contain potassium equivalent to 20 tons of potash, worth $2,000, as potash is valued in the fertilizer market, and yet the addition to such a soil of a few pounds of a potassium salt may materially increase the yield of crops grown upon it.

Soil phosphorus—Phosphorus is almost universally distributed through the soil, usually in combination with lime or iron, and an acre-foot of soil only moderately stocked with phosphorus may contain the equivalent of 5,000 pounds of phosphoric acid—an acre so moderately stocked that the effect of the addition of a few pounds of a soluble phosphate will be manifested by the superior growth of the wheat crop as soon as the young plant has exhausted the phosphorus stored in the seed grain. Immense deposits of phosphate of lime are found in various parts of the world, which are the chief source of supply of this element for fertilizing purposes. Some of these deposits, notably those of Tennessee, South Carolina and Florida, have been subjected to the large annual rainfall of a humid climate for countless ages, and thus so exhausted of their soluble material that, even when they are ground into an almost impalpable powder, this powder must first be dissolved in acid, or partially decomposed by incorporation with fermenting organic matter, such as manure, before the plant can make use of it.

Soil nitrogen—An acre-foot of air-dry swamp muck or peat may contain 40,000 pounds, or 20 tons, of nitrogen. The farmer pays about 20 cents a pound for nitrogen when he buys it at retail in nitrate of soda, and frequently considerably more than that when he buys it in mixed fertilizers, so that if the nitrogen in the peat bog were as available as that in nitrate of soda, an acre of such a bog, in which the muck or peat is frequently 3 feet in depth and sometimes much more than that, would have a potential value of $6,000 for each foot in depth. As a matter of fact, peat is being used as a source of nitrogen in mixed fertilizers; but unless the peat is first subjected to chemical treatment calculated to make its nitrogen available the farmer who purchases it will be disappointed in the effect produced; for the nitrogen of the peat is necessarily in an insoluble form, otherwise the drainage would long ago have carried it away. It is true that peat nitrogen may become slowly available when subjected to the bacterial and other agencies of decomposition which are found in arable soil, but the slowness with which this operation takes place is evidenced by the fact that peat bogs which have been drained and put under cultivation eventually require the addition of nitrogenous fertilizers, or of some material calculated to hasten their decay. The inertness of soil nitrogen may be illustrated by the fact that land at the Ohio experiment station, on which the yield of wheat has been reduced to 11 bushels an acre by three-quarters of a century of exhaustive cropping, has given a 17-year average yield of 20 bushels when treated with fertilizers carrying phosphorus and potassium, and has given a further increase to 27 bushels when nitrogen was added to the phosphorus and potassium. Yet this soil still contains about 3,000 pounds of nitrogen per acre in the upper 12 inches, or enough for 100 forty-bushel crops of wheat.

Total store of plant food not an index to productiveness—From these examples it will be seen that the total invoice of plant food in a given soil is not a sufficient basis on which to predicate its productiveness, and for more than half a century chemists have been endeavoring to discover a method by which the availability of the plant food in the soil may be measured. To this end various solvents have been employed in the chemical laboratory, and pot-cultural methods have been tested under glass or in the open; but the outcome has been that, while much useful information has been obtained in both lines of investigation, we have yet to go to the field itself and put our problem to the test of field conditions before a satisfactory solution is obtained.

Plant food availability not merely a chemical problem—One reason for the failure of the chemists is that, until quite recently at least, they have assumed that the extraction from the rocks of the mineral elements upon which our crops feed is merely a question of chemical solution; but the bacteriologist is showing us that chemical solution is only a secondary factor in the preparation of the food of the higher plants; and that between these plants and the rocks there exists an organic world, infinitely minute in its individuals, infinitely vast in their aggregation, to whose action is primarily due the conversion of the rocks into soluble form.

Different plants have different powers of assimilation—Another factor which enters into this question is the different capacity for obtaining and assimilating their food possessed by different crops. Take, for example, the experiments at the Pennsylvania State College, in which corn, oats, wheat and clover have been grown in rotation since 1882. During the first 25 years of this test the annual yields of crops on the unfertilized land, as reported in Bulletin 90 of the state college experiment station, were as given in the table below, which also shows the composition of these crops, as computed from average analyses.

TABLE I. CONSUMPTION OF PLANT FOOD BY PENNSYLVANIA CROPS.

Plant food removed from crops grown on unfertilized land at Pennsylvania State College Experiment Station—25-year average

Crop and yield an acre	Pounds an acre			
	Nitrogen	Phosphorus	Potassium	Calcium
Corn { 42.1 bushels grain, 1,955 lbs. stover }	53.9	10.8	32.6	8.2
Oats { 32.3 bushels grain, 1,403 lbs. straw }	26.9	5.4	24.7	5.8
Wheat { 13.6 bus. grain, 1,403 lbs. straw }	21.8	3.2	12.5	2.7
Clover, 2,783 lbs. hay	54.8	6.7	43.1	39.8

The Pennsylvania Experiments: Plot 13 (left), 300 pounds land plaster; Plot 14 (middle), nothing; Plot 15 (right), phosphorus (in 320 pounds dissolved boneblack) and potassium (in 200 pounds muriate of potash).

The table shows that under the conditions of this part of the experiment the corn crops have removed from the land more nitrogen and phosphorus than the succeeding oats and wheat crops combined, and nearly as much potassium and calcium;* while the

TABLE II. PERCENTAGE COMPOSITION OF OHIO GROWN CROPS.

Crop	Nitrogen	Phosphorus	Potassium
Corn grain	1.76	0.24	0.34
Oats "	2.01	0.41	0.58
Wheat "	1.97	0.35	0.35
Corn stover	0.81	0.07	0.78
Corn cobs	0.50	0.03	0.64
Oat straw	0.58	0.09	1.09
Wheat straw	0.53	0.09	0.83
Clover hay	2.17	0.18	1.12
Timothy hay	0.84	0.13	1.34

clover crop, coming at the end of the rotation, has stored about the same quantity of nitrogen as the corn crop, about two-thirds as much phosphorus and nearly five times as much calcium, or nearly 2½ times as much lime as all three of the preceding crops.

It is true that the corn crop has had the advantage of following immediately after the clover, and thus has found a larger amount of ready-prepared plant food than would fall to the succeeding crops. It

* The composition of the plant is materially influenced by the relative amount of the different elements of plant food available in the soil (see Bulletin 221 of the Ohio Experiment Station), hence crops grown on different soils and under different conditions of climate and fertilization will show differences in composition. The table below is compiled from average analyses made at the Ohio Experiment Station, and the factors given are employed in the calculations which follow.

will be interesting, therefore, to study the results obtained on one of the plots at the Ohio experiment station, on which corn, oats, wheat, clover and timothy have been grown in a five-year rotation since 1894, the only fertilization being a dressing of 50 pounds dried blood, 120 pounds nitrate of soda, 160 pounds acid phosphate and 100 pounds muriate of potash, all applied to the wheat crop.

TABLE III. CONSUMPTION OF PLANT FOOD BY OHIO CROPS.

Plant food removed by crops on partly fertilized land at Ohio Experiment Station—17-year average.

Crop and yield an acre	Pounds an acre			
	Nitrogen	Phosphorus	Potassium	Calcium
Corn { 33.3 bus. grain, 1,811 lbs. stover }	43.6	9.0	27.4	7.4
Oats { 33.2 bus. grain, 1,386 lbs. straw }	27.3	5.5	24.6	5.9
Wheat { 24.4 bus. grain, 2,536 lbs. straw }	40.5	6.0	23.7	5.4
Clover, 2,638 lbs. hay	52.0	6.4	40.9	37.7
Timothy, 2,990 lbs. hay ...	28.1	4.3	35.3	9.6

The land on which the Ohio experiment station is located lies over sandstones and is deficient in lime, while that at the Pennsylvania station is underlaid with limestones. This deficiency of lime has materially reduced the clover yield in the Ohio test, and the timothy crop has received most of the benefit from the clover, and yet the corn has been able to secure more of each of the fertilizing elements than the wheat, notwithstanding the liberal treatment that crop has received.

One explanation of the superior foraging ability of the corn crop is the fact that it is grown through the summer months, when the processes are most active by which the plant food of the soil, and especially its nitrogen, is converted into available form. Moreover, the tillage the corn receives is just such an operation as would be resorted to were we to intentionally set about the forwarding of the process of nitrification; for the tillage distributes the nitric ferment and admits air to the soil, which is essential to its action.

Composition of the crop not a sufficient guide to its fertilizing—A corollary of the selective power of different crops, shown by the above comparisons, is that the analysis of the plant is not always a sufficient guide to its fertilizing. If we were to take the analysis of the crop as a guide, we would assume that clover would respond decidedly to nitrogenous fertilizers; but scientific investigation and practical farm experience concur in the conclusion that if clover is abundantly furnished with the mineral elements of fertility, including lime, it will be able to secure a sufficient supply of nitrogen. With the cereal crops, however, the case may be different, and we now have available for the study of this question several long-continued experiments in which the principal American farm crops have been grown continuously and in rotation under such conditions as to afford data bearing upon this question.

In 1882 the Pennsylvania State College instituted an experiment in which corn, oats, wheat and clover are grown in rotation, each crop being grown every season, the corn and wheat receiving various combinations of fertilizing materials and manures, the oats and clover being left unfertilized. This experiment has been continued without interruption, and the average results for 30 years are now available.*

The land on which this experiment is located lies a few feet above stratified limestones, from which it has been derived and which furnish natural drainage.

Since 1888 experiments have been conducted at the Dominion experimental farm, at Ottawa, Canada, in which wheat, barley, oats, corn, mangels and turnips have been grown continuously on the same land, the soil being described as "a piece of sandy loam, more or less mixed with clay, which was originally covered with heavy timber, chiefly white pine," this having been succeeded by a second growth, chiefly poplar, birch and maple, which was cleared off in 1887.†

Since 1893 several experiments have been instituted by the Ohio experiment station, described as follows:

1. A five-year rotation of corn, oats, wheat, clover and timothy, begun at the central station at Wooster, in 1893.

* Pennsylvania State College Experiment Station, Bulletin 70, and supplement.

† Experimental Farms Reports, 1898, p. 34.

2. An experiment in the continuous culture of corn, oats, and wheat, begun at the central station in 1894.

3. A three-year rotation of potatoes, wheat and clover, begun at the central station in 1894.

4. A five-year rotation of corn, oats, wheat, clover and timothy, begun at the Strongsville test farm, Cuyahoga county, in 1895.

5. A three-year rotation of tobacco, wheat and clover, begun at the Germantown test farm, Montgomery county, in 1903.

6. A three-year rotation of corn, wheat and clover, begun at Germantown in 1904.

7. A three-year rotation of corn, wheat and clover, begun at the Carpenter test farm, Meigs county, in 1904.

In all these experiments each crop is grown every season. In the Ohio experiments the land is divided into plots of one-tenth acre and one-twentieth acre each, and every third plot, beginning with No. 1, is left continuously without fertilizer or manure.

The plots are 16 feet wide and are separated by paths 2 feet wide. A tile drain is laid under alternate paths, making the drains 36 feet apart. The drains are 30 inches deep.

The soil at the central station is a light, yellow, silty clay, lying over the upper, sandy shales of the Waverly series.

That at the Strongsville test farm contains a larger proportion of clay than that at the central station, is lighter colored, more difficult to work and much less productive. It lies over an argillaceous shale of the Waverly series. Both soils have been modified by glacial action, but both have been largely derived from the underlying rock, and both are quite deficient in lime.

That at Germantown is a yellow clay, formed from the decomposition of glacial gravel, chiefly derived from the limestones which underlie the western half of the state.

That at Carpenter is a yellow clay of residual origin, derived from sandstones and shales of the coal measures.

The five-year rotation and the experiment in continuous culture at Wooster are located on land which had been subjected to exhaustive cropping for more than half a century before the experiments were begun.

Feeding the corn crop—Let us now study the feeding habits of a few of the principal crops, as illustrated by these experiments:

Corn stands next to clover in the amount of nitrogen removed from the soil by equivalent crops, and because of this habit of the corn plant it is usually grown on soils rich in nitrogen, such as black lands or those which have had their stock of nitrogen reinforced by manuring or by the growth of clover. In all the experiments under review corn, when grown in rotation, follows immediately after clover or timothy, and thus is enabled to profit by the nitrogen and other elements accumulated in the surface soil by the clover. The results of these tests are given in Table IV, from which it will be seen that on the

TABLE IV. EFFECT OF FERTILIZING ELEMENTS ON CORN GROWN IN ROTATION.

Treatment	Increase or decrease (—) in bushels, an acre				
	Penna. 30-yr. av.	Wooster 18-yr. av.	Strongsville 15-yr. av.	Germantown 7-yr. av.	Carpenter 7-yr. av.
Nitrogen alone	—0.7	4.79	0.89	....	....
Phosphorus alone	5.1	7.48	8.87	7.20	4.71
Potassium alone	2.3	4.61	0.74	....	....
Nitrogen and phosphorus	8.8	14.50	10.19	8.16	5.18
Nitrogen and potassium	0.3	6.76	2.12	5.14	2.23
Phosphorus & potassium	13.4	14.22	9.65	12.51	7.36
Phosphorus, potassium and low nitrogen	10.5	18.93	11.66	....	....
Phosphorus, potassium and medium nitrogen	14.4	18.45	11.65	13.75	10.53
Phosphorus, potassium and high nitrogen	15.6	18.78	11.29	13.13	10.74
Average fertilized yield	38.8	29.74	26.20	44.84	36.27

comparatively productive soils of the Pennsylvania and Germantown experiments the addition of nitrogen has produced a very small gain over the increase produced by phosphorus and potassium alone. On the thinner soils of the Wooster and Strongsville tests the first addition of nitrogen produces a larger increase, but no further gain follows the increase of the dose of nitrogen, the dressing of phosphorus and potassium remaining the same.

Further light on this point is given by the experiments in continuous culture at the Wooster station, in which corn has been grown continuously on the same land since 1894. The results of this test for the 17 years, 1894-1910, are shown in Table V.

In this experiment the fertilizers are applied to

TABLE V. CORN IN 17 YEARS' CONTINUOUS CULTURE AT OHIO EXPERIMENT STATION, WOOSTER.

Plot No.	Treatment: pounds an acre	Increase an acre	
		Grain Bushels	Stover Pounds
2	Nitrate soda, 160; acid phosphate 160; muriate potash, 100	21.85	948
8	Nitrate soda, 320; acid phosphate 160; muriate potash 100	32.05	1,244
3	Nitrate soda, 160; acid phosphate, 60; muriate potash, 30	15.60	631
9	Nitrate soda, 320; acid phosphate, 120; muriate potash, 60	30.63	1,164
	Average unfertilized yield	16.87	1,237

plots 2 and 8 in arbitrary quantities, while on plots 3 and 9 the nitrogen, phosphorus and potassium are given in approximately the same ratio in which they are found in the plant. Taking the average analysis of the corn crop, as made at the Ohio station, the outcome of this test may be thus summarized:

TABLE VI. CORN IN CONTINUOUS CULTURE; BALANCE SHEET OF FERTILIZING ELEMENTS IN POUNDS AND PER CENTS.

Plot No.	Given in fertilizers			Recovered in increase			Percentage recovery		
	Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium	Nitrogen %	Phosphorus %	Potassium %
2	25	10.	41.	30.7	3.6	13.5	123	36	33
8	50	10.	41.	45.9	5.2	18.7	92	52	45
3	25	3.7	12.5	21.6	2.6	9.3	86	70	74
9	50	7.4	25.	41.7	5.0	17.7	83	68	71

The table shows that where phosphorus and potassium have been furnished in abundance the crop has been able to secure more nitrogen than that given in the fertilizer, even under the conditions of this test in which no nitrogen-gathering crop has been grown. The amount of nitrogen thus secured, however, may be in part accounted for by the nitric acid carried to the earth in the annual rainfall. When the fertilizing elements have been supplied more nearly in the proportions in which they are found in the plant there has been a more complete utilization, the average recovery of the three elements being 77 per cent on plot 3, 74 per cent on plot 9, 64 per cent on plot 2, and 63 per cent on plot 8. In considering this point, however, it must be remembered that the cost of a pound of fertilizer nitrogen is much greater than that of a pound of phosphorus or potassium, and hence the highest per cent of utilization may not always indicate the highest net gain.

We cannot expect to recover the entire amount of a fertilizer in the increase of crop harvested, for the reason that a portion will always be left in the roots and stubble, which, of course, are increased proportionally to the parts of the plant which are harvested. Making allowance for this factor, it would seem that in this experiment, conducted on a soil depleted of its virgin fertility by many years of cropping, the most effective fertilizer for corn has been one in which nitrogen, phosphorus and potassium in available form have been carried to the crop in approximately the same ratio to each other in which they are found in the plant, and that the response of the crop has been in direct proportion to the quantity of the fertilizing elements given.

In the Canadian experiments corn has been grown for silage, and the fertilizers have not been applied as regularly as in the other tests under consideration, the fertilizing having been discontinued from 1899 to 1905, when it was begun again. The average yield for 18 years under the treatments most nearly comparable with those of the Pennsylvania and Ohio stations are as below:

TABLE VII. YIELD AND INCREASE IN TONS OF SILAGE CORN AT THE DOMINION EXPERIMENTAL FARMS—18-YEAR AVERAGE.

Plot		Yield an acre	Increase an acre
3-12	None	7.15	....
15	Nitrogen alone (in nitrate of soda, 200 pounds)	9.74	2.59
9	Phosphorus alone (in acid phosphate, 1500 pounds)	9.03	1.88
18	Potassium alone (in muriate of potash, 300 pounds)	8.58	1.43
10	Nitrogen and phosphorus (in nitrate of soda, 200 pounds, and acid phosphate 350 pounds)	10.75	3.60
19	Phosphorus, potassium and nitrogen (in acid phosphate, 500 pounds; muriate of potash, 200 pounds, and dried blood, 300 pounds)	10.44	3.29

In this test the fertilizing materials have been used in very much larger quantity than in the tests previously described, especially the acid phosphate, and the relative action of nitrogen and phosphorus in producing increase is the reverse of that observed in the Pennsylvania and Ohio tests, while the general effect of treatment, whether with fertilizer or manure, has been much smaller.

Taking the Pennsylvania and Ohio experiments, as more applicable to the conditions under which corn is generally grown, it would seem that the greater part of the nitrogen required by this crop may be supplied by systematic rotation of crops, and that in order to enable the corn crop to profit in the fullest measure by the nitrogen supply thus furnished, it must be provided with available phosphorus and potassium.

May we omit potassium from the fertilizer for corn?—The large quantity of potassium found in most soils—the soils of the Ohio station, for example, containing from 12 to 17 tons of potassium per acre in the upper 7 inches—justifies the question why it should be necessary to add this element in fertilizers. Table IV shows that when potassium has been used alone or with nitrogen only, it has produced only a small increase or none at all, but when added to phosphorus potassium has always materially increased the yield. This point is brought out more clearly in Table VIII, which shows that in every experiment, except the one at Strongsville, the addition of potassium to phosphorus in the fertilizer has caused, not only a larger total, but also a greater net gain, notwithstanding the fact that the cost of the fertilizer has been very greatly increased.

TABLE VIII. EFFECT OF ADDING POTASSIUM TO PHOSPHORUS IN FERTILIZING CORN.

Station and treatment	Bushels increase an acre	Value of increase*	Cost of fertilizer	Net gain
Pennsylvania				
Phosphorus alone	5.10	$2.55	$2.40	$0.15
Phosphorus and potassium	13.40	6.70	4.90	1.80
Wooster				
Phosphorus alone	7.48	3.74	0.56	3.18
Phosphorus and potassium	14.22	7.11	2.56	4.55
Strongsville				
Phosphorus alone	8.87	4.43	0.56	3.87
Phosphorus and potassium	9.65	4.82	2.56	2.26
Germantown				
Phosphorus alone	7.20	3.60	0.84	2.76
Phosphorus and potassium	12.57	6.28	1.84	4.44
Carpenter				
Phosphorus alone	4.71	2.35	0.84	1.51
Phosphorus and potassium	7.36	3.68	1.84	1.84

* Rating corn at 50 cents a bushel and taking no account of increase of stover.

It seems probable, moreover, that potassium has been given extravagantly in the older tests, judging from the results at Germantown, where only 20 pounds of muriate of potash is used, as against 80 pounds at Wooster and 200 pounds at State College.

The outcome at Strongsville shows that there may be some soils which will not respond to potassic fertilizing, and emphasizes the necessity for bringing each separate soil type under experiment before adopting a system of fertilizing.

Does corn need lime?—On plots 22 and 23 in the Pennsylvania experiments quicklime has been applied to the corn crop, or once in four years, at the rate of two tons per acre, the lime being reinforced on plot 22 with six tons of stable manure, applied to both corn and wheat, or 12 tons every four years.

On plot 34 ground limestone has been used at the same rate of two tons per acre, and applied to the corn crop. The outcome of this test has been as shown in Table IX.

TABLE IX. EFFECT OF LIME AND LIMESTONE ON CORN AT PENNSYLVANIA STATE COLLEGE.

Treatment	ushels of corn an acre	
	First 25 years	Last 5 years
None	42.1	22.1
Yard manure, 6 tons	57.5	44.4
Yard manure, 6 tons Lime, 1 ton	58.2	55.9
Lime alone	35.3	22.9
Ground limestone alone	43.1	29.4

During the first 25 years quicklime used alone has diminished the yield by nearly seven bushels per acre, although it has slightly increased the yield, when used as a reinforcement of manure, while ground limestone, used alone, has apparently increased the yield by one bushel per acre.

During the last five years the unfertilized yield has dropped from a previous average of 42.1 bushels to 22.1 bushels, a loss of 20 bushels, and the yield from yard manure alone from 57 bushels to 44.4 bushels, a loss of 13.1 bushels, but where the yard manure has been reinforced by lime the yield has fallen by only 2.3 bushels. Where lime has been used alone the yield has dropped from 35.3 bushels to 22.9 bushels—a loss of 12.4 bushels, and on the land receiving ground limestone it has fallen by 13.7 bushels. Ground limestone has not been used on manured land.

It appears from these results that raw limestone has to some extent checked the downward tendency of the yield, and that lime has produced a similar effect when used as a supplement to manure. As has been stated, the soil upon which this test is being conducted is a residual soil, formed from the decomposition of limestones over which it lies, and it would not be expected that such a soil would show deficiency of lime at so early a date as one formed from noncalcareous rocks, such as that upon which the Ohio station's experiments at Wooster are located.

At the Ohio station the use of lime was begun in the five-year rotation in 1900, the lime being applied to one-half the land and distributed over all the plots, fertilized and unfertilized alike, while the land was being prepared for corn. There are 30 one-tenth acre plots in each of the five tracts of land in this experiment, the plots being 16 feet wide by 272 1-3 feet long and separated by paths 2 feet wide, except that between plots 10 and 11, and 20 and 21, a roadway 12 feet wide is left to facilitate harvesting the small grains. A tile drain is laid at the depth of 30 inches under alternate paths, making the drains 36 feet apart. The plots are plowed separately about once in 10 years, thus keeping them slightly ridged in order to remove surface water more uniformly. At other times the plowing is across the plots. The five sections of the experiment are named A, B, C, D and E. Each section is subdivided into 30 plots, and every third plot, beginning with No. 1, is left continuously unfertilized. The plots run east and west. When the liming was begun the lime was applied to the west half of Section E, and it was continued on the west sides of the remaining sections until the five sections had all been limed on this side. In order to make sure that the effects observed were due to the lime and not to soil variation, the liming was then transferred to the east sides of the sections, and was so continued for three years. By this time the results had become so unmistakable that the liming of the east ends was discontinued, in order to leave some of the land unlimed from the beginning of the test. In Table X is given the outcome of this work, so far as the corn crop is concerned, for six crops which have

TABLE X. EFFECT OF LIME ON CORN. SIX YEARS' AVERAGE RESULTS AT OHIO EXPERIMENT STATION.

Treatment*	Bushels an acre	Bushels increase for lime
No fertilizer, no lime	25.57	....
No fertilizer, lime	36.40	10.83
Phosphorus, no lime	35.52	....
Phosphorus and lime	47.09	11.57
Phosphorus and potassium, no lime	40.26	....
Phosphorus, potassium and lime	52.15	11.89
Phosphorus, potassium and nitrogen, no lime	46.20	....
Phosphorus, potassium, nitrogen and lime	57.75	11.55

* Phosphorus given in acid phosphate, 80 pounds an acre. Potassium in muriate of potash, 80 pounds an acre, and nitrogen in nitrate of soda, 100 pounds an acre.

Wheat in the fertility tests of the Ohio Experiment Station at Wooster. Plots 11 and 12, with parts of unfertilized plots No. 10 (left) and No. 13 (right) in the background. Showing effect of fertilizer containing acid phosphate in hastening maturity. Part of Plot 14 shows at extreme right.

been grown on continuously unlimed land, as compared with those grown immediately after liming during the same seasons.

The experiments above described clearly show that the corn plant requires a supply of available nitrogen, phosphorus, potassium and calcium, all four, for its complete development, and that a particular soil may be deficient in part or all of these elements, owing to its geological origin and previous treatment.

TABLE XI. EFFECT OF FERTILIZING ELEMENTS ON OATS GROWN IN ROTATION.

Treatment	Increase or decrease (*) in bushels an acre		
	Penna 30-yr. av.	Wooster 18-yr. av.	Strongsville 15-yr. av.
Nitrogen alone	*1.0	3.96	0.12
Phosphorus alone	4.7	8.54	9.36
Potassium alone	0.2	3.42	0.52
Nitrogen and phosphorus	8.1	15.14	12.36
Nitrogen and potassium	2.6	5.79	2.38
Phosphorus and potassium	8.2	12.02	9.50
Phosphorus, potassium and low nitrogen	8.2	18.51	13.66
" " " medium "	11.5	18.40	12.67
" " " high "	10.3	17.80	12.47
Average unfertilized yield	31.5	30.83	34.51

Feeding the oats crop—Oats has been grown in rotation in the above-described experiments at the Pennsylvania experiment station and in the Wooster and Strongsville experiments of the Ohio station. In the Pennsylvania test the oats crop is not directly fertilized, the fertilizers being divided between the corn and wheat crops; but in the Ohio tests the oats crop receives the same quantities of fertilizing materials as the corn crop. The general outcome of these tests is shown in Table XI.

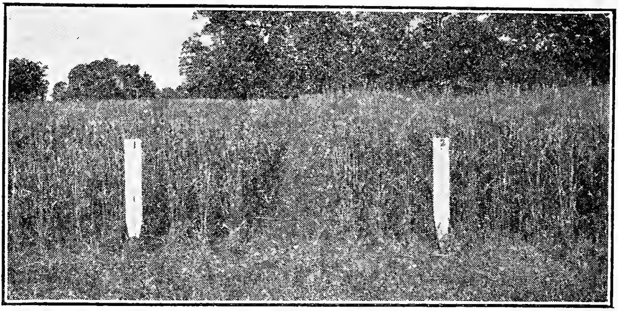
Comparing Table XI with Table IV, page 47, it will be seen that there has been a close uniformity in the effect of the different elements on corn and oats.

Feeding the wheat crop—Wheat is grown in all the above-described tests, following oats in the cereal rotations in the Pennsylvania, Wooster and Strongsville tests; following corn in one of the tests at Germantown and the one at Carpenter; following

TABLE XII. EFFECT OF FERTILIZING ELEMENTS ON WHEAT GROWN IN ROTATION.

Treatment	Increase or decrease (*) in bushels an acre						
		Wooster			Germantown		
	Penna 30-yr. av.	Cereal R. 18-yr. av.	Potato R. 17-yr. av.	Strongsville 14-yr. av.	Cereal R. 7-yr. av.	Tobacco R. 7-yr. av.	Carpenter
Nitrogen alone	*0.9	1.92	0.84	*0.10	....	....	....
Phosphorus alone	2.3	7.97	5.96	6.97	4.88	6.64	4.65
Potassium alone	*2.0	1.24	1.72	*0.59	....	....	....
Nitrogen and phosphorus	2.8	13.04	7.30	10.37	7.10	10.93	6.51
Nitrogen and potassium	0.2	2.73	4.98	1.61	1.35	5.85	2.48
Phosphorus and potassium	5.1	8.89	8.25	8.32	6.34	9.28	6.42
Phosphorus, potassium and low nitrogen	7.7	12.88	10.20	9.03	....	....	....
Phosphorus, potassium and medium nitrogen	10.3	16.25	9.19	10.13	8.88	11.41	9.60
Phosphorus, potassium and high nitrogen	11.8	16.95	9.18	12.42	8.27	12.32	9.97
Average unfertilized yield	13.6	10.18	25.57	7.62	9.66	11.10	10.48

potatoes in one rotation at Wooster; and following tobacco in one at Germantown. The general outcome of this work is exhibited in Table XII, from which it will be seen that the same general law has controlled the effect on wheat of the three fertilizing elements, nitrogen, phosphorus and potassium, as on corn and oats. With all three crops and in every test phosphorus has been the dominant element in producing increase, although it has been necessary to reinforce the phosphorus with both potassium and nitrogen before the full demands of the crop have been met. It is true that the rate of increase produced by the different applications has varied in the different soils; apparently the Pennsylvania and Strongsville soils are less responsive to treatment than those at Wooster and Germantown; and in the case of the two Wooster soils, the high unfertilized yield in the potato rotation leaves but a comparatively small margin for increase. In the case of the two Germantown tests—which are located on a soil as absolutely uniform in present appearance and previous treatment as it is possible to be, the two tests lying side by side on the same original farm—it is to be noted that the wheat is directly fertilized in the cereal rotation, but in the tobacco rotation all the fertilizers are applied to the tobacco crop, the wheat following as a gleaner. The total quantity of fertilizer applied in the tobacco rotation, however, is much larger than in the cereal rotation, but as the tobacco pays for it all the increase of wheat is net gain.



Wheat in the fertility tests at Wooster of the Ohio Experiment Station. Plot 1 (left), unfertilized and Plot 2 (right), acid phosphate; 18-year average yield of Plot 1, 10.6 bushels; of Plot 2, 18.7 bushels per acre.

Do oats and wheat need lime?—Unfortunately, the oats and wheat crops were not harvested separately on the limed and unlimed land throughout the entire course of the first rotation, after the lim-

TABLE XIII. EFFECT OF LIME ON OATS AND WHEAT.

Treatment	Yield in bushels an acre			
	Oats		Wheat	
	Average 2 crops	Gain for lime	1906	Gain for lime
No fertilizer, no lime	30.47	....	17.02	....
No fertilizer, lime	40.44	9.97	23.98	6.96
Phosphorus, no lime	49.84	....	27.42	....
Phosphorus and lime	54.34	4.50	34.00	6.58
Phosphorus and potass., no lime	52.26	....	29.33	....
Phosphorus, potass. and lime	58.51	6.25	35.25	....
Phosphorus, potass. and nitrogen, no lime	59.92	....	40.08	....
Phosphorus, potass., nitrogen and lime	58.51	*1.41	45.33	5.25

* Loss.

ing was begun, only two oats crops, those of 1901 and 1905 being thus separated, and only the wheat crop of 1906. The results obtained for the crops separately harvested were as shown in Table XIII.

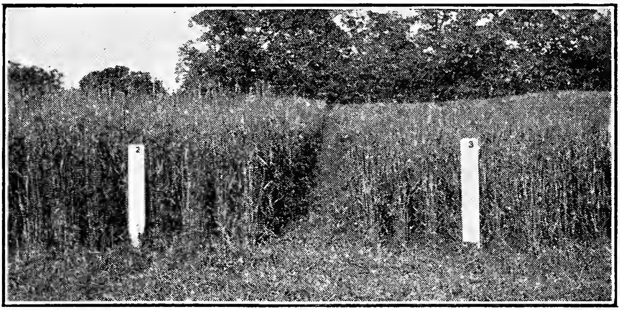
The failure of the lime to produce a further increase in the oats crop after the addition of nitrogen was probably due to accidental variation, as other plots receiving like quantities of phosphorus, potassium and nitrogen, with the nitrogen in different carriers and quantities show a different result.

TABLE XIV. EFFECT OF LIME IN CONJUNCTION WITH VARIOUS CARRIERS OF NITROGEN ON WHEAT AND OATS.

Plot No.	Nitrogen carrier	Yield in bushels an acre			
		Oats		Wheat	
		Average 2 crops	Gain for lime	1906	Gain for lime
11	Nitrate of soda, no lime..	59.92	....	40.08	....
11	" " and lime	58.51	*1.41	45.33	5.25
12	" " no lime..	56.15	....	41.17	....
12	" " and lime	58.89	2.74	47.17	6.00
17	" " no lime..	58.90	....	37.92	....
17	" " and lime.	61.32	2.42	43.08	5.16
21	Linseed oilmeal, no lime..	57.34	....	37.17	....
21	" " and lime	63.59	6.25	39.67	2.50
23	Dried blood, no lime	57.81	....	33.50	....
23	" " and lime	60.70	2.89	38.50	5.00
24	Sulphate of ammonia, no lime	55.70	....	30.42	....
24	Sulphate of ammonia and lime	61.79	6.09	40.67	10.25
18	Barnyard manure, no lime	44.45	....	39.00	....
18	" " and lime	49.21	4.76	46.17	7.17

* Loss.

On plot 11 each cereal crop receives 25 pounds of nitrogen; on plot 12, 38 pounds; and on plots 17, 21, 23 and 24, 12½ pounds. The larger applications of nitrogen have caused more lodging in the oats, and thus have sometimes diminished the yield instead of increasing it. The wheat, however, shows regularly a larger yield for the larger dose of nitrogen, although the rate of increase is smaller for the second increment of nitrogen than for the first.



Wheat in the fertility tests at Wooster of the Ohio Experiment Station. Plot 2 (left), acid phosphate; Plot 3 (right), muriate of potash; 18-year average yield of Plot 2, 18.7 bushels; of Plot 3, 12.1 bushels per acre.

Taking all these results, it seems reasonable to assume that on this soil, originally deficient in lime, and having had that deficiency accentuated by nearly a century of cropping, the addition of lime has increased the yield of corn by about 10 bushels per acre, and that of oats and wheat by five bushels or more for each crop, under the conditions of ordinary fertilizing or manuring. (In this experiment the manure is applied only to the corn and wheat, the oats receiving no direct manuring, but the fertilizers are applied to all three crops.)

Liming the cereals on limestone land—At Pennsylvania State College the soil under experiment, as has been previously stated, lies over limestone from which it has been derived by weathering. In these experiments plot 22 has received quicklime at the rate of two tons per acre, applied once in four years to the corn crop; plot 23 has received the same quantity of quicklime, together with 12 tons of yard manure, the manure being divided between the corn and wheat crop, six tons to each crop, and plot 34 has received two tons of ground limestone every two years, on the corn and wheat crops. The effect on the cereal crops of these treatments is shown in Table XV.

TABLE XV. EFFECT OF LIME ON CEREAL CROPS AT PENNSYLVANIA EXPERIMENT STATION.

Treatment	30-year average yield an acre			
	Bushels			Pounds
	Corn	Oats	Wheat	Hay
Nothing	38.8	31.5	12.5	2,608
Lime	33.5	28.6	15.0	2,569
Increase (+) or decrease (—) for lime	−5.3	−2.9	+1.5	−39
Powdered limestone	41.3	33.4	15.9	2,961
Increase for powdered limestone	+2.5	+1.9	+2.4	+353
Farmyard manure	55.2	39.4	23.3	3,956
Farmyard manure and lime	58.7	40.9	23.2	4,267
Increase (+) or decrease (—) for lime	+3.5	+1.5	−0.1	+311

Two tons of quicklime applied every four years to unmanured land, or the equivalent of half a ton annually, has reduced the yield on this soil of every crop grown except wheat; whereas powdered limestone, carrying an equivalent quantity of calcium, has increased the yield of every crop, the average increase for each rotation having a total value of $5.05, counting corn at half a dollar per bushel, oats

Wheat in the fertility tests at Wooster of the Ohio Experiment Station: Plot 7 (left), unfertilized; Plot 8 (right), acid phosphate and muriate of potash; 18-year average yield of Plot 7, 10.9 bushels; of Plot 8, 19.9 bushels per acre.

at one-third of a dollar, wheat at 90 cents and hay at $8 a ton.

It will be observed that although the quicklime when used alone has diminished the yield, it has produced a small increase in every crop but wheat when used in conjunction with manure, over the yield from manure alone.

In the Ohio experiments lime was used at the first application at the rate of one ton of quicklime or two tons of powdered limestone once in five years, or less than half the quantity applied in the Pennsylvania test, while the second application was reduced to half these quantities, and this smaller rate of application—less than one-fourth that used in the Pennsylvania test—appears to be sufficient to satisfy the need for lime of a soil originally deficient in that substance. There is ground, therefore, for

Wheat in the fertility tests at Wooster of the Ohio Experiment Station: Plot 12 (left), acid phosphate, muriate of potash and nitrate of soda; Plot 13 (right), unfertilized; 18-year average yield of Plot 12, 27.8 bushels; of Plot 10.9 bushels per acre.

the conjecture that the unfavorable effect of quicklime on the otherwise untreated soil in the Pennsylvania test has been due to an excessive use, a conjecture which is supported by the different result attained where lime has been used in conjunction with manure, as the manure would to some extent restore the organic matter oxidized by the lime.

Since 1905 another experiment has been conducted at the Ohio experiment station in which different forms of lime and ground limestone have been used alone and as supplements to manure in a three-year rotation of corn, oats and clover; the manure being plowed under for the corn crop at the rate of eight tons per acre, and the lime and limestone applied to the surface. The results of this comparison for the seven years, 1905-11, are given in Table XVI.

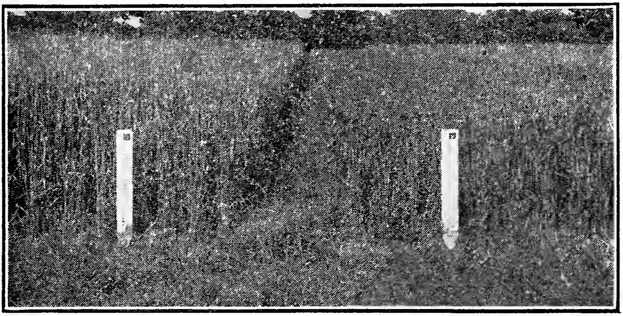
TABLE XVI. COMPARATIVE EFFECT OF LIME AND LIMESTONE ON CORN, OATS AND CLOVER, GROWN IN ROTATION AT OHIO EXPERIMENT STATION.

Treatment	Value of increase an acre
Manure, 8 tons; caustic lime, 1,000 pounds	$11.83
Manure, 8 tons; ground limestone, 1,780 pounds	13.60
Manure, 8 tons; air-slacked lime, 1,780 pounds	12.03
Manure, 8 tons; hydrated lime, 1,320 pounds	13.21
Caustic lime alone, 1,000 pounds	5.75
Ground limestone alone, 1,780 pounds	2.55

The land on which this test is located had been under regular rotative cropping before the test was begun, manure having been applied every fourth or fifth season, and was in such condition that the unmanured yields during the seven years of the test have averaged 58½ bushels of corn, 48 bushels of oats and 2 1-3 tons of hay, and the increase over these yields produced by the treatment has been relatively small, as compared with that attained on less fertile land. It appears, however, that the ground limestone has been the more effective when used as a supplement to manuring, while the caustic lime has produced the larger increase when used alone.

The air-slaked lime used in this test had been slaked a year in advance of application and exposed to the air so that it had in part returned to the carbonate form.

Feeding the clover crop—Table XVII shows the effect on the clover crop of fertilizing elements ap-



Wheat in the fertility tests at Wooster of the Ohio Experiment Station: Plot 18 (left), barnyard manure; Plot 19 (right), unfertilized; 18-year average yield of Plot 18, 22.2 bushels; of Plot 19, 10.7 bushels per acre.

plied to the preceding crops in the several experiments under consideration. From this table it appears that on the soil on which the Pennsylvania experiments are located nitrogen and potassium, when used alone, have diminished the yield of clover; when the two have been used in conjunction there has been a very slight increase in yield; phosphorus has increased the yield in every case, but the combined effect of either phosphorus and nitrogen or phosphorus and potassium has been much greater than that of phosphorus alone. In fact, the combination of phosphorus and potassium has produced a greater increase than any combination of the three elements, thus indicating that for this soil it has not been necessary to add nitrogen to the fertilizer for clover.

In the cereal rotation at Wooster, while the superiority of phosphorus is marked, yet both nitrogen

TABLE XVII. RESIDUARY EFFECT ON CLOVER OF FERTILIZING ELEMENTS APPLIED TO PRECEDING CROPS OF ROTATIONS.

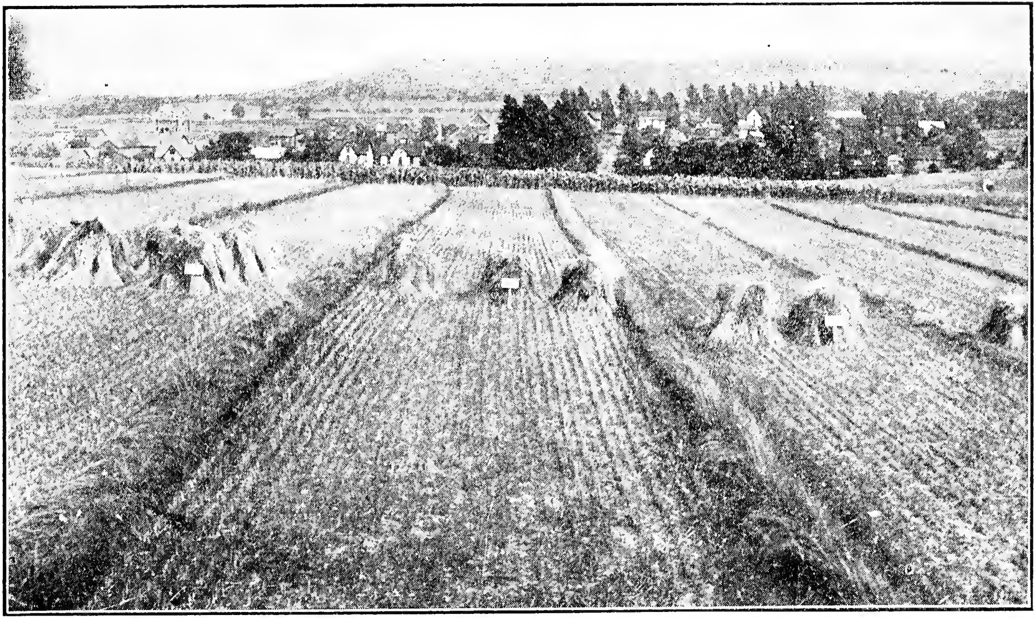
Treatment	Increase or decrease (—) in pounds an acre						
	Penna. 30-yr. aver.	Wooster		Strongsville 15-yr. aver.	Germantown		Carpenter Cereal R
		Cereal R 17-yr. aver.	Potato R 13-yr. aver.		Cereal R. 7-yr. aver.	Tobacco R 7-yr. aver.	
Nitrogen alone....	—398	332	349	210	....	....	....
Phosphorus alone..	526	497	382	887	548	747	298
Potassium alone ..	—280	252	185	87	....	....	....
Nitrogen and phosphorus	965	1,080	570	764	645	1,150	426
Nitrogen and potassium	40	400	565	247	110	530	35
Phosphorus and potassium	1,566	914	456	663	640	1,211	515
Phosphorus, potass. and low nitrogen	1,388	1,220	934	914	....	....	....
Phosphorus, potass. and medium nitrogen	1,512	1,325	574	897	637	1,250	760
Phosphorus, potass. and high nitrogen	1,547	1,390	714	803	572	1,441	732
Average unfertilized yield...........	2,608	1,808	3,693	1,847	2,367	2,066	1,819

and potassium have produced a decided increase, whether used separately or in combination with each other only, and when combined with phosphorus the effect of nitrogen has apparently been greater than that of potassium, the largest total increase being found on the plot receiving the complete fertilizer containing the largest quantity of nitrogen.

In the potato rotation at Wooster the unfertilized yield of clover has averaged nearly two tons of hay per acre, and the increase over this yield has been relatively small and somewhat irregular, but even on this fertile soil it is surprising to note that the largest increase is found on plots receiving nitrogenous fertilizers.

In the Strongsville experiments the role of phosphorus appears to be more important than that of either of the other elements, nitrogen coming second, while potassium has produced a very small effect, whether used separately or in combination.

In the Germantown and Carpenter tests nitrogen and potassium have not been used separately; but at Germantown their combination has produced a relatively small effect in the absence of phosphorus. When added to phosphorus, however, they have materially increased the yield in the tobacco rotation; although the smaller quantities used in the cereal rotation have produced but little effect, the crops in this rotation receiving but 25 pounds of nitrogen and 16 pounds of potassium per acre for each three-year rotation. And yet the application

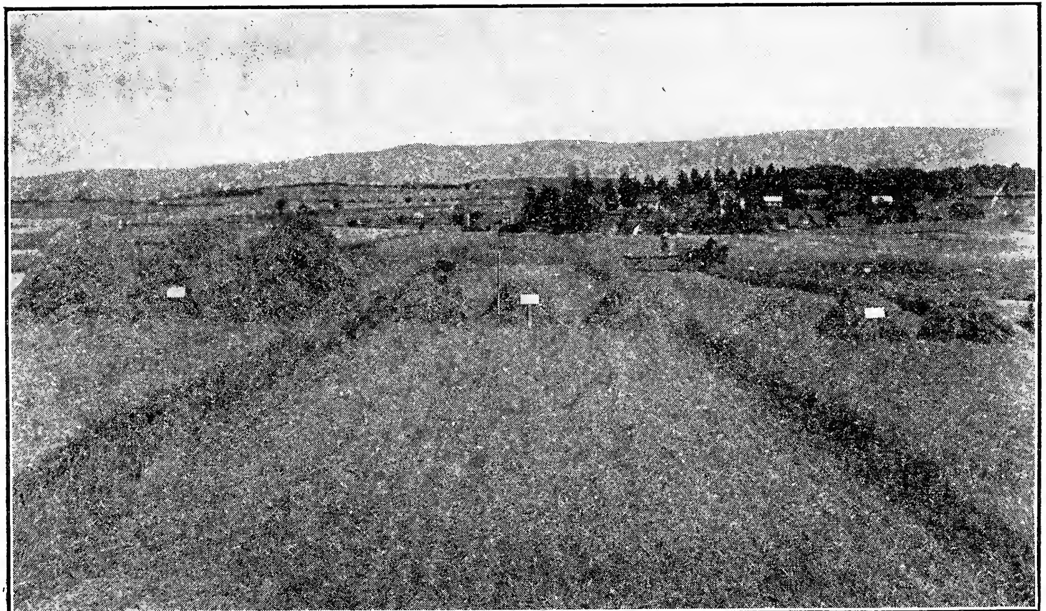


Wheat in the fertility tests of Pennsylvania State College Experiment Station: Plot 22 (left), 6 tons yard manure and 2 tons burned lime every 4 years; Plot 23 (middle), 2 tons burned lime every 4 years; Plot 24 (right), nothing.

of only 15 pounds of phosphorus per acre during the same period has produced an unmistakable effect.

A point of importance in this study of clover is that of the vehicle in which the fertilizer nitrogen is carried. In the Pennsylvania experiments dried blood has been used as the standard carrier of nitrogen, while in the Ohio experiments nitrate of soda has been the standard. In both experiments the standard carrier has been the only one used where nitrogen has been given alone or in combination with only one of the other elements, but in both tests other carriers have been employed in the combinations containing all three elements. In the Pennsylvania test dried blood, nitrate of soda and sulphate of ammonia have each been employed, in quantities calculated to furnish 24, 48 and 72 pounds of nitrogen per acre. In the Ohio tests at Wooster and Strongsville nitrate of soda has been similarly used, while dried blood, sulphate of ammonia and linseed oil meal have been used in the smaller quantity.

In the cereal rotation at Wooster lime has been applied to one-half the land, fertilized and unfertilized alike, since 1900; the lime being used when the land was being prepared for corn, and at the rate of one ton of quicklime or two tons of powdered limestone per acre for the first application, and in half these quantities subsequently. After treating the west half of each of the five tracts of land in the experiment the liming was transferred to the east half, and so continued for three years,



Clover in fertility tests of Pennsylvania State College Experiment Station: Plot 22 (left), 6 tons yard manure and 2 tons burned lime every 4 years; Plot 23 (middle), 2 tons burned lime every 4 years; Plot 24 (right), nothing.

or long enough to make sure that the effects observed were not due to variations in the soil. Since then the lime has been used only on the west half. In the following table, therefore, part of the land given as unlimed has had one liming, but an interval of eight years had elapsed between the application of the lime and the harvesting of the clover crop. Even after this long interval the clover has still shown considerable advantage from the liming.

TABLE XVIII. RESIDUAL EFFECT ON THE CLOVER CROP OF FERTILIZERS APPLIED TO PRECEDING CROPS ON CENTRAL FARMS OF OHIO EXPERIMENT STATION. AVERAGE FOR 9 YEARS, 1903-1911.

Treatment	Increase an acre (Pounds)	
	Unlimed	Limed
Nitrogen (in nitrate of soda)	372	442
Phosphorus	471	789
Potassium	147	140
Nitrogen (in nitrate of soda) and phosphorus	1,213	1,383
Nitrogen (in nitrate of soda) and potassium	414	421
Phosphorus and potassium	903	1,479
Phosphorus, potass. and nitrogen in nitrate of soda	1,360	1,959
Phosphorus, potass. and nitrogen in dried blood	876	1,762
Phosphorus, potass. and nitrogen in sulphate amm.	935	1,956
Phosphorus, potass. and nitrogen in linseed oilmeal	1,047	1,699
Average unfertilized yield	1,605	2,105

In this experiment the fertilizers have been applied to all three of the cereal crops, and the standard carrier of nitrogen has been nitrate of soda, which has been used at the rate of 160 pounds per acre on each crop, when used alone, or with phosphorus or potassium only, which quantity, on the average analysis of this salt, would contain about 25 pounds of nitrogen. In the complete fertilizers, however, carrying nitrogen, phosphorus and potassium, all three, the nitrogen has been reduced to one-half this quantity for the plots given in the above table, while the phosphorus has been increased from the standard application of 20 pounds of phosphorus to 30 pounds.

The table shows that all the fertilizing combinations have increased the clover crop, both on the limed and unlimed land, and that the increase on the limed land is much greater than that on the unlimed land whenever the fertilizer has carried phosphorus. At first glance it would seem that the nitrogen had increased the yield; and that nitrate of soda has caused an increase there can be no doubt, but it is not so certain that the principal effect of the nitrate of soda has been due to the nitrogen carried. For further light on this point let us compare the yields of clover obtained in the Ohio and Pennsylvania experiments from a fertilizer carrying phosphorus and potassium only—made up in the Pennsylvania experiments from dissolved bone black and muriate of potash, calculated to carry 42 pounds of phosphorus and 166 pounds of potassium for each four-year rotation, the fertilizer being divided between the corn and wheat crops in a rotation of corn, oats, wheat and clover, and in the Ohio experiments of acid phosphate and muriate of potash, calculated to carry 20 pounds of phosphorus and 108 pounds of potassium for every five-year rotation, and so divided between the corn, oats and wheat as to give the wheat half the total phosphorus and about two-fifths of the total potassium—with those found after nitrogen has been added to the fertilizer.

The table shows that when the results on the unlimed land in the Ohio test are compared with

TABLE XIX. AVERAGE YIELD IN POUNDS OF CLOVER HAY AN ACRE FROM PHOSPHORUS AND POTASSIUM, AND INCREASE OR DECREASE WHEN NITROGEN IS ADDED. PENNSYLVANIA AND OHIO EXPERIMENT STATIONS.

Treatment	Nitrogen an acre	Pennsylvania 30-year average		Ohio, Wooster, 9-year average			
				Unlimed		Limed	
		Yield	Increase (+) or decrease (−)	Yield	Increase (+) or decrease (−)	Yield	Increase (+) or decrease (−)
Phosphorus and potassium......	..	4.174	....	2.494	....	3.672	....
Phosphorus, potassium and dried blood..	24	3.996	−178	2.338	−156	3.719	+47
	48	4.120	− 54	....	....	....	....
	72	4.155	− 19	....	....	....	....
Phosphorus, potassium and nitrate of soda	24	4.308	+134	2.815	+321	3.977	+305
	48	4.302	+128	3.074	+580	3.808	+136
	72	4.302	+128	3.075	+581	3.900	+228
Phosphorus, potass. and sulphate of ammonia	24	3.966	−208	2.473	− 21	4.005	+333
	48	3.574	−600	....	....	....	....
	72	3.270	−904	....	....	....	....

those at the Pennsylvania station, they agree in showing a decrease in yield when nitrogen has been added in dried blood or sulphate of ammonia, but an increase when the nitrogen carrier has been nitrate of soda; whereas, when lime has been added to the Ohio land, it has not only caused a large increase in the yield of clover on the land treated only

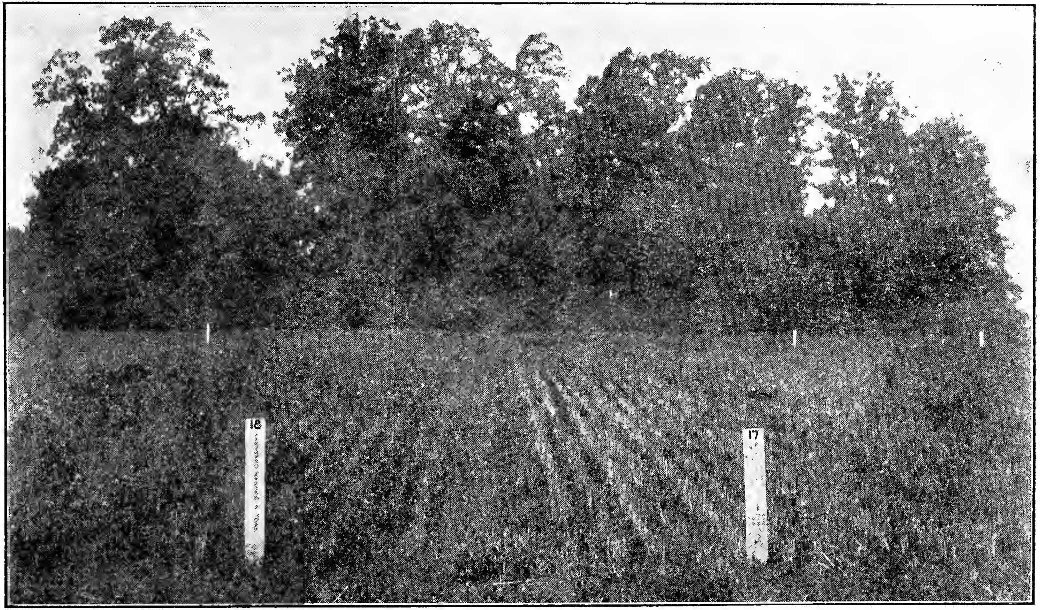
Clover in the fertility tests of Pennsylvania State College Experiment Station: Plot 13 (left), 320 pounds gypsum; Plot 14 (middle), nothing; Plot 15 (right), 320 pounds dissolved boneblack and 200 pounds muriate of potash on preceding wheat crop.

with phosphorus and potassium, but has reversed the results on the plots receiving dried blood or sulphate of ammonia in addition to the phosphorus and potassium, thus producing a still greater increase on these plots than that found where the nitrogen has been omitted.

That the superiority of nitrate of soda as a fertilizer for clover is not altogether due to greater effectiveness as a carrier of nitrogen is indicated by Table XX, which gives the average increase in the cereal crops of the five-year rotation at Wooster and Strongsville from different treatments on land, half of which has been limed for each corn crop since 1900 at Wooster, and since 1905 at Strongsville.

TABLE XX. COMPARATIVE EFFECT OF CARRIERS OF NITROGEN ON CEREAL CROPS GROWN IN ROTATION AT OHIO EXPERIMENT STATION.

Plot	Treatment	Station, crop, duration of test and average increase an acre (bushels)					
		Wooster			Strongsville		
		Corn 18 yrs.	Oats 18 yrs.	Wheat 18 yrs.	Corn 15 yrs.	Oats 15 yrs.	Wheat 14 yrs.
No. 2	Phosphorus alone.....	7.20	8.54	7.95	8.87	9.36	6.97
8	Phosphorus and potassium..............	14.22	12.02	8.85	9.64	9.50	8.32
23	Phosphorus, potassium and 38 pounds nitrogen in dried blood........	17.87	17.13	12.25	10.69	13.30	9.16
24	Phosphorus, potassium and 38 pounds nitrogen in sulphate ammonia..	17.34	17.96	12.46	9.82	13.95	9.79
21	Phosphorus, potassium and 38 pounds nitrogen in linseed oil meal....	17.79	16.06	13.55	10.15	12.87	9.87
17	Phosphorus, potassium and 38 pounds itrogen in nitrate of soda.....	18.93	18.51	12.88	11.66	13.66	9.03
11	Phosphorus, potassium and 76 pounds nitrogen in nitrate of soda.....	18.45	18.40	16.25	11.66	12.67	10.13
12	Phosphorus, potassium and 114 pounds nitrogen in nitrate of soda..	18.78	17.80	16.95	11.29	12.50	12.42



Clover in fertility tests of Ohio Experiment Station. Unlimed ends of Plot 18 (left, manured), and Plot 17 (right, fertilized). Neither manure nor fertilizers will produce clover on this land without the help of lime. See next illustration.

The table shows that when the fertilizer has contained nitrogen, in whatever carrier, there has been a much greater increase in the cereal crops than when the nitrogen has been omitted, and that the different carriers of nitrogen have differed much less widely in their effect on the cereals than on the clover crop.

It is true that plots 17, 21, 23 and 24 have received more phosphorus than plots 2 and 8, but in the fertilizing of plots 8, 11 and 12 the only difference is in the nitrate of soda, the phosphorus and potassium being the same for all. While the corn and oats have not responded to the increase of nitrogen on plots 11 and 12, the wheat shows an increase in yield for each addition of nitrogen.

Considering these results as a whole, we must conclude that, notwithstanding its high content of nitrogen, clover is comparatively indifferent to nitrogenous fertilizers, and that the superior growth of clover following applications of nitrate of soda on acid soils is probably chiefly due to the neutralizing effect of the soda; for the plant probably does not absorb nitrate of soda as such in any considerable quantity, but by the selective power of its roots separates the salt into its constituents, absorbing the nitric acid and leaving the soda, or most of it, in the soil, where it will immediately recombine with other acids, thus neutralizing their effect. Such an hypothesis would account for the fact that where nitrate of soda has been given in larger quantity than the cereal crops have been able to utilize there has been no further increase in the yield of clover.

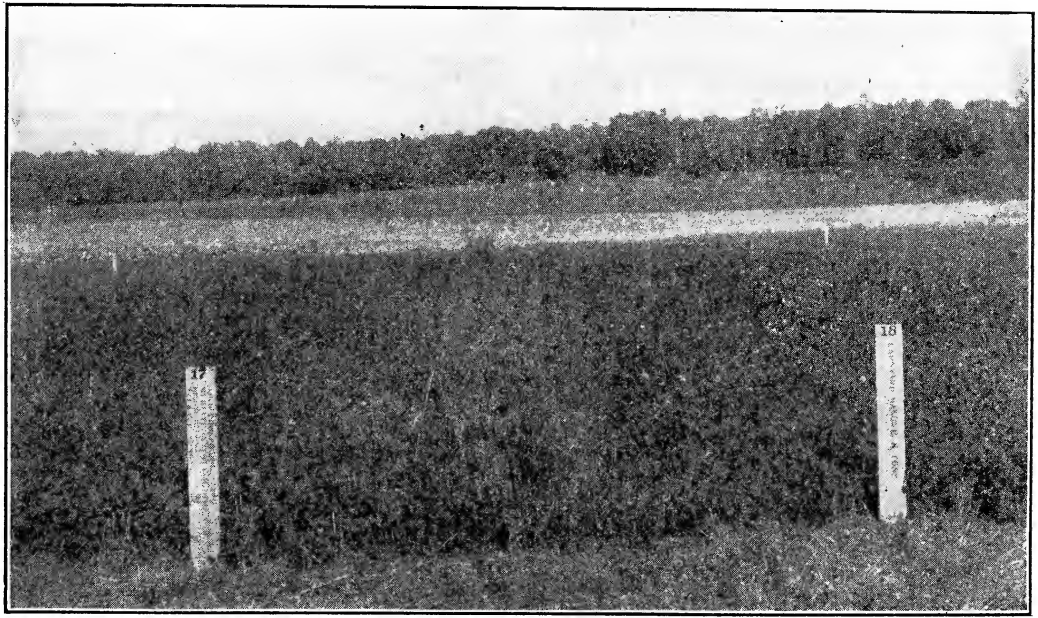
The larger growth of the cereal crops resulting from the application of nitrogenous fertilizers has left correspondingly larger residues of roots and stubble, which would account for a considerable increase in the clover crops following; but, as has been shown above, the difference between the residual effect of fertilizers in which the nitrogen carrier has been nitrate of soda and those in which it has been sulphate of ammonia or organic materials has been greater in the clover crop, on acid soils, than on the crops directly fertilized.

CHAPTER IV

The Composition of Manure

Terminology—The word manure is derived from the French "manœuvrer," to manipulate, to work, and in its earlier significance manuring meant both tilling or working the land and adding to it materials designed to increase its productiveness. Eventually the term became restricted to its narrower meaning of adding fertilizing materials, and in England manures are substances of any kind used for this purpose, whether the excreta of animals, chemical fertilizers, or crops grown to be turned under without harvesting. In America we sometimes speak of such crops as "green manures," but with this exception we limit the words manure and manuring to the excreta of animals and their use for soil enrichment; the use of chemical substances for this purpose being expressed as "fertilizing." In the following pages, therefore, "manure" will mean the excreta of animals—dung and urine with the straw or other material used as the absorbent; "green manure" will mean crops grown to be plowed down for soil improvement, and "fertilizer" will mean a chemical or manufactured material used for the same purpose.

The food controls the composition of manure—The food of the animal is the source of its manure,



Clover in the fertility tests of the Ohio Experiment Station. Limed ends of Plots 17 and 18 (see preceding illustration).

and the composition of the manure must, then, depend largely upon that of the food. It is true that this composition may be modified by the quantity of water drunk, and that in case of under feeding the body substance may be drawn upon to a limited extent to replace elements not sufficiently abundant in the food; but these are factors of minor importance.

The dung—A considerable part of the food, especially the coarser portion, resists the digestive action and passes out unchanged, except that it is ground to a finer condition by mastication, softened by admixture with water and digestive fluids, and with small amounts of waste tissue, cast off from the linings of the digestive tract. This constitutes the dung, or solid part of the excrement. The larger portions of the nitrogen and potassium of the food are dissolved out and carried into the circulation, to be excreted through the kidneys; hence the dung is relatively poor in these elements, as compared with the total excrement, while the portion that it does contain is in a comparatively insoluble form, and therefore less available to plants, being chiefly that contained in the food residues which have resisted the action of the digestive fluids.

The urine—The substances dissolved out of the food by the digestive process are carried into the blood, by which they are conveyed to all parts of the body, and from which the various tissues and organs appropriate what is needed for the maintenance and heat of the body, for growth, and for the renewal of worn-out tissues. Such of the dissolved nitrogen and mineral elements of the food as are not thus appropriated, together with the waste, are excreted through the kidneys in the urine, which thus carries off about half the nitrogenous excretions and about three-fifths of the potassic. That a larger portion of phosphorus is not excreted through the kidneys appears to be due to the fact that this element chiefly enters the blood as phosphate of lime, which is insoluble in alkaline fluids, and the urine is usually alkaline.

Relative production and composition of dung and urine—In 1891 the Cornell University experiment station collected separately the dung and urine from four cows for 24 hours.* The total production of dung was 225 pounds, and of urine 72.25 pounds. The average live weight of the cows was 1,178 pounds. Calculated per 1,000 pounds, live weight, the production was as follows:

DAILY WEIGHT OF EXCRETA

Average daily weight of dung,	54.12 pounds
" " " " urine,	15.33 "
Average daily total excrement,	69.45 pounds

The dung and urine were analyzed and found to contain the following percentages of fertilizing elements:

* Cornell University Experiment Station, Bulletin 27.

PERCENTAGES OF ELEMENTS IN EXCRETA

	In dung	In urine	In total excrement
Nitrogen,	0.26	1.32	0.49
Phosphorus,	0.123	....	0.097
Potassium,	0.166	0.83	0.315

The daily excrement would therefore contain the following quantities per 1,000 pounds live-weight:

POUNDS OF ELEMENTS IN EXCRETA

	In dung	In urine	In total excrement
Nitrogen,	0.14	0.203	0.35
Phosphorus,	0.066	....	0.066
Potassium,	0.09	0.128	0.218
Value,*	$0.034	$0.038	$0.072

In 1893 Prof. Harry Snyder, of the Minnesota experiment station,† collected separately the dung and urine from cows—weight not given—for five days, with results as below:

AVERAGE WEIGHT OF EXCRETA FROM COW

Average daily weight of dung, a cow,	40.8	pounds
" " " " urine, "	22.6	"
" " total excrement, "	63.4	"

* Computing nitrogen at 15 cents, phosphorus at 11 cents, and potassium at 6 cents a pound.

† Agricultural Experiment Station, University of Minnesota, Bulletin 26.

The analysis of the dung and the urine showed the following percentages:

PERCENTAGES OF ELEMENTS IN EXCRETA

	In dung	In urine
Nitrogen,	0.26	1.21
Phosphorus,	0.194	0.026
Potassium,	0.266	0.905

Calculated per cow per day, these percentages would show the following production (pounds):

DAILY WEIGHT OF ELEMENTS IN EXCRETA

	In dung	In urine	In total excrement
Nitrogen,	0.106	0.273	0.379
Phosphorus,	0.079	0.059	0.138
Potassium,	0.108	0.205	0.318
Value,	$0.031	$0.060	$0.091

Both the quantity and the composition of urine are variable, both for the different classes of animals and for the same animal under different conditions, being affected by the character of the food, the water drunk, the external temperature, etc. The tables of the Mentzel u. von Lengerke Landw. Kalender give the following as the average percentage composition of fresh urine from different classes of animals:

AVERAGE PERCENTAGE COMPOSITION OF URINE

	Nitrogen	Phosphorus	Potassium
From horses,	1.5	0.004	1.6
" cattle,	1.0	0.004	1.6
" sheep,	2.0	0.004	2.0
" swine,	0.5	0.04	2.0

The experiments above described show that more than half the fertilizing value of the excrement of dairy cows may be found in the urine.

Variation of composition—Since the manure is derived from the food consumed, it is evident that its composition may be materially modified, according to the character of the food. The feeding of highly nitrogenous foods, such as bran and oil meal, for example, will produce a manure rich in nitrogen; and as these substances, bran especially, also contain a large amount of phosphorus, that element also will be found abundant in the manure.

If, on the contrary, the ration be largely made up of such foodstuffs as corn and timothy hay, it will contain very little surplus of nitrogen and phosphorus beyond the needs of the animal, and the manure will consequently be relatively low in these elements.

If clover hay should replace timothy, there would be an increase of calcium and potassium in the manure, as the percentage of these elements is much greater in clover than in timothy.

The age and function of the animal also affect the composition of the manure. A growing calf, for example, gaining say 50 pounds per month in live weight, will store away 3½ to 4 pounds of phosphorus annually in its bones and other tissues, or as much as would be contained in two tons of mixed hay; and a cow, giving 4,000 pounds of milk a year, would put into the milk about 3 1-3 pounds of phosphorus; while a two-year-old steer, fattened in three or four months' feeding, may not appropriate more than a fraction of a pound of this element during the fattening period, although he may be consuming a much larger quantity of phosphorus in his food than is ordinarily given to the growing calf.

Manure is never entirely depleted of phosphorus— It is, of course, impossible to extract all the phosphorus from the food. A portion passes through in the undigested material, while of that digested, a considerable portion merely takes the place of an equivalent quantity which is being liberated in the metabolic processes and excreted; for growth is not simply a process of building up; the old structure is constantly being torn down to make room for the new. Hence a very much larger quantity of each of the various elements must pass through the body than is required for the actual growth of the animal. In this respect the growth of the animal organism differs radically from that of the plant.

The possible differences in composition of manure may be illustrated by the following analyses, the first being of manure from well-fed dairy cows, the second of that from fattening steers:

ELEMENTS IN MANURE OF ANIMALS VARIOUSLY FED

	Pounds a ton of manure		
	Nitrogen	Phosphorus	Potassium
Cow manure,	8.88	2.42	11.90
Steer "	9.78	4.73	9.34

Both cows and steers were being fed liberally with corn meal and bran, but the cows were consuming a larger proportion of roughage than the steers, which were being fed all the concentrates they could consume.

The following table gives the composition of various manures as found by the authorities quoted:

TABLE XXI. PERCENTAGE COMPOSITION OF MANURES

Kind of manure	Water	Nitrogen	Phosphorus	Potassium	Authority
HORSE MANURE					
Fresh with straw..........	70.8	0.51	0.092	0.440	Cornell Exp. Sta. Bul. 27
" " "	72.0	0.49	0.163	0.747	" " " " "
" " "	48.7	0.49	0.114	0.398	" " " " 56
" " "	60.0	0.63	0.123	0.564	Ohio " " " 183
" " "	62.7	0.73	0.116	0.647	" " " " "
Average..............	62.8	0.57	0.122	0.539	
Fresh without straw.......	...	0.47	0.172	0.780	Cornell " " " 27
From city stables[4].........	75.8	0.53	0.180	0.420	Conn. " " Rpt. 1889
" " "	69.3	0.69	0.295	0.522	" " " " "
From open yard[2]..........	80.1	0.45	0.176	0.415	Cornell " " Bul. 27
Dung only[3]...............	67.3	0.47	0.154	0.183	Conn. " " Rpt. 1889
" "	73.2	0.43	0.140	0.351	Ohio " " Bul. 183
COW MANURE					
Fresh with straw..........	81.4	0.47	0.141	0.398	Cornell " " " 27
" " " 4..........	75.2	0.43	0.128	0.365	" " " " 56
" " "	71.7	0.43	0.132	0.398	Conn. " " Rpt. 1889
" " "	81.5	0.49	0.122	0.324	Ohio " " Bul. 183
" " "	80.1	0.47	0.132	0.304	" " " " "
Average..............	78.0	0.46	0.131	0.358	
Fresh, without straw.......	85.3	0.53	0.070	0.299	Conn. " " Rpt. 1889
" " "	...	0.50	0.145	0.365	Cornell " " Bul. 27
" " " 5......	86.8	0.45	0.114	0.325	N. J. " " (Note)

Kind of manure	Water	Nitrogen	Phosphorus	Potassium	Authority
Fresh, dung only[5]	84.6	0.35	0.135	0.170	N. J. Exp. Sta. (Note)
" " "	85.0	0.36	0.113	0.174	Ohio " " Bul, 183
From covered shed	82.4	0.42	0.088	0.249	Conn. " " Rpt. 1889
" open yard[6]	67.0	0.55	0.224	0.705	Cornell " " Bul. 27
Urine only	...	0.32	....	0.830	" " " " "
" "	...	0.90	....	0.558	Ohio " " " 183
STEER MANURE					
Fresh with straw					
From cemented floor[7]	80.5	0.79	0.313	0.417	" " " " "
" earth floor[7]	78.8	0.73	0.326	0.390	" " " " "
Untreated	75.2	0.51	0.162	0.407	" " " " "
Treated with gypsum[8]	76.0	0.48	0.138	0.393	" " " " "
" " kainit[8]	76.2	0.49	0.144	0.585	" " " " "
" " floats[8]	76.5	0.53	0.430	0.369	" " " " "
" " acid phosphate[8]	77.0	0.49	0.285	0.344	
From open yard					
Untreated	83.1	0.35	0.121	0.164	" " " " "
Treated with gypsum[8]	83.1	0.39	0.131	0.126	" " " " "
" " kainit[8]	81.7	0.33	0.121	0.243	" " " " "
" " floats[8]	81.1	0.34	0.349	0.162	" " " " "
" " acid phosphate[8]	82.6	0.35	0.235	0.147	" " " " "
MIXED YARD MANURE					
Open-yard manure[9]	77.1	0.53	0.150	0.589	Conn. " " Rpt. 1889
" " " (old)[10]	54.7	0.46	0.317	0.133	" " " " "
" " "	72.3	0.44	0.154	0.469	Hatch " " Bul. 70
Hog manure	74.1	0.84	0.172	0.265	Cornell " " " 56
" "	...	0.54	0.290	0.606	N. Y. State" " Rpt. 9
" "	...	0.57	0.365	0.307	" " " " "
Sheep manure					
Fresh, without straw[11]	59.5	0.77	0.172	0.490	Cornell " " Bul. 56
Fresh, with straw[12]					
Ration, corn, mixed hay	58.4	1.49	0.228	1.115	Ohio " " " 183
" " oil meal "	65.7	1.55	0.235	1.022	" " " " "
" " " "	66.2	1.56	0.218	1.088	" " " " "
" " stock food, hay	67.9	1.35	0.181	0.974	" " " " "
Ration, corn, oilmeal, clover hay	62.0	1.68	0.259	1.037	" " " " "
Ration, corn, stock food, clover hay	61.8	1.48	0.259	1.014	" " " " "
Ration, corn, clover hay	61.0	1.60	0.254	1.002	" " " " "
" " " "	59.1	1.70	0.259	1.171	" " " " "
Average Ohio tests	62.8	1.55	0.236	1.052	
HEN MANURE					
Fresh, nitrogenous ration[13]	59.7	0.80	0.405	0.266	N. Y. State" " Rept. 8
Fresh, carbonaceous ration[13]	55.3	0.66	0.317	0.207	" " " " "
Fresh from capons	65.0	1.24	0.409	0.299	" " " " "
" average sample	55.0	1.15	0.405	0.373	N. J. " " Bul. 84
" no description	59.0	1.20	0.440	0.739	Mass. " " " 37
" " "	52.6	0.46	0.304	0.930	" " " " 63
Air dry	8.3	2.13	0.889	0.825	" " " Rpt. 8
" " nitrogenous ration	7.4	1.81	0.972	0.921	N. Y. State" " " "
" " carbonaceous ration	7.1	1.52	0.245	0.838	" " " " "

Notes.

1. Manure without bedding, from 10 work horses liberally fed on oats and hay.
2. After five months' exposure in open yard. During this time the total weight of manure was reduced by 57 per cent, that of the nitrogen by 60 per cent, that of the phosphorus by 47 per cent and that of the potassium by 76 per cent.
3. Fresh dung from a horse fed daily with 14 pounds of timothy hay and four quarts of oats with cracked corn. Somewhat dried.
4. Average of four analyses of manure from 18 cows bedded with cut wheat straw and the drops sprinkled with plaster.
5. Average of 17 analyses made 1898 to 1906, inclusive.
6. After six months' exposure in an open yard. The total weight of manure was reduced from 10,000 pounds to 5,125 pounds, and the nitrogen, phosphorus and potassium from 47, 14 and 40 pounds to 28, 11.5 and 36.5 pounds respectively, or by 40, 18 and 9 per cent.
7. Manure treated during accumulation with floats, at the rate of one pound per steer per day.
8. The materials were used for treatment at the rate of 40 pounds per ton of manure in each case.
9. Manure taken from a heap containing the accumulations from young, growing cattle and a few horses. A liberal quantity of bran, a few oats and a little corn meal with good timothy made up the feed.
10. Old yard manure made by young cattle fed in yard on hay. It represents well-rotted yard manure in its usual washed condition.
11. Average of six analyses.
12. Average of two analyses in each case of manure made by fattening lambs.
13. Part of the nitrogen believed by the analyst to have been lost in drying the samples for analysis.

A large number of analyses of manure, including some of the foregoing, have been collected by Professor Storer in his "Agriculture in Some of its Relations with Chemistry." These are averaged below:

PERCENTAGE COMPOSITION OF MANURES

Kind of manure:	Percentage composition: Nitrogen	Phosphorus	Potassium
Horse manure, 17 analyses,	0.59	0.150	0.432
Cattle " 53 "	0.58	0.123	0.440
Yard " 36 "	0.51	0.145	0.440
Sheep " 11 "	0.68	0.176	0.622

Corn in fertility tests at Southwestern Test Farm, Ohio Experiment Station (Germantown): Plot 8 (left), complete fertilizer; Plot 7 (right), unfertilized.

Computed in pounds per ton, the foregoing analyses indicate the range and average in composition shown in Table XXII.

TABLE XXII. AVERAGE COMPOSITION OF MANURES IN POUNDS A TON.

		Nitrogen	Phosphorus	Potassium
Fresh manure with straw	Range	9.8–14.6	1.8–3.2	9.0–15.0
	Average	11	2.4	11
Same from cows.........	Range	8.6– 9.4	2.5–2.8	6.0– 8.0
	Average	9	2.6	7
" " fattening steers	Range	9.6–15.8	2.7–3.2	6.8– 8.3
	Average	11	3.0	8
" " sheep..........	Range	12.6–34.0	3.4–5.2	9.8–23.4
	Average	20	3.9	14
Manure from hogs.......	Range	10.8–16.8	3.4–7.3	5.3–12.1
	Average	13	5.5	8
" " fowls......	Range	9.2–24.8	6.1–8.8	4.1–18.6
	Average	18	7.6	8
Yard manure from cattle	Range	6.6– 7.8	2.4–2.6	2.5– 2.3
	Average	7	2.5	3
" " mixed.....	Range	8.8–10.6	3.0–6.4	1.7–11.8
	Average	9	4.1	8

CHAPTER V

THE PRODUCTION OF MANURE

Manure from horses—In 1889 the experiment station of Cornell university collected the manure from a stable on two successive Sundays, the horses being in the stable all day on that day of the week; the first Sunday from nine, the second from eight horses, or a total of 17 horses for one day, with the following result:*

WEIGHT OF HORSE MANURE

Total weight of manure and bedding,	1,025.5	pounds
Weight of bedding,	68.5	"
" of excrement, solid and liquid,	975.0	"
" of excrement, a horse, a day,	56.2	"
" manure and straw, a horse, a day,	60.3	"

The weight of the horses is not given.

The next year this experiment was repeated with ten horses for a period of 11 days, including one Sunday. The horses were mostly grade draft horses, of about 1,400 pounds weight, doing heavy work and liberally fed on oats and hay. There was secured in the stables 3,461 pounds of clear excrement, or 31.5 pounds per horse per day—about three-fifths of the total production.†

* Cornell University Agricultural Experiment Station, Bulletin 13.
† Ibid., Bulletin 27.

This experiment was repeated a year later with five horses, four work horses and one two-year-old colt, the five having a total weight of 6,410 pounds. The food consisted of a grain ration of 12 quarts of a mixture of oats, corn meal and wheat bran with hay, for the work horses, and hay only for the colt, the exact amount consumed not being given. One hundred and twenty-nine pounds of gypsum was used on the stable floor, and 112¾ pounds of straw was given for bedding. The total weight of manure was 555 pounds, including bedding and plaster, or 48.8 pounds of excrement per 1,000 pounds live weight of animal per day, excluding the bedding and plaster. The manure was analyzed and found to contain 0.49 per cent nitrogen, 0.08 per cent phosphorus and 0.179 per cent potassium.*

These experiments indicate an average production of manure by horses amounting to about 50 pounds per 1,000 pounds live weight per day, exclusive of bedding.

Manure from dairy cows—In 1891 the same station collected the manure for one day from 18 Jersey and Holstein cows which were consuming daily 114 pounds of hay, 893 pounds of silage, 186 pounds of beets and 154 pounds of a mixture of 12 parts wheat bran, nine parts cottonseed oil meal, three parts corn meal and one part malt sprouts. The outcome is given below:†

* Ibid., Bulletin 56.
† Ibid., Bulletin 27.

DAIRY COW MANURE

Average weight of cows,	1,132	pounds
Excrement produced,	1,452	"
" per cow, per day,	81	"
" per 1,000 pounds, live weight,	71½	"

In 1893 this experiment was repeated on a larger scale, 18 cows being included in the test for three days, and 17 for one day.*

The average weight of the cows was 1,125 pounds, and during the test they consumed 780 pounds of hay, 3,105 pounds silage, 475 pounds beets, 275 pounds bran, 52 pounds corn meal, 171 pounds cottonseed meal and 612 pounds straw. The cows produced per day and per 1,000 pounds live weight 74.2 pounds excrement (excluding bedding), found to contain 0.351 pound nitrogen, 0.108 pound phosphorus and 0.237 pound potassium. Somewhat more than 60 per cent of the fertilizing elements in the feed and bedding was recovered in the manure.

In 1907 the Ohio experiment station fed six cows for ten days, the average weight of the cows being 905 pounds and the feed consisting of 170 pounds bran, 1,577 pounds corn silage, 400 pounds stover, 34 pounds hay and 125 pounds distiller's grains, with 240 pounds straw for bedding. The total production of manure was 3,705 pounds, or 61¾ pounds per cow per day, or 57¾ pounds excrement, excluding bedding. Calculated per 1,000 pounds live weight, the daily production of manure was 68¼

* Ibid., Bulletin 56.

pounds; or that of the excrement only, exclusive of bedding, 63.81 pounds.*

Director E. B. Voorhees, of the New Jersey experiment station, states that the records kept at the Rutgers college farm show that the average production of excrement, unmixed with litter, has amounted to 70 pounds per day for cows averaging about 1,000 pounds in weight.†

The above data, together with those furnished by the New York and Minnesota experiments, in which the dung and urine were separately collected, are summarized in Table XXIII, the bedding being excluded in all cases:

TABLE XXIII. PRODUCTION OF MANURE BY DAIRY COWS.

Station	Number of cows in test	Average live weight of cows	Quantity of excrement a day	
			Per cow	Per 1,000 lbs. live-weight
N. Y. (Cornell)	4	1,178	81.81	69.45
" "	18	1,132	80.71	71.30
" "	18	1,125	....	74.20
Minnesota	2	....	63.40	70.00
New Jersey	..	1,000	....	....
Ohio	6	905	57.75	63.81

It appears from the above experiments that the larger cow produces more manure, in proportion to live weight, than the smaller one. The quantity

* Ohio Agricultural Experiment Station, Bulletin 183, p. 201.
† Annual Report New Jersey Experiment Station, 1901, p. 141.

of manure is, of course, affected by the total quantity of food consumed, and also by the water drunk.

Manure from fattening steers—Forty-eight grade Angus steer calves, bred in the "Panhandle" of Texas, and weighing 448 pounds each on the average, were stabled at the Ohio experiment station January 1, 1903. On May 15, 1904, 24 of these calves were turned on pasture, where they ran until November 15, when they were returned to the stable, where the other 24 had remained during the summer. On March 15, 1904, the cattle which had been continuously stabled were withdrawn from the test, their average weight being then 1,216 pounds. The 24 which had been pastured were fed until June 15, their weight then averaging 1,083 pounds. The average weight of the 48 cattle, during the period when they were stabled, was 950 pounds. The total time they were stabled was equivalent to 624 months for one animal. During this time they produced 699,504 pounds of manure, including bedding, or almost 350 tons, equivalent to 1,120 pounds, or a little more than one-half ton per animal per month, or practically 40 pounds per day for each thousand pounds of live weight.*

Table XXIV gives the total quantities of the different kinds of feed consumed by these cattle while stabled and the straw used for bedding; the chemically dry substance in the feed and bedding, and the nitrogen, phosphorus and potassium contained, computed on average analyses.

* Ohio Agricultural Experiment Station, Bulletin 183, p. 196.

TABLE XXIV. PRODUCTION OF MANURE BY FATTENING STEERS; QUANTITY OF FEED AND BEDDING, AND FERTILIZING ELEMENTS CONTAINED.

Feed and bedding	Quantity Pounds	Dry substance Pounds	Elements (Pounds)		
			Nitrogen	Phosphorus	Potassium
Wheat bran	83,256	73,348	2,223	1,059	1,112
Corn meal	100,121	85,103	1,822	308	332
Linseed oil meal	25,446	23,410	1,382	186	289
Dried beet pulp	2,088	1,775	32	1	31
Mixed hay	79,093	73,008	1,115	94	1,018
Clover hay	12,817	10,856	265	21	234
Corn silage	120,027	30,000	336	58	368
Corn stover	23,707	21,336	247	30	275
Total in feed	....	318,836	7,422	1,751	3,659
Straw and bedding	107,778	97.431	636	57	456
Grand total	....	416,267	8,058	1,814	4,115

The increase in live weight of the cattle while stabled amounted to 33,492 pounds, or 10½ pounds for each hundred pounds of dry substance in the feed. This increase is estimated to have contained 733 pounds of nitrogen, 210 pounds of phosphorus and 46 pounds of potassium, as computed on the basis of Lawes & Gilbert's investigations. The Ohio station's analyses of the manure indicate that it contained 0.496 per cent nitrogen, 0.237 per cent phosphorus and 0.473 per cent potassium, or 9.92, 4.74 and 9.46 pounds, respectively, per ton, thus showing a total recovery in the manure of 3,472 pounds of nitrogen, or 46 per cent of that given in the feed and bedding; 1,659 pounds of phosphorus, or 92 per cent, and 3,311 pounds of potassium, or 81 per cent.

In the light of subsequent investigations it seems probable that the actual recovery of nitrogen was much greater than that indicated above, a part of the nitrogen having been lost in the analysis through the methods employed.

Valuing nitrogen at 15 cents, phosphorus at 7 cents, and potassium at 6¼ cents per pound, the manure in this experiment would have a total value of $902, or $2.57 per ton, a value which the field experiments of the same station have shown to be quite possible to realize, when the manure is properly used.

Feeding on earth or cement floors—This experiment was followed the next year by another,* in which 58 grade Hereford and Shorthorn steers were fed from December 1, 1904, to June 1, 1905—182 days. These steers were fed in two divisions—one of 28 head, which were fed on a cemented floor; and one of 30 head, which were fed on an earth floor, which had been packed by several years' use.

Table XXV shows the quantities of different feeds consumed by each division during this test, with the amounts of dry substance and nitrogen, phosphorus and potassium contained, as computed on average analyses. In both cases the stables were dusted occasionally with the finely powdered phosphate rock, known as floats, using a little less than a pound per animal per day. The total quantity thus used is given in the table. The manure was allowed to accumulate for several weeks at a time, when it was weighed out.

* Ibid., p. 197.

The 28 steers fed on the cemented floor produced a total of 255,203 pounds of manure, including bedding and floats, or 50 pounds each per day, equivalent to 47½ pounds per day per 1,000 pounds live weight, the steers weighing on the average 874

TABLE XXV. PRODUCTION OF MANURE BY FATTENING STEERS. QUANTITY OF FEEDS AND ELEMENTS CONTAINED.

Feeds	Total quantity Pounds	Dry substance Pounds	Elements contained (Pounds)		
			Nitrogen	Phosphorus	Potassium
28 steers on cement floor					
Wheat bran	9,448	8,324	252.3	120.1	126.2
Corn meal	48,128	40,909	875.9	148.2	159.8
Linseed oilmeal	5,593	5,083	304.0	40.9	63.7
Cottonseed oilmeal	5,097	4,685	346.1	64.6	36.8
Corn silage	63,231	15,808	177.0	30.6	194.2
Corn stover	4,896	4,406	50.9	6.2	56.8
Mixed hay	31,814	26,946	448.6	37.8	409.3
Total feed	....	106,161	2454.8	448.4	1,046.8
Straw	39,033	35,131	230.3	20.6	165.2
Floats	4,753	....	....	564.6	....
Total	....	141,292	2,685.1	1,033.6	1,212.0
30 steers on earth floor					
Wheat bran	2,325	2,048	62.1	29.6	31.0
Corn meal	53,654	45,606	976.5	165.3	178.1
Linseed oilmeal	6,695	6,079	363.5	48.9	76.1
Cottonseed oilmeal	6,125	5,622	415.9	77.6	44.2
Corn silage	54,355	13,588	152.2	26.1	166.9
Corn stover	3,440	3,096	35.8	4.4	40.0
Mixed hay	36,986	31,318	521.5	44.0	475.8
Total feed	....	107,357	2,527.5	395.9	1012.1
Straw	38,762	34,886	228.7	20.5	164.1
Floats	4,720	....	....	560.7	....
Total	....	142,243	2,756.2	977.1	1,176.2

pounds when the test began and 1,230 pounds at the close, making a gain of one pound for every 10.65 pounds of dry substance in the feed.

From the 30 steers fed on the earth floor there was weighed out 236,399 pounds of manure, or 43.3 pounds per steer per day, or 41.3 pounds per day per 1,000 pounds average live weight, the steers averaging 867 pounds each at the beginning and 1,227 at

TABLE XXVI. PERCENTAGE COMPOSITION OF MANURE.

Constituents	A—On cement floor	B—On earth floor	A more (+) or less (−) than B
Water	80.526	78.786	+1.740
Ash	3.006	3.597	−0.591
Organic matter	16.467	17.619	−1.152
Nitrogen total	0.786	0.727	+0.059
Nitrogen water-soluble	0.498	0.427	+0.071
Phosphorus total	0.313	0.326	+0.013
Phosphorus water-soluble	0.089	0.074	+0.015
Potassium total	0.417	0.390	+0.027
Potassium water-soluble	0.363	0.334	+0.029

the close of the test, the gain being one pound for 9.9 pounds dry substance in the feed. Thus there was a loss of six pounds of manure per head per day on the earth floor as compared with that collected on the cement floor, presumably due to the seepage of urine, and amounting to half a ton per steer, or 15 tons for the 30 steers during the six months of the test.

Excluding the floats, the steers fed on the cemented floor produced 1,772 pounds of manure for 1,000 pounds of dry substance in the feed and bedding, and those on the earth floor, 1,628 pounds.

Four analyses were made of the manure produced on the cemented floor, under the supervision of the station chemist, Prof. J. W. Ames, and five of that on the earth floor, which indicated the composition shown in Table XXVI.

The table shows more water and less ash and organic matter in the manure from the cemented floor; more nitrogen and potassium, both total and water soluble, and less total phosphorus, but more water-soluble phosphorus.

In April, 1907, these stables were again filled with 63 grade steers,* 21 of which were fed on the cemented floor and 42 on the earth floor, but no separate record was kept of the manure production on the two floors. The steers averaged 1,089 pounds each at the beginning of the test, and 1,234 pounds at its close, 60 days later. They consumed feeds and bedding containing a total of 110,627 pounds of dry substance, and produced 178,740 pounds of manure, equivalent to 1,615 pounds of manure to 1,000 pounds of dry substance in feed and bedding, or 49.37 pounds manure per steer per day, or 42.52 pounds manure per day per 1,000 pounds live weight.

Hogs following steers—In February, 1907, 42 steers, in six lots of seven steers each, were placed in this stable,† on the earth floor, and were fed until July 20th, 150½ days.

The steers were confined to their pens throughout

* Ibid., p. 200.
† Ibid., p. 224.

the test, being watered in the pens. In each pen were kept three shoats, which had no other feed than the droppings of the steers, except that one lot received tankage in addition, the total quantity of tankage fed amounting to 135 pounds.

Three of the lots of steers received corn silage, two years old, as part of their ration, while the other three lots were fed corn stover instead of silage.

The silage-fed steers averaged 1,111.3 pounds in live weight during the experiment, and the dry-fed steers 1,101.1 pounds.

The feed consumed daily by the silage-fed steers is estimated to have contained 23 pounds of dry substance per thousand pounds live weight, and that by the dry-fed steers, 25.7 pounds.

The silage-fed steers received bedding to the amount of 9.69 pounds daily per thousand pounds live weight, and the dry-fed steers to the amount of 9.47 pounds, these amounts being two or three pounds greater than for the bedding used in previous experiments. All the pens were dusted with floats at the rate of one pound per steer per day.

The total manure taken from the silage-fed lots amounted to 174,805 pounds, and that from the dry-fed lots, to 206,320 pounds. The production of total manure, including bedding and floats, was therefore 57.8 pounds per day per thousand pounds live weight for the silage-fed steers and 65.3 pounds for the dry-fed steers.

Excluding bedding and floats, the average daily production of excrement was 47.2 pounds per day per thousand pounds live weight of steers for the silage-fed lots and 54.5 pounds for the dry-fed lots.

This production of excrement, it will be observed, is considerably greater per thousand pounds live weight than that found in the previous experiments. The increase is due to the fact that the steers were kept constantly in the stable, and to the presence of the pigs. It is true that the pigs merely worked over material that would otherwise have gone into the manure, with the trifling exception above noted, but they added to this material a considerable quantity of water.

The average total weight of the nine pigs following the silage-fed cattle amounted to 1,188 pounds, and that of those following the dry-fed steers, to 1,270 pounds. Adding their weight to those of the steers, the average production of excrement for the silage-fed lots was 41.5 pounds per day per thousand pounds live weight, and that for the dry-fed lots was 47.7 pounds.

The larger production of manure by the dry-fed steers was due to a larger consumption of feed. These steers had a larger proportion of roughage in their ration, and consumed daily 2.7 pounds more dry substance per thousand pounds live weight than the silage-fed steers.

The data for these tests in steer feeding are summarized in Table XXVII.

The table shows a recovery of excrement amounting to nearly two pounds for each pound of dry substance in the feed on the cemented floor, and to about 1.75 pound on the earth floor, where there were no pigs following the cattle. Where the pigs were added the recovery on the earth floor has been practically the same as that on the cemented floor without them.

Manure from sheep—Bulletin 183 of the Ohio station reports the production of manure in two

TABLE XXVII. PRODUCTION OF MANURE BY FATTENING STEERS—SUMMARY.

No. steers in test	Average weight of steers Pounds	Daily weight excrement (Pounds)		Kind of floor
		Per 1,000 pounds live weight	Per 1,000 pounds dry substance in feed	
48	950	34.2	1,856	Cement
28	1,052	38.9	1,991	Cement
30	1,047	34.2	1,797	Earth
63	1,161	35.2	1,700	Earth and cement
20	1,111	41.5	1,843	Earth
21	1,101	47.7	1,925	Earth

co-operative experiments in the feeding of western range lambs. In the first experiment, made during the winter of 1905-6, 160 lambs were fed over a period of 112 days. The lambs were fed in lots of 40 each on an earth floor, and the manure was trampled under foot with the bedding, being removed once during the course of the experiment and again at its close. The average weight of the lambs during the test was 84 pounds, and there was a total production of 49,895 pounds of manure, including 4,950 pounds of bedding. The lambs received the following quantities of feeds and bedding:

FEED AND BEDDING USED BY FLOCK OF LAMBS

Corn,	20,057	pounds
Cottonseed oil meal,	905	"
Linseed oil meal,	905	"
Clover hay,	11,110	"
Mixed alfalfa and bluegrass hay,	15,826	"
Oat straw,	3,020	"

Of the hay, 1,933 pounds was rejected, and was returned to the pens as bedding, together with the straw, which was chiefly oat straw.

The nitrogen was determined in the hays and eight analyses were made of the manure. On the basis of these determinations and of average analyses for the other feeding stuffs the following balance sheet is computed:

AVERAGE WEIGHT OF ELEMENTS IN FEED, BEDDING AND MANURE

Pounds	nitrogen in feed and bedding,	1,150
"	phosphorus " " "	137
"	potassium " " "	538
"	nitrogen recovered in manure,	743
"	phosphorus " " "	108
"	potassium " " "	525
Per cent	nitrogen " " "	64
"	phosphorus " " "	79
"	potassium " " "	97

The total manure amounted to 33.15 pounds per day per 1,000 pounds live weight of animal, or to 29.86 pounds of excrement, excluding bedding.

This experiment was repeated the following winter, with 176 lambs, which were fed 115½ days, during which they averaged 62½ pounds in live weight. They consumed feed and bedding as follows:

FEED AND BEDDING USED BY FLOCK OF LAMBS

Corn,	21,917	pounds
Linseed oil meal,	930	"
Clover hay,	23,315	"
Wheat straw,	3,060	"

Of the hay, 1,888 pounds was rejected, and was used for bedding. The feeds were not analyzed, but eight analyses were made of the manure as before. Assuming average composition for the feeds and bedding and taking the station analyses of the manure, the outcome of this test was as below:

AVERAGE WEIGHT OF ELEMENTS IN FEED, BEDDING AND MANURE

Pounds nitrogen in feed and bedding,	950
" phosphorus " " "	115
" potassium " " "	521
" nitrogen recovered in manure,	681
" phosphorus " " "	109
" potassium " " "	450
Per cent nitrogen " " "	72
" phosphorus " " "	95
" potassium " " "	86

While it is probable that an exact analysis of all the feed and bedding would have shown a larger quantity of the fertilizing elements than has been assumed in the above computations, thus reducing the percentage recovery, yet those accustomed to feeding sheep after the method employed in these tests will readily agree that such feeding involves the smallest possible loss of the manurial elements of the feeds, as the smaller quantities in which the urine is voided by sheep permits a more thorough absorption by the bedding than is practicable in the feeding of larger animals.

Manure from pigs—The Cornell University experiment station fed three lots of grade Poland-China pigs,* three pigs in each lot, for one week on galvanized iron pans, collecting all the excrement. The pigs received the following quantities of feed:

FEEDS CONSUMED BY PIGS (POUNDS)

Skim milk,	413.00
Corn meal,	128.29
Wheat bran,	4.57
Linseed meal,	6.86
Meat scraps,	61.76

The pigs weighed 134 pounds each on the average, and produced a total of 803.5 pounds of excrement, or 85.6 pounds per day per 1,000 pounds live weight of animal. The percentage composition of the manure was:

* Cornell University Experiment Station, Bulletin 56.

ELEMENTS IN PIG MANURE: PERCENT

Nitrogen,	0.84
Phosphorus,	0.172
Potassium,	0.266

This composition would indicate a value per ton of $2.71. There was no doubt a larger quantity of manure than would have been the case if the pigs had had dry feed only, instead of milk, and it was higher in nitrogen because of the large amount of nitrogen contained in the meat scraps.

Table XXVIII shows the estimated quantities of fertilizing elements given in the feed and recovered in the manure in this test.

TABLE XXVIII. RECOVERY OF MANURIAL ELEMENTS IN PIG FEEDING.

	Weight of various elements (Pounds)		
	Nitrogen	Phosphorus	Potassium
Given in feed	10.761	2.266	1.274
Recovered in manure	8.028	1.597	1.103
Percentage recovery	74.6	70.5	86.6

Manure from hens—In 1888 the New York state experiment station* made a series of experiments on the production and composition of hen manure. In one of these experiments two pens, No. 6 and No. 7, containing 13 to 16 laying hens each, about evenly divided between the larger and the smaller breeds,

* N. Y. Agricultural Experiment Station, 8th Annual Report.

were fed for ten months, pen No. 6 receiving a more nitrogenous ration than No. 7. The weight of manure collected from the roost platforms was at the rate of 13.4 pounds per hen per year, equivalent to 33.3 pounds of fresh manure, for pen No. 6, and of 13 pounds, equivalent to 29 pounds fresh manure, from pen No. 7.

In another experiment two pens of fowls, 12 in each, one pen of cockerels and one of capons, were fed for fattening. The cockerels produced manure at the rate of 42.8 pounds of fresh manure per year per fowl, and the capons at the rate of 43.6 pounds, while on the roosts, thus indicating a total annual production per fowl of 70 to 80 pounds, as probably at least as much manure is dropped through the day as while on the roosts.

The composition of these manures is given in Table XXI, together with that of samples analyzed by other stations, but for which no data of production are given.

In its fresh state hen manure contains 55 to 65 per cent of moisture, so that it is relatively drier than the excrement of quadrupeds. Moreover, it is in such physical condition that it loses moisture readily, and thus soon comes to the air-dry state, which is practically the only form in which it is used.

CHAPTER VI

THE VALUE OF MANURE

The Rothamsted experiments—The longest continued experiments in the use of manures and fertilizers in the world are those of the Rothamsted experiment station, in England, which were begun in 1843 and are still in progress. In one of these experiments wheat has been grown continuously on the same land, in "Broadbalk Field," either without any manure or fertilizer, or with various combinations of fertilizing chemicals, or with barnyard manure. The field contains about eleven acres and is subdivided into half-acre plots.

Previous to 1843 the land had been cropped in a five-course rotation. The latest manuring was in 1839, and the first experimental crop of wheat, harvested in 1844, yielded but 15 bushels per acre on the unmanured land, although the season was one of more than average yield in general.*

In this experiment plot 2 has received manure at the rate of 14 long tons, equivalent to 15½ short tons, or 31,366 pounds, per acre every year since the beginning of the test, and plot 3 has been continuously unmanured for the same period. After the first eight years a change was made in the fertilizing of the other plots in the test, but beginning

* The Book of the Rothamsted Experiments, by A. D. Hall.

with the crop of 1852 plot 6 has received per acre every year a dressing made up of 200 pounds of ammonia salts, containing 43 pounds of nitrogen, 392 pounds of superphosphate (or acid phosphate, as it is called in America), 200 pounds of sulphate of potash and 100 pounds each of the sulphates of soda and magnesia, a total of nearly 1,000 pounds per acre. Omitting the sulphates of soda and magnesia as probably unnecessary, the other materials would cost, at present prices in this country, about $15.25, of which $7.30 would go for nitrogen in the ammonia salts.

On plot 7 the same mineral substances have been used, in combination with 400 pounds of ammonia salts, thus raising the cost to $22.55, and on plot 8 the same minerals again, with 600 pounds of ammonia salts, at a total cost of $29.85 per acre annually.

Both the manure and the fertilizers have been used in excessive quantities in this test, the object being primarily to study the feeding habits of the wheat plant, and only incidentally to obtain a guide to the use of fertilizers and manures; but the test is not without its value from the practical as well as from the scientific standpoint.

In Table XXIX the results of this test are arranged in six periods, the first of eight years preliminary to the final organization of the test, the others of ten years each.

The table shows that there was a general depression in yield during the period 1872 to 1881, a depression which was due to a series of unfavorable seasons. Eliminating this period, we see that the unfertilized yield fell slowly for 30 years, after which it remained practically stationary.

TABLE XXIX. AVERAGE YIELD OF WHEAT IN BROADBALK FIELD IN BUSHELS AN ACRE, BY PERIODS.

Period	Treatment				
	Plot 3 None	Plot 2 14 tons manure	Plot 6 200 pounds ammonia salts with minerals	Plot 7 400 pounds ammonia salts with minerals	Plot 8 600 pounds ammonia salts with minerals
1844-51	17.2	28.0	....	....	....
1852-61	15.9	34.2	27.2	34.7	36.1
1862-71	14.5	37.5	25.7	35.9	40.5
1872-81	10.4	28.7	19.1	26.9	31.2
1882-91	12.6	38.2	24.5	35.0	38.4
1892-01	12.5	39.2	23.1	31.8	38.5
50 years 1852-1901	13.1	35.6	23.9	32.9	36.9

The manured yield has arisen steadily from the beginning of the experiment, the increase from the manure rising from 10.8 bushels per acre during the first eight years to 26.7 bushels during the last 10 years, averaging 22.5 bushels for the 50-year period 1852 to 1901, an increase of 1.44 bushel of wheat for each ton of manure.

The yield on plot 6, receiving 200 pounds of ammonia salts with minerals, has steadily diminished, ending the 50-year period with a 10-year average of 23 bushels, or 16 bushels per acre less than that given by the manure for the same period. The 50-

year average increase for this application has been 10.8 bushels per acre, or 0.71 bushel for each dollar's worth of fertilizers at present valuations.

On plot 7, with its larger application of a highly nitrogenous fertilizer, the yield stood, for the first 10-year period after the beginning of the application, at a point slightly above that given by the manure during the same period; but during the four succeeding periods the yield on this plot has remained below that on the manured plot, finally ending the 50-year period more than seven bushels under it. The average increase on this plot for the 50 years has been 19.8 bushels per acre, or 0.88 bushel for each dollar's worth of fertilizers.

On plot 8, with a still larger dressing of ammonia salts, the yield for 40 years was a little higher than on the manured land, but here also the yield has dropped below the manured yield for the last 10 years. The average increase on this plot for the 50-year period has been 23.8 bushels per acre, or 0.80 bushel for each dollar's worth of fertilizers, thus showing that the point of greatest net effectiveness in fertilizing lies somewhere between the applications given to plots 7 and 8.

The dressing on plot 8 has carried annually about 129 pounds of nitrogen, 28 pounds of phosphorus and 83 pounds of potassium, while the manure applied to plot 2 is estimated by Director Hall to have carried each year about 200 pounds of nitrogen, 34 pounds of phosphorus and 195 pounds of potassium. If we were to rate these elements at the same prices at which they are computed in the chemicals, the value of 15½ short tons of manure applied annually would amount to $50, or more than $3.00 per ton, and the increase would average 0.45 bushel of wheat for each dollar's worth of manurial chemicals.

Such a comparison is manifestly unfair to the manure, both because the manure has evidently carried far larger quantities of fertilizing elements than the crops could utilize, and because these elements must necessarily exist in a less readily available condition in the manure than in the chemicals; but taking the results as they stand, the immediate effect from the manure has been about 60 per cent of that from the combination of chemicals most nearly comparable with the manure—that used on plot 8.

Valuing wheat at 80 cents per bushel and straw at $2 per ton, the manure used in this test has produced increase to the value of $1.45 per ton of 2,000 pounds.

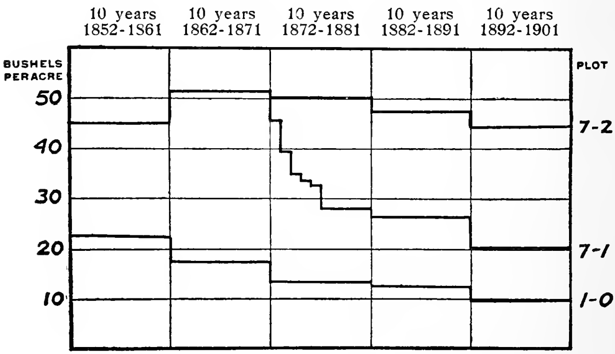
The fact that the manure has carried to the soil much larger quantities of fertilizing elements than have been removed by the crops would lead us to expect a considerably greater residual effect from the manure than from the chemicals, were manuring and fertilizing to be discontinued—an expectation which these experiments justify, as will be shown later.

Experiments on barley—In another of the Rothamsted experiments, conducted in "Hoos Field," barley has been grown continuously since 1852, both with and without manure and fertilizers. In this experiment, also, the manure has been used at the same rate of 14 long tons per acre, but the most effective chemical fertilizer has been made up of 200 pounds of ammonia salts and 392 pounds of superphosphate without any potash. This application has produced a 50-year average increase of 28.6 bushels per acre, raising the total yield to 43.9 bushels; and while the manure has produced an increase of 32.4 bushels, it is evident that it has been used in quantity far beyond the capacity of the crop to utilize it.

Residual effect of manure—The most interesting feature of this experiment is that after 20 years the manuring was discontinued on one-half of the manured plot, and this half has been left without any manure or fertilizer since. The result has been that at the end of the 50-year period, or thirty years after the manuring had been discontinued, this land was still yielding twice as much barley as the continuously unmanured land. The course of this experiment is illustrated by the accompanying diagram, compiled from Director Hall's "Book of the Rothamsted Experiments."

In this diagram the upper heavy line shows the yield of the continuously manured plot, No. 7, by 10-year periods. At the end of 20 years this plot was divided into 7-1, on which the manuring was discontinued, and 7-2, still manured as before. The diagram shows that there was a rapid falling off in the yield of plot 7-1 during the first five years, but after that its yield has fallen much more slowly, maintaining an average about twice that of the land which has had no manure—plot 1-0—during the 50 years of the test.

Diagram I. Barley in Hoos Field, Rothamsted. Average Yield of Grain Per Acre, for Successive 10-Year Periods, 1852-1901, Inclusive.



Plot 7-2, manured continuously; Plot 7-1, manured first 20 years, manuring then discontinued; Plot 1-0, continuously unmanured.

Evanescent effect of chemicals—In striking contrast with this outcome is that of another experiment in Broadbalk Field, in which two plots receive one season 400 pounds of ammonia salts and the next season 600 pounds of a mixture of superphosphate and the sulphates of potash, soda and magnesia, the plots being alternately fertilized—the one receiving the ammonia salts while the other receives the minerals, and vice versa. The result has been a 50-year average production, for the years when the ammonia salts were applied, of 30.4 bushels per acre, against 15.3 bushels for the years when the minerals only were given, the unfertilized yield averaging 13.1 bushels, thus illustrating the paramount influence of nitrogen in producing increase of crop in this continuously grown wheat, and also showing the evanescent effect of the nitrogen carried in chemicals, as compared with that carried in manure.

It is true that phosphorus and potassium have been relatively less effective on the wheat in Broadbalk Field than on the barley in Hoos Field, as the 50-year average increase of wheat from fertilizers carrying these elements, but no nitrogen, has been less than two bushels per acre, whereas the increase of barley from similar fertilizers has been five bushels. Yet, after making full allowance on this score, it is evident that the effect of manure, while not so immediate as that of chemicals, is much more permanent.

Excessive quantities of manure and fertilizers— In these English experiments both manure and chemicals have been applied in quantities containing much more nitrogen, phosphorus and potassium than the entire crops have carried away, consequently there has been a waste of fertilizer, so far as the immediate needs of the crops were concerned, for in addition to the reinforcements of such materials, carried in the manure and chemicals, the soil itself has been able to furnish a considerable quantity of plant food, as shown by the unfertilized yields, that of wheat having remained practically stationary at about 12 bushels per acre during the last 30 years of the test.

The Woburn experiments—Next to the Rothamsted experiments, the longest continued field experiments in the world are those of the Woburn experiment station, on the estate of the Duke of Bedford. These experiments were begun in 1877, and had as one of their objects the study on a soil of different type of some of the problems suggested by the Rothamsted experiments, the soil at Woburn being more sandy and containing less lime than that at Rothamsted. In one of these experiments, in which wheat and barley are grown continuously, plot 11 has received annually a quantity of manure produced by steers fed a fattening ration, and described as "well-rotted, cake-fed dung."* The manure has been estimated to contain 200 pounds of ammonia (equivalent to 164 pounds of nitrogen) per acre. In the earlier years of the test the quantity of manure was reported at eight (long) tons per acre, but in the summary of the first 20 years' results, above referred to, Dr. Voelcker states that the average application has been about seven tons per acre, which would be equivalent to nearly eight tons of 2,000 pounds each.

After five years this plot was subdivided, the manuring being discontinued on 11-a, but remaining as before on 11-b.

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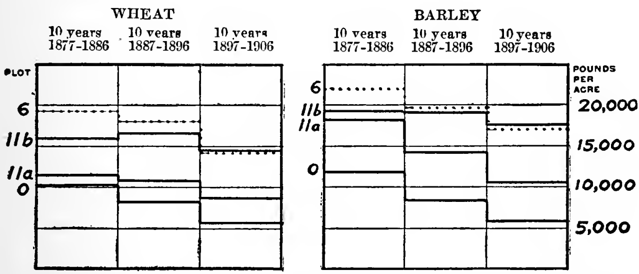
* Journal Royal Agriculture Society of England, 8, 282.

The outcome of this test is shown in Diagram II, which represents the total yield for each 10-year period of the continuously unmanured land (plot 0); of the land manured for five years, after which the manuring was discontinued (plot 11-a); of the continuously manured land (plot 11-b); and of plot 6, receiving each year a chemical fertilizer composed of 392 pounds of superphosphate, 200 pounds of sulphate of potash, 100 pounds each of the sul-

DIAGRAM II. WHEAT AND BARLEY AT WOBURN. AVERAGE YIELD OF GRAIN PER ACRE FOR SUCCESSIVE TEN-YEAR PERIODS, 1877-1906, INCLUSIVE.



Plot 6, chemical fertilizer; Plot 11b, manured continuously; Plot 11a, manured first 5 years, manuring then discontinued. Plot O, continuously unmanured.

phates of soda and magnesia, and 260 pounds of nitrate of soda per acre.

The diagram shows that during the first 10-year period the chemical fertilizer produced a much larger yield than the manure; the second period shows a slightly larger gain from the fertilizer than from the manure, but the difference is much less conspicuous than at first; the final period shows a practically equal yield of wheat from both applications, and a slightly larger yield of barley from the manure. In all cases there has been a considerable reduction in yield, showing that neither fertilizer nor manure, in the quantities here employed, has been able to maintain the yield of these crops when grown continuously, but the reduction on the fertilized land has been much greater than on that receiving manure.

Residual effect of manure at Woburn—Considering now the land which has received manure only during the first five years of the 30-year period, we see that its yield remains much greater than that of the continuously unmanured land, up to the end of the period.

It is probable that the land received for each crop (wheat and barley), about 40 tons of manure, of 2,000 pounds each, during the five years of application. This produced a total increase of crop, for the first ten years, amounting to 24 bushels of wheat and 126 bushels of barley. For the next 10 years the residual increase from this manuring was 46 bushels of wheat and 124 bushels of barley, and for the last 10 years it was 45 bushels of wheat and 95 bushels of barley, so that the total increase from the application of 40 tons of manure to wheat has amounted to 115 bushels, and that from the same quantity of manure given to barley, to 295 bushels, while it is evident that the end of the effect of the manure is not yet reached.

The Pennsylvania experiments—At Pennsylvania State College experiments in the use of manures and fertilizers were begun in 1882. In these experiments corn, oats, wheat and clover are grown in a four-course rotation, each crop being grown every season. Three quantities of yard manure are used, six, eight and 10 tons per acre, in comparison with chemical fertilizers carrying 24, 48, and 72 pounds of nitrogen per acre, combined with 21 pounds of phosphorus and 83 pounds of potassium. The nitrogen is carried in dried blood to one series of plots, in nitrate of soda to another, and in sulphate of ammonia to a third. Both manure and fer-

TABLE XXX. THIRTY-YEAR AVERAGE YIELD AND INCREASE AT THE PENNSYLVANIA EXPERIMENT STATION.

Crop	Average unfertilized yield per acre	Applied an acre during each rotation					
		Fertilizers containing			Manure at the rate of		
		48 lbs. nitrogen	96 lbs. nitrogen	144 lbs. nitrogen	12 tons	16 tons	20 tons
		Increase an acre					
Corn, bushels grain ...	38.8	13.9	16.1	17.0	16.4	13.6	17.5
" pounds stover...	1,898	1,021	1,102	1,109	792	641	915
Oats, bushels grain....	31.5	9.0	10.5	10.3	7.9	9.6	9.7
" pounds straw	1,342	393	514	564	520	602	606
Wheat, bushels grain..	13.5	8.7	10.9	12.2	9.8	10.6	11.3
" pounds straw ..	1,264	1,124	1,552	1,763	1,095	1,363	1,372
Clover, pounds hay ...	2,608	1,544	1,603	1,620	1,348	1,595	1.600
Total value of increase. (grain and hay only)	......	$24.14	$28.44	$30.12	$24.96	$25.73	$28.24

tilizers are applied twice during each rotation—to the corn and wheat.

The results of this work for the first 25 years are given in Bulletin 90 of Pennsylvania State College experiment station, and for the next five years in a supplement published in 1911, from which the following comparisons are drawn:

In Table XXX is shown the 30-year average yield of the unfertilized crops grown in this experiment, with the average increase produced by fertilizers carrying different quantities of nitrogen and by different applications of manure, together with the value of this increase, reckoned as in previous computations of this kind.

The increase given for each quantity of nitrogen is the average for two plots, one receiving its nitrogen in dried blood and one in nitrate of soda. A third series of plots receives nitrogen in sulphate of ammonia, but this carrier has produced an injurious effect on the crop when used in the larger quantities.

The table shows that the three applications of fertilizers and manures have produced nearly the same total increase; but the dressings of manure have carried more than twice as much nitrogen as the fertilizers, although the manure has contained only about four-fifths as much phosphorus and a little more than half as much potassium as the fertilizer. It seems probable that the low yield of corn under the medium application of manure has been due to some other cause than effect of the manure.

Valuing corn at 40 cents per bushel, oats at 30 cents, wheat at 80 cents, hay at $8 per ton, stover at $3 and straw at $2,* we find that the 30-year average increase from 12 tons of manure, 6 tons each on corn and wheat, has had a total value of $24.96, or $2.08 per ton of manure; that from 16 tons, 8 tons each on corn and wheat, has amounted to $25.73, or $1.61 per ton of manure; and that from 20 tons, 10 tons each on corn and wheat, has amounted to $28.24, or $1.41 per ton of manure.

The application of chemical fertilizers carrying 24 pounds of nitrogen would cost $21.80; that containing 48 pounds, $29.00; and that containing 72 pounds, $36.20 for each rotation. The value of the increase from the fertilizers containing the smallest amount of nitrogen has been $24.14; that from the medium quantity, $28.44; and that from the largest $30.12; or $1.11, 98 cents and 84 cents for each dollar expended in fertilizers.

The total recovery of fertilizing elements has been nearly as great on the manured land as on that treated with fertilizers; but the percentage recovery has varied with the amount given in the carrier.

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* The Bureau of Statistics, U. S. Dept. of Agriculture, estimates the average farm prices of the different crops for the 10 years, 1900-1909, as follows, for Ohio and Pennsylvania:

	Ohio	Pennsylvania
Corn	48 cents a bushel	59 cents a bushel
Oats	36 " " "	42 " " "
Wheat	86 " " "	87 " " "
Hay	$10.06 a ton	$13.45 a ton

The prices used in computing this and subsequent tables are therefore sufficiently low to leave an ample margin for cost of harvesting the additional crops produced by the fertilizers or manure, and also for the labor cost of applying the fertilizers. No attempt is made to compute the cost of the manure, as that will vary with every farm and with different fields on the same farm.

That is, the crops grown in this rotation have been able to obtain a large part of their nitrogen from other sources than fertilizers or manure, so that the proportion of nitrogen to phosphorus and potassium in the manure has been relatively greater than could be used with economy, thus suggesting that manure should be looked upon primarily as a carrier of nitrogen, and that, considering the relatively great cost of this element in commercial fertilizers, it should be the policy to so care for the home supply of manure as to conserve its nitrogen to the utmost extent possible, and then to reinforce it with phosphorus and potassium.

The Ohio experiments—In the experiments with fertilizers and manures conducted at the Ohio station on crops grown in rotation, plot 18 of the five-year rotation has received per acre 16 tons of open-yard manure every five years, eight tons each on corn and wheat, and plot 20 half that quantity, while plot 14 has received a chemical fertilizer, made up of nitrate of soda, dried blood, muriate of potash and acid phosphate, calculated to carry per acre about 51 pounds of nitrogen, 15 pounds of phosphorus and 75 pounds of potassium. This dressing is likewise distributed over the corn and wheat only, leaving the oats, clover and timothy without any treatment.

The smaller application of manure is estimated to have carried about 76 pounds of nitrogen, 10 of phosphorus and 56 of potassium per acre. Valuing these elements as before, the quantity carried in the manure would have cost $2.06 per ton, or $16.50 per acre if purchased in chemicals, while the chemical fertilizers applied to plot 14 would cost, at the same rate of prices, $14.80 per acre for each rotation. The increase on plot 14 has amounted to an average value of $30.59 per acre for each rotation during the first 18 years of the experiment; that on plot 18 to $39.32, and that on plot 20 to $25.34.* In other words, a dollar invested in chemicals has brought increase to the value of $2.07 on plot 14, while yard manure, carrying fertilizing constituents which would have cost $1.00 if purchased in chemicals, has produced increase to the value of $1.19 on plot 18, and $1.53 on plot 20, thus indicating an effectiveness for the constituents of yard manure of 57 per cent and 74 per cent of that of the same constituents in the chemicals.

This experiment is being duplicated on the Strongsville test farm of the Ohio station, the soil of which is a cold, heavy clay, much less responsive to treatment than that of the main station at Woos-

TABLE XXXI. COMPARATIVE EFFECT OF MANURE AND FERTILIZERS AT STRONGSVILLE.

Plot	Treatment	Value of increase a rotation
14	Chemical fertilizer	$19.31
18	Yard manure, 16 tons	22.59
20	" " 8 tons	13.38

* Ohio Agricultural Experiment Station, Circular 120.

ter. The experiment has been in progress since 1895, and the following results have been obtained as the average for the first 17 years, plots of the same number receiving the same treatment in both tests:

A dollar in chemicals has here produced increase to the value of $1.30, while manure of equivalent chemical value has produced increase to the value of 68 cents in the larger, and 80 cents in the smaller application, these sums being 52 and 62 per cent respectively of the increase produced by an equivalent quantity of chemicals on plot 14.

This manure, be it remembered, in both tests was open barnyard manure; that given to the corn having been subjected to the washing occurring in an ordinary barnyard for several winter months before being applied to the crop, and that given to the wheat having suffered the additional loss incident to further exposure during the spring and summer months. By such treatment the manure is deprived of the more soluble, and therefore more immediately effective portions of its constituents.

Fresh vs. yard manure—In another experiment at the Ohio station cattle manure, taken directly from the stable, is compared with manure from cattle similarly fed, but which has lain in an open barnyard through the winter and has thus been subjected to considerable leaching. Both kinds of manure are spread on clover sod and plowed under for corn, the corn being followed by wheat and clover in a three-year rotation without any further manuring or fertilizing. The manure is used at the uniform rate of 8 tons per acre.

Several analyses have been made of the manures used in this experiment, from which the following figures are deduced as representing the approximate average composition and value per ton, computing nitrogen at 15 cents per pound, phosphorus at 11 cents and potassium at 6 cents,* these valuations being employed as representing the approximate cost of the different elements in tankage, bonemeal and muriate of potash, when purchased in carloads.

VALUE OF ELEMENTS IN MANURE

	Yard manure	Stall manure
Nitrogen, pounds a ton,	9.5	10.5
Phosphorus " " "	2.0	3.0
Potassium " " "	7.0	10.0
Value a ton,	$2.06	$2.50

This experiment has been in progress for 15 years, and the increase produced by the yard manure has had an average value of $2.55 for each ton of manure, and that by the stall manure of $3.31 per ton. Reckoned on the basis of market value of the chemical constituents, one dollar's worth of such constituents has produced increase to the value of $1.24 when carried in yard manure, and of $1.32 when in stall manure.

* Equivalent to 12.3 cents per pound for ammonia, 4.84 cents for phosphoric acid, and 4 92 cents for potash.

· **Reinforcement of manure**—On two other plots in this test the two kinds of manure are treated with acid phosphate, which is mixed with the manure at the rate of 40 pounds per ton of manure a short time before spreading it in the spring, thus raising the chemical value of the manure to $2.38 per ton for the yard manure, and $2.82 for the stall manure. The increase of crop, however, has been raised to a value of $4.10 per ton of manure for the yard, and to $4.82 for the stall manure, thus giving a value of $1.72 for each dollar represented in the chemicals contained in the ton of treated yard manure, and $1.71 for the similarly treated stall manure.

Comparing this outcome with that found on plot 14, in the five-year rotation at Wooster, the increase on which has amounted to $2.07 for each dollar's worth of chemicals in the fertilizer, we see that when manure is used in moderate quantity and so reinforced as to adapt it to the needs of the soil to which it is applied, it may yield returns very closely approximating those given by the most

TABLE XXXII. CUMULATIVE EFFECT OF MANURE AND FERTILIZERS.

Plot	Treatment	Average value of increase an acre by five-year periods		
		First 5 years	Second 5 years	Third 5 years
14	Chemical fertilizer, 740 pounds...	$21.37	$32.91	$37.33
18	Yard manure, 16 tons..........	19.82	34.24	55.94
20	" " 8 tons..........	13.02	21.28	35.36

effective chemical combinations, pound for pound, of the elements carried, the immediate effectiveness of this reinforced manure being about 85 per cent of that of the chemical fertilizer.

The claim is sometimes made that manure possesses a greater value than would be indicated by its chemical composition, in the physical effect produced on the soil and in favoring the distribution and work of the nitrifying bacteria, but the experiments above quoted would seem not to support this claim. It is true, however, that the cumulative effect of the manure is increasing more rapidly than that of the fertilizers, as shown in Table XXXII, a comparison of the average annual value of the increase per acre by five-year periods in the five-year rotation at Wooster.

This study of the comparative effectiveness of manure and chemicals leads to the conclusion that the chief function of these substances is that of carrying to the plant the elements necessary for its growth in such form that it may most readily make use of them; and that the efficiency of a plant nutrient, whether in the form of chemicals or manure, is proportionate to the solubility of its constituents and to their relationship to the constitution of the plant and to each other.

CHAPTER VII

THE WASTE OF MANURE

Losses in the stable—The experiments quoted on page 85 show that, in the case of dairy cows at least, more than half the total value of the manure is found in the urine, and it is probable that cow manure is not exceptional in this respect. It is therefore evident that when the stable floor is so constructed as to permit the liquid to escape through open cracks to the ground below, a very large part of its fertilizing value may be lost.

The Ohio experiment station replaced a plank floor, through which the liquid had been permitted to escape, with a cemented floor from which the liquid was conducted to a cistern. In this cistern there was collected from 30 cows in 125 days 24,000 pounds of liquid, which was found to contain 0.64 per cent of nitrogen and 0.925 per cent of potassium, or a total of 155 pounds of nitrogen and 222 pounds of potassium, representing a total value of at least $36, at the current cost of these elements in commercial fertilizers.

In this case the cows were well bedded with straw, which absorbed part of the liquid. The majority of stable floors, however, are the ground itself, sometimes carefully puddled with clay, but more often left with such compacting as it gets from the animals standing on it. Many farmers assume that very little loss can occur on such a floor, but the experiment quoted on page 100 indicates that such losses may amount to more than is suspected.

The data given in Chapter VI show that when manure is properly reinforced and handled without waste, either from exposure or from using it in larger quantity than the crop can utilize, it is a

TABLE XXXIII. VALUE OF MANURE PRODUCED IN SIX MONTHS BY ONE STEER AVERAGING 1,000 POUNDS LIVE WEIGHT.

Constituents	On cemented floor		On earth floor	
	Pounds	Value	Pounds	Value
Nitrogen	67.2	$7.56	54.0	$6.07
Phosphorus	26.8	2.21	24.2	2.00
Potassium	35.6	1.60	29.0	1.30
Total manure	8,550	11.37	7,434	9.37
Value a ton	....	2.66	....	2.52

conservative estimate to rate the potential crop-producing value of its nitrogen, phosphorus and potassium at 75 per cent of the cost of the same elements when purchased in nitrate of soda, acid phosphate and muriate of potash. On this basis Table XXXIII has been computed from the data given in Tables XXV and XXVI, calculating the total value on the average production of manure per thousand pounds live weight.

Deducting the floats, the cost of which for the six months was 64 cents per thousand pounds live weight for the steers on the cemented floor, and 60 cents for those on the earth floor, the total value of the manure was $10.73 for the thousand-pound steer on the cemented floor, and $8.77 for the steer of equivalent weight fed on the earth floor.

Reference to the table giving the feed statistics will show that the steer fed on the earth floor received less food than the one on the cemented floor. This point, however, does not affect the following statement, which shows the total quantity of nitrogen, phosphorus and potassium contained in the feed, bedding and floats, for each lot of steers; the quantity recovered in the manure, and the percentage which this recovery bears to the original amount:

ELEMENTS GIVEN IN FEED AND RECOVERED IN MANURE ON CEMENTED AND EARTH FLOORS

	On cemented floor	On earth floor
Nitrogen in feed, etc., pounds,	2,685	2,756
" " manure, "	2,006	1,719
" per cent recovered,	74.7	62.4
Phosphorus in feed, etc., pounds,	1,033	977
" " manure, "	799	771
" per cent recovered,	77.5	78.9
Potassium in feed, etc., pounds,	1,212	1,176
" " manure, "	1,064	922
" per cent recovered,	87.8	78.4

The percentage recovery of phosphorus was as large on the earth as on the cemented floor, as would be expected from the fact that this element is voided in the solid portion of the excrement, but the recovery of nitrogen and potassium was considerably smaller on the earth floor. Had the proportionate recovery of these elements been as great on the earth as on the cemented floor, the manure taken from the earth floor would have contained 339 pounds more nitrogen and 103 pounds more potassium than it did, thus having a total value greater by $50 than that actually recovered.

The cattle fed in these experiments had been dehorned, and they were fed in lots of six to eight steers each, running loose in stables which gave to each steer about 50 square feet of space.

The cemented floor had been made by the ordinary labor of the farm, and at a total cost of about 6 cents per square foot, so that more than half the cost of the floor was recovered in the superior value of the manure made upon it during the six months.

It will be observed that in the discussion of this experiment the comparisons are based on the assumption that the fertilizing elements of the manure, as taken from the two floors, were in an equally available condition. The station's analyses, however, show that this was not the case, there being a greater loss on the earth floor of the water-soluble portions of the different constituents, as shown on the following page:

POUNDS OF WATER-SOLUBLE ELEMENTS A TON OF MANURE

	Nitrogen	Phosphorus	Potassium
On earth floor,	8.54	1.48	6.69
On cement floor,	9.96	1.80	7.25

Losses in the feed lot—Throughout the corn-belt states it is the custom to feed cattle in open lots, often around straw stacks, the manure being trampled under foot and mixed with straw and corn-stalks. This method unquestionably involves the loss of a very large part of the value of manure through the leaching action of the rain. The fact that no stream of brown liquid is seen running from the feed lot is no evidence that this loss is not taking place, for the mulch of manure and litter is just what is needed to keep the ground beneath in condition to absorb the liquid, whether from manure or from rainfall.

We see the showers falling on the plowed fields and do not think it strange that the water is at once absorbed by the loose earth, but the ground under the feeding yard is in as good a condition to absorb the water as in the field, and the accumulating heap of manure and litter serves as a sponge to receive and hold the excess of moisture until the ground below can dispose of it.

Loss from heating—The prevention of the waste which manure undergoes by drainage through loose stable floors or from barnyards is a simple physical problem which requires for solution only the mechanical methods of tight floors and shelter from excess of rain; but the loss which results from the chemico-vital processes by which the nitrogen of the manure is converted into ammonia gas is not so easily prevented.

For the manure heap is at once occupied by organisms similar to those by which the organic matter of the soil is reduced to humus, and if left unchecked their work eventually results in the conversion of the heap into a small quantity of ash.

Bacteria of the manure heap—Two general classes of organisms are concerned in this work—the one living near the surface where air circulates, and the other limited to the lower and more compact portions of the heap. The fermentation produced by the first class is known as aerobic, and that by the second class as anaerobic. In aerobic fermentation much heat is evolved, the carbon of the matter undergoing decay is united with oxygen and is given off as carbon dioxide (carbonic acid gas), while its nitrogen, liberated from its combinations with carbon, is recombined with hydrogen derived from the moisture of the heap and passes off as ammonia gas, or there may be a combination of this gas with carbon dioxide, forming ammonium carbonate, which also is volatile.

When the manure heap contains a considerable portion of soluble nitrogen compounds, as when it contains the urine as well as the solid excreta, there may be a direct conversion of these compounds into nitric acid, by combination with atmospheric oxygen, which will sink to the lower portions of the heap, to serve there as a source of oxygen to the organisms inhabiting the layers from which the air is excluded, and which feed upon the carbon of the vegetable refuse in the manure. By this action the nitric acid is decomposed, and its nitrogen may escape as free nitrogen into the air.

Losses in rotting—In the rotting of manure, therefore, there are three channels of loss: (1) The liberation of carbonic acid gas, by the breaking down of the carbonaceous material and thus reducing the humus matter; (2) the formation of ammonia and ammonium carbonate and its escape into the air; and (3) the liberation of free nitrogen. In this way, if the manure heap is left exposed long enough, it will be as effectually deprived of everything of value for plant food, except its mineral elements, as if it had been burnt. But if to these sources of loss be added the leaching of the heap with water, the mineral substances also may be dissolved out and carried away. These losses, moreover, may go forward for a considerable time without reducing the weight of the heap, for the rotting process makes the heap capable of containing a larger proportion of water, by breaking down the litter and thus making the interstices smaller, so that water will take the place of the elements which have been lost.

The rotting of the manure tends to make its constituents more soluble, and if rotting could be accomplished without escape of ammonia gas on the one hand and without leaching on the other, it would add to the value of the manure. This result, however, is very difficult of attainment, and the general outcome of the rotting process is a considerable loss of nitrogen in the gaseous form, and a conversion of both the nitrogenous and mineral substances into a more soluble condition, in which they are caught and washed out of the heap by the rain.

Relative value of the nitrogen and ash constituents of manure—On the black soils of the central provinces of India cattle dung is largely used for fuel during the dry season, and during the rainy season much of it is allowed to go to waste. The improvidence of this practice is shown by the following experiment, made by the Nagpur experiment farm and reported by D. Clouston in the Agricultural Journal of India for July, 1907:

TABLE XXXIV. NITRATE AND MANURE ON IRRIGATED WHEAT IN INDIA.

Treatment	Average yield of grain in pounds				Average increase
	5 years 1890-94	5 years 1895-1900	5 years 1901-06	15 years '90-06	
Saltpeter, 240 pounds	931	826	1,278	1,012	517
Cattle dung, 12,800 pounds	717	915	1,500	1,044	594
Ashes of 12,800 pounds dung	584	618	820	677	182
Nothing	486	371	627	495	...

The table shows the same cumulative effect from systematic treatment which has been shown in other experiments of this character, the manured yield being twice as great during the third five years of the test as during the first. It is true that this was a period of better seasons, as shown by the yield of the untreated land, but the increase over the unmanured yield rose on the dunged land from 231 pounds during the first five years to 873 pounds during the third period.

The manure ash has improved the yield, but to a far less degree than the manure itself, the experiment thus confirming such long-continued tests as those at the experiment stations of Rothamsted, Woburn, Pennsylvania, Canada and Ohio, in showing that as cropping is continued the addition of nitrogen becomes more and more essential to the production of wheat. This is further exemplified by the effect of the saltpeter, which was in this case presumably the nitrate of potash and not that of soda, and which has produced a much greater relative effect than the similar application has done on the American soils.

Losses from leaching—When manure is thrown from the stable into the barnyard it contains on the average about 80 per cent of water if from cattle, or about 70 per cent if from horses. Of this water a small fraction—less than 5 per cent—is the hygroscopic water of the organic matter in the manure, but the greater portion is liquid water from the alimentary and urinary canals. This water, whichever its source, holds in solution the major part of the salts which give the manure its value for soil fertilization, that part contained in the undigested organic residue being a comparatively insignificant factor.

Let such material, saturated as it is to its full capacity for holding moisture, be exposed to rain under conditions which allow the escape of drainage, and the liquid of the manure will be replaced by that from the clouds, the former flowing away, or being absorbed by the soil beneath the heap, and carrying with it the salts contained. This fact is most familiarly illustrated in the leaching of ashes. In regions where wood is used for fuel the ashes are placed in a V-shaped receptacle, the bottom of which rests in a trough—many of the older readers will remember the trough hewn out of a log which served the pioneers for this purpose—and under the end of the trough a vessel is placed to catch the drainage. Water is poured on the top of the vat until the entire contents are saturated, when a brown stream begins to issue from the bottom. More water is added as long as the liquid collected will float an egg, but when it becomes so weak that the egg sinks quickly then the leaching is discontinued. In this way the pioneer farmer's wife secured potash for soap making; but the potash of the manure heap is undoubtedly more easily leached out than that of the ash vat, for it is already largely in solution in the urine.

The experiment station of Cornell University has conducted some noteworthy investigations on this point. In 1889 this station placed a lot of horse manure, taken from a tight floor and weighing 529½ pounds, of which 38½ pounds was straw bedding, in a wooden box which was not water tight and exposed it out of doors from April 1st until September 30th, the box being surrounded with similar manure in order that the whole might heat up evenly, the object being to subject the manure to the same conditions as if it had been thrown loosely in a heap from the stable door. The box was left exposed for six months during the summer, after which its contents were found to weigh but 372 pounds. The analysis of this manure, before and after the six months' exposure, is given below:

LOSSES IN EXPOSED MANURE

	Percentage composition of manure			
	Water	Nitrogen	Phosphorus	Potassium
Fresh manure	70.79	0.51	0.092	0.440
After six months	81.74	0.46	0.066	0.257

Not only was there a loss in weight, but also in the percentages of fertilizing elements contained. Calculated per ton of manure, the results of this test were as below:

LOSSES IN EXPOSED MANURE

	Pounds each original ton of manure			
	Nitrogen	Phosphorus	Potassium	Value
Before exposure	10.2	1.84	8.8	$1.98
After "	6.5	0.92	3.6	1.12
Percentage loss	36.	50.	60.	43.

The net loss in value amounted to 43 per cent, on the valuation here employed, assuming that the constituents found in the manure at the end of the period were equally effective with those at the beginning, pound for pound.*

The following season this experiment was repeated with a pile of 4,000 pounds of horse manure and one of 10,000 pounds of cow manure, the experiment extending over six spring and summer months, as before. This season proved to be a very rainy one, and when the manure was taken up the horse manure weighed but 1,730 pounds, a loss of 57 per cent in gross weight, and the cow manure but 5,125 pounds, a loss of 49 per cent. Calculated per ton of manure, the outcome was as below:

LOSSES IN EXPOSED MANURE

	Pounds each original ton of manure			
	Nitrogen	Phosphorus	Potassium	Value
Horse manure:				
Before exposure	9.80	3.25	14.94	$2.41
After "	3.89	1.71	3.59	0.84
Loss, per cent	60.	47.	76.	65.
Cow manure:				
Before exposure	9.40	2.82	7.97	1.89
After "	5.60	2.29	7.30	1.29
Loss, per cent	41.	19.	8.	32.

The loss in value amounted to 65 per cent for the horse manure and 32 per cent for the cow manure.

* Cornell University Experiment Station, Bul. 13

A valuable contribution to this subject has been made by Prof. F. T. Shutt, of the Dominion experimental farms, who placed four tons of a mixture of equal parts of horse and cow manure in a weather-tight shed, and an equal quantity in an outside bin, open to the weather but with sides and bottom practically water tight. These manures were analyzed monthly for a year. The more important data are given in Tables XXXV and XXXVI, reproduced from Bulletin 31 of that station.

TABLE XXXV. WEIGHTS (POUNDS) OF FERTILIZING CONSTITUENTS IN "PROTECTED" AND "EXPOSED" MANURES.

Fertilizing constituents	Fresh		At the end of 3 months		At the end of 6 months		At the end of 9 months		At the end of 12 months	
	Protected	Exposed	Protected	Exposed	Protected	Exposed	Protected	Exposed	Protected	Exposed
Weight of manure	8000	8000	2980	3903	2308	4124	2224	4189	2158	3838
Organic matter	1938	1938	880	791	803	652	760	648	770	607
Total nitrogen	48	48	40	34	39	33	37	29	37	31
Total phosphoric acid	25	25	25	23	26	22	25	21	24	21
Available phosphoric acid	15	15	20	15	19	15	21	17	19	16
*Total potash	62	62	65	48	59	44	60	41	60	40
†Available potash	54	54	62	45	52	42	56	38	55	35

* Soluble in strong hydrochloric acid.
† Soluble in dilute citric acid.

From the data given in Table XXXV, Professor Shutt calculates the loss of fertilizing constituents as shown in Table XXXVI.

TABLE XXXVI. LOSS OF FERTILIZING CONSTITUENTS IN THE ROTTING OF MANURE.

Fertilizing constituents	At the end of 3 months		At the end of 6 months		At the end of 9 months		At the end of 12 months	
	Protected	Exposed	Protected	Exposed	Protected	Exposed	Protected	Exposed
	%	%	%	%	%	%	%	%
Loss of organic matter ..	55	60	58	65	60	67	60	69
Loss of nitrogen........	17	29	19	30	23	40	23	40
Loss of phosphoric acid..	None	8	None	12	None	16	4	16
Loss of potash..........	None	22	3	29	3	34	3	36

In 1888, Director Voorhees, of the New Jersey experiment station, began a series of experiments on this subject which are still in progress. In these experiments 100 pounds each of fresh dung and of fresh total excrement, liquid and solid mixed, and in both cases without litter and from cows, are collected and placed in galvanized iron boxes, 8 inches deep and with perforated bottom, so as to permit drainage, though covered with wire gauze above and below, in order to prevent the escape of solid matter. The boxes with their contents are placed in the open air and allowed to remain undisturbed for several weeks or months. The manure is analyzed both before and after exposure. The results of this work are averaged in Table XXXVII for eight years, the reports of the station for 1902 and 1903 not giving the necessary data for those years.

The average duration of the test was 77 days, and the average final weight of the sample was 64.4 pounds for the solid manure, and 59.3 pounds for the solid and liquid.

TABLE XXXVII. LOSS OF MANURE IN LEACHING AT NEW JERSEY EXPERIMENT STATION.

Constituents	Percentage Composition		Pounds each original ton of manure	
	Before leaching	After leaching	Before leaching	After leaching
Solid manure				
Water	83.983	79.723	....	....
Nitrogen	0.348	0.433	6.96	5.58
Phosphorus	0.139	0.158	2.78	2.04
Potassium	0.203	0.168	4.06	2.16
Solid and liquid manure				
Water	85.823	80.005	....	....
Nitrogen	0.427	0.495	8.54	5.87
Phosphorus	0.112	0.154	2.24	1.82
Potassium	0.291	0.279	5.82	3.30

Table XXXVII shows that the percentage of nitrogen and phosphorus has been higher in the leached than in the fresh manure, but when we apply the percentage found at the end of the leaching period to the actual quantity of manure left we find that, in the case of the solid manure, of the 0.348 pound of nitrogen contained in the original 100 pounds of manure the residue contains but 0.279 pound; the phosphorus has been reduced from 0.139 pound to 0.102 pound, and the potassium from 0.203 pound to 0.108 pound.

To put it in another form: A ton of the fresh dung would have contained 6.96 pounds of nitrogen, 2.78 pounds of phosphorus and 4.06 pounds of potassium, the whole worth $1.59 if we compute nitrogen at 15 cents per pound, phosphorus at 11 cents, and potassium at 6 cents; but after about two and one-half months' exposure there is left but 5.58 pounds of nitrogen, 2.04 pounds of phosphorus, and 2.16 pounds of potassium, reducing the total value to $1.19, a loss of more than 25 per cent.

Taking the total excrement, solid and liquid, we find that a ton when first put out would have contained 8.54 pounds nitrogen, 2.22 pounds phosphorus and 5.82 pounds of potassium, having a total value of $1.87, but after leaching there would remain only 5.87 pounds nitrogen, 1.82 pounds phosphorus, and 3.30 pounds potassium, the value being reduced to $1.28, a loss of nearly 33 per cent, thus illustrating again the fact that the liquid portion of the manure is the first to waste.

In 1907 the Ohio station exposed lots of manure, of 1,000 pounds each, for three months, from January until April, the manure being analyzed when first exposed and again when taken up, by Mr. J. W. Ames, chemist to the station. In this experiment four of the lots were treated with preservative or reinforcing materials, while the fifth lot was left untreated.

The average weight of the manure was as great—in some instances greater—when taken up than when put out; but the analyses revealed the fact

TABLE XXXVIII. COMPOSITION OF STEER MANURE BEFORE AND AFTER EXPOSURE FOR THREE MONTHS, EXPRESSED IN POUNDS A TON.

Treatment		Organic matter	Ash	Nitrogen		Phosphorus		Potassium	
				Total	Water soluble	Total	Water soluble	Total	Water soluble
Floats	Lbs. at beginning	349.00	120.20	10.70	4.28	8.60	1.52	7.38	6.58
	Lbs. at end	310.74	98.95	7.46	1.06	7.57	1.32	3.52	3.47
	Percent loss	10.96	17.67	30.28	75.23	11.97	13.16	52.30	47.26
Acid Phosphate	Lbs. at beginning	357.80	101.40	9.86	3.04	5.70	2.28	6.88	6.88
	Lbs. at end	269.89	85.88	7.18	.84	4.79	1.51	2.99	2.51
	Percent loss	24.57	15.30	27.18	72.36	15.96	33.77	56.54	63.51
Kainit	Lbs. at beginning	369.00	107.40	9.76	3.14	2.88	1.36	10.70	10.66
	Lbs. at end	291.50	83.64	6.68	.31	2.48	1.31	4.98	4.96
	Percent loss	21.00	22.12	31.56	90.12	13.89	3.68	53.46	53.47
Gypsum	Lbs. at beginning	375.40	104.60	9.68	2.12	2.76	.78	7.86	7.86
	Lbs. at end	267.35	75.72	7.94	1.46	2.66	.75	2.56	2.49
	Percent loss	28.78	27.61	17.97	31.13	3.63	3.85	67.42	68.32
Untreated	Lbs. at beginning	416.00	79.20	10.30	3.36	3.24	1.66	8.14	8.14
	Lbs. at end	254.79	65.68	7.18	1.14	2.47	1.26	3.35	2.84
	Percent loss	38.75	17.07	30.29	66.07	23.76	24.10	58.84	65.11
Average percent loss		24.81	19.95	27.46	66.93	13.84	15.70	57.71	59.53

that there was a considerable substitution of water for the organic matter and ash elements in the manure. Calculated per ton of manure, this experiment furnishes the data shown in Table XXXVIII.

Taking the average analyses, the ton of manure originally put out in this test was worth $2.50; when taken up, although it still weighed a ton, its value had been reduced to $1.74, a loss of nearly one-third.

These Ohio experiments show that there may be a considerable loss in the value of the manure heap without any diminution in weight or bulk, the reduction of its materials to finer particles, through the process of decay, enabling it to retain a larger proportion of water, which gradually displaces the organic matter and ash constituents, each fresh rainfall taking the place of water saturated with fertilizing elements, just as the pail of clear water poured on the top of an ash vat displaces an equal quantity of brown lye at the bottom.

In these experiments again the Ohio station's tests show that it is usually in the water-soluble, and, therefore, the more valuable constituents, that the manure suffers most loss.

The enormous waste of manure—The United States department of agriculture estimated the number of cattle in the United States on January 1, 1907, at 72,533,000; the number of sheep at 53,240,000, and the number of swine at 54,794,000. If we assume that 10 sheep or swine are equivalent to one cattle beast in manure production, we shall have a total of 83,000,000 cattle. These, of course, are of all ages, and may be assumed to be equivalent to 60,000,000 one-thousand pound cattle. If these are yarded four months each winter, there should be a total manure production during that period of 150,-000,000 tons, having a potential crop-producing value of at least $200,000,000, over and above all cost of handling. It is a very conservative estimate to place the waste of this manure under the prevalent system of management at 25 per cent, or $50,000,000 annually. It is probably more nearly twice that amount.

CHAPTER VIII

THE PRESERVATION OF MANURE

Manure loses nothing but water in drying—The fact is familiar to the farmer that when manure is loosely piled the evolution of ammonia gas begins within a few hours; the overnight accumulations in the stable give off this gas by morning, and it is constantly produced in the heaps into which the manure has been thrown, as evidenced by the odor of ammonia constantly pervading such heaps, an odor greatly intensified when the heaps are stirred, by the sudden liberation of the gas which has accumulated in their interstices.

This fact, of the increase in odor from freshly stirred manure, led to the practice of piling the manure in small heaps in the field, to be distributed just ahead of the plow, the assumption being that it was the drying of the manure that caused its loss of ammonia; but an experiment made by Prof. F. T. Shutt, of the Dominion experimental farms, shows that the loss of nitrogen due to mere drying is insignificant. In this experiment two samples of manure were dried in thin layers, with the result indicated in Table XXXIX.

The chief source of the nitrogen loss of manure is to be found in the work of the bacterial organisms which pervade the manure heap and which cause the combination of its nitrogen with hydrogen in the form of ammonia. Moisture is indispensable to all plant life (and the bacteria are plants) and it is moreover water which furnishes the hydrogen of the ammonia; hence, when the drying is complete there is no further production of ammonia, and consequently no further loss of nitrogen.

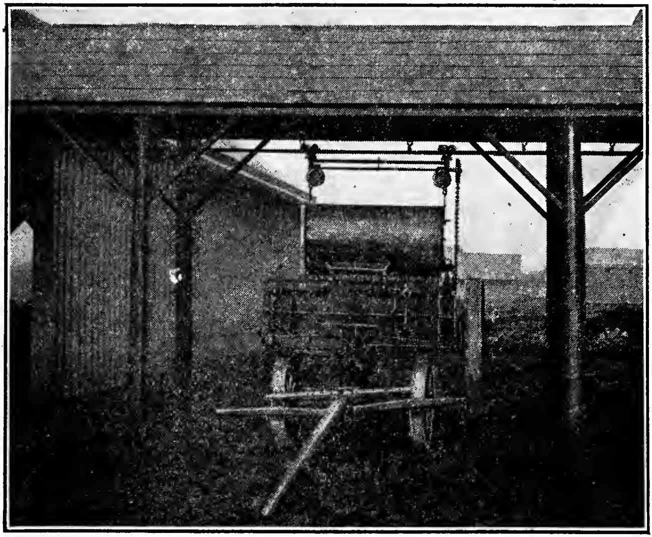
The best place to preserve manure is in the soil— If, therefore, it were practicable to at once quickly and thoroughly dry the accumulations of the stable,

TABLE XXXIX. LOSS OF NITROGEN IN MANURE BY DRYING IN THIN LAYERS.

Manure	Nitrogen in manure		
	Per cent	Lbs. a ton	Value
Well rotted: before exposure	.515	10.3	$1.75
" " after "	.505	10.1	1.72
Rotting: before exposure	.490	9.8	1.67
" after "	.466	9.3	1.58

and keep them in this condition until the opportunity came to incorporate them with the soil, there would be the least possible loss of fertilizing value. The nearest approach to this condition which it is practicable to attain on the ordinary farm is to haul the manure daily from the stable to the field, when weather and other conditions permit, and spread it there at once and as uniformly as possible.

The manure spreader as a manure preserver—In humid climates, however, there will be wet days, when the team cannot go upon the fields intended for tillage without causing more damage than would be compensated in the saving of the manure. There will be other days when urgent work of other kinds may make it seem impossible to give the time neces-



Manure shed on the left, stable on the right, manure spreader ready for its load.

sary to this care of the manure, although such emergencies may be reduced to the minimum by keeping a manure spreader expressly for this work, and so locating it that it will be more convenient to drop the morning's accumulations of the stable into the spreader than anywhere else; such an arrangement as is shown on this page.

Times when manure cannot be drawn to the field—There will also be days when the ground will be covered with snow, which interferes with the working of the manure spreader, and which, if it should go off in a flood of rain, might carry with it part of the more soluble portion of the manure, although the danger of loss from this source is probably smaller than is generally supposed. The loss which manure suffers from leaching in open barnyards is undoubtedly many times greater than that resulting from spreading on the snow.

There will be other days when the land upon which it is desired to put the manure is occupied by crops, although this difficulty might often be met by systematic planning of the manuring, so that meadows, pastures and orchards would receive their share when the manuring of the tillage land would be impracticable.

Under the best of management, however, there will be some manure which cannot be drawn out at once to the field, and the preservation of such accumulations becomes a matter of considerable importance.

Air must be excluded to preserve moist manure—With manure, as with all other perishable substances, the first essential to preservation is the exclusion of air. This, in the case of manure, is for two reasons: First, because the air is constantly laden with germs of the microscopic organisms which promote fermentation or decay; and, second, because the presence of free oxygen is essential to the activity of those organisms which produce the destructive changes in the manure heap. Whatever will exclude the air, therefore, will preserve the manure.

The box stall method of manure preservation— The simplest method by which this exclusion of air can be effected is that of trampling the manure under foot in cemented pits during accumulation, following the method made familiar in the process of ensilage, and, where it is practicable to employ it, the old English box stall, the floor consisting of a shallow, cemented pit, the manger being so adjusted to be raised with the accumulation underfoot, is the ideal system of saving manure, as by this method the least possible handling is required, and handling is an important item in the cost of manure.

This method, however, is not adapted to horses under any conditions, nor to dairy cows; as the manure of horses, if left without any further treatment, would evolve an amount of ammonia injurious to the eyes of the animals, and in large dairies the cost would be considered prohibitive, although with liberal use of bedding it is probable that this method would be found as cleanly as the ordinary stall with its daily removal of excrement and consequent renewal of odor.

In the case of fattening cattle or sheep, however, this method of preserving the manure is both the simplest and most effective possible. With hornless cattle it involves no waste of space, since such cattle may be handled like sheep and will thrive better when so handled than if tied up in separate stalls. The one important point is to provide abundant litter, of which cattle require a larger quantity than sheep, because of the greater proportion of water in the dung.

The manure shed—For horses and dairy cows some other method of manure storage is necessary, and it is here that the manure shed comes into play. For the manure shed to serve its purpose, however, it must be so situated that stock can have access to it, and they must be encouraged to frequent it in order to trample the manure well; for if this is not done the shed will only serve to waste the manure the more rapidly instead of preserving it.

It will be found very difficult to preserve horse manure alone in any kind of shed, because of its great tendency to heat. This point is illustrated in the making of hotbeds, for which fresh horse manure is piled in loose heaps until active fermentation has begun, when it is placed in shallow pits, moderately packed by trampling, covered with earth and sheltered from excess of moisture. The fermentation continues for weeks with considerable evolution of heat.

This tendency of horse manure to ferment may be held in check by mixing it with cow manure and packing it thoroughly, or by keeping it soaked with water. The manure shed, therefore, should be located so as to receive the mixed manure of both classes of animals, and should also be where its contents can be wet down when necessary. If a cistern is used to collect the urine, this should be pumped over the contents of the manure shed occasionally, both for the purpose of wetting the latter and also to improve the effectiveness of both; for the urine, as has previously been shown, carries a large quantity of nitrogen and potassium, but almost no phosphorus; but on most soils nitrogen and potassium produce comparatively little effect unless reinforced with phosphorus.

For example, in the Pennsylvania experiments, in which corn, oats, wheat and clover are grown in rotation under different combinations of fertilizing materials, a mixture carrying nitrogen in dried blood and potassium in the muriate has produced an average increase for each rotation, for the first 30 years of the test, to the value of $1.98 at the valuations heretofore employed. When this mixture was reinforced with superphosphate the value of the increase rose to $20.91, although the same quantity of superphosphate, used alone, has produced but $8.88 in increase of crop. These results are tabu-

TABLE XL. EFFECT OF COMBINATION IN FERTILIZERS.*

Fertilizer	Value of increase a rotation		
	Penna.	Wooster	Strongsville
Potassium and nitrogen	$ 1.98	$11.08	$ 4.62
Potassium, nitrogen and phosphorus	20.91	39.14	24.35
Phosphorus alone	8.88	16.53	17.39

*For details of the Pennsylvania test, see Bulletin No. 90 of Pennsylvania State College Experiment Station; for those of the Ohio tests see Bulletins 182, 183 and 184 and Circular 120, of the Ohio Agricultural Experiment Station.

lated above, together with those of the Ohio station's five-year rotations, averaged for 18 years at Wooster and 17 years at Strongsville.

Of course, the superior effect of phosphorus in these tests is due to the fact that the soils under experiment are deficient in available phosphorus, a condition which is found in the majority of soils which have been long in cultivation, although there are occasional exceptions, as in the case of the Lexington soil of the Kentucky experiment station,* that of the Massachusetts experiment station at Amherst,† and certain muck soils,§ in which potassium seems to be the element most deficient. On sandy soils potassium appears to be more frequently needed than on clays.

It may be asked, "Why build a manure shed if the manure must be kept wet under it?" The answer is that the manure shed gives us control of the moisture, enabling us to use a sufficient quantity to preserve the manure without causing leaching.

It may be doubtful whether the manure shed will pay for itself simply as a shelter for manure; but those farmers who have built such sheds have usually made them also serve the purpose of straw storage overhead, and of an exercise yard for stock in stormy weather. When these functions are judiciously combined there can be no question of the economy of the manure shed.

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* Kentucky Agricultural Experiment Station, Bulletin 61.
† Hatch Experiment Station, Fifteenth Annual Report, p. 132.
§ Agricultural Experiment Station, University of Illinois, Bulletin 93, and Purdue University Experiment Station, Bulletin 95.

The manure cellar—A substitute for the manure shed is the manure cellar. But such a cellar is not practicable on flat building sites, and it is generally open to the serious objection of keeping the animals in a contaminated atmosphere and of being an unwholesome place to work in cleaning out. With the modern litter carrier a manure shed may be built adjoining, or even entirely separate from the barn, thus entirely removing the odor of its contents from the barn itself. It may be so arranged that the litter carrier may pass over a manure spreader, standing ready to receive its contents when practicable to take the manure at once to the field, as shown by the illustration on page 153.

The manure pit—Where horse manure must be kept alone, it is probable that the outdoor pit will be found the most satisfactory receptacle in which to preserve it. Such a pit should be deep enough to hold the annual rainfall, less evaporation and plus the amount of material that may be thrown into it, in order that there may be no leaching. The bottom and sides should be cemented, and it should be so arranged that a wagon can be driven through it, unless the quantity of manure is so small that it can be emptied from the side with not more than one extra handling.

Horse manure thrown into such a pit would ordinarily receive water enough from the rain to prevent fermentation, and would probably suffer less destructive losses than under any other practicable method of preservation.

Such a pit is but a modification of the basin-shaped manure yard, which is in occasional use, but which is very seldom so constructed as to be absolutely secure from leaching on the one hand and overflow on the other.

Manure preservatives—Many experiments have been made by European investigators, in the endeavor to find some practicable method of arresting the ammonia escaping from the manure heap, but while it has been shown that many finely pulverized materials perform this function to a greater or less extent, the quantity required, or the difficulty of application, is usually so great as to counterbalance the saving accomplished.

One of the most effective materials for this purpose is dry earth, and especially dry muck, which has the advantage not only of preventing some escape of ammonia, but also of reinforcing the manure with nitrogen, and where this material is available it might often be used with advantage.

Sulphate of lime, commonly known as gypsum, or land plaster, has been used for this purpose for many years, being dusted over the manure heap and over the stable floors. This substance is probably partly decomposed by the manure, its sulphuric acid uniting with ammonia to form sulphate of ammonia, which is a comparatively stable salt.

Dilute sulphuric acid would perhaps be one of the most effective of manure preservatives if it were practicable to use it, but it is too dangerous to handle, and, moreover, it would be injurious on some soils, because of increasing the tendency to soil acidity.

Common salt is an excellent manure preservative, and those living near salt works are sometimes able to procure the refuse salt almost without cost. One of the properties of salt is that of conserving moisture, and this may partly explain its effect on the manure heap.

The crude potash salt, kainit, which is a mixture of the chlorides of sodium and potassium with sulphates of potassium and magnesium (common salt being chloride of sodium), is also a useful manure preservative, and would be a very suitable material to use on manure intended for soils deficient in potassium, or for such systems of cropping as cause heavy drafts upon the soil stores of potassium, such as market gardening.

While there are a few soils that are relatively deficient in potassium, there are many more in which phosphorus is the limiting element, and for such soils such phosphatic materials as floats and acid phosphate, or even bone meal, would seem to be appropriate materials with which to treat manure. These materials, together with those previously mentioned, have been used by German and French investigators, chiefly in laboratory experiments, or in field tests extending over one or two seasons only, with considerable diversity in results. The general outcome of the work appears to have been that attention has been directed chiefly to the conservation of ammonia, and it has been found that the effect produced in this direction alone has seldom been sufficient to justify the expense of the treatment. It does not appear that there has been in Europe any systematic, long-continued study of the effect of manure treatment by experiments made under the natural conditions of the field, nor that, in either field or laboratory tests, the question of the better adaptation of the manure to the needs of particular soils or systems of cropping has been adequately studied.

One of the most satisfactory of these European experiments was made by Maercker and Schneidewind at Lauchstadt in 1896-97,* who made three experiments, two with cattle and one with sheep, fed in stalls about 2 feet deep and with cemented bottoms, the manure accumulating under foot, and parallel experiments on open and covered heaps of manure from animals receiving the same treatment, as to feed and bedding, as those in the deep stalls.

The outcome of this work was that the loss of nitrogen from the deep stalls, when the manure was sampled immediately after the removal of the animals, amounted to about 13 per cent of the total nitrogen; but when the manure was allowed to lie in the stalls for four weeks during warm weather after the cattle were removed, the loss increased to 35 per cent.

In an ordinary uncovered heap the loss of nitrogen was 37 per cent, and there was practically the

* Landw. Jahresb. 72 (1898). abs. Experiment Record, 10 (1899).

same loss when the heap was covered. The weather conditions, however, were especially favorable to the uncovered manure, being wet and cloudy, while the covered manure became too dry.

The addition of 30 per cent of marl to the manure reduced the loss of nitrogen to less than 10 per cent, and the addition of 30 per cent of marl and two per cent of peat reduced it to 6 per cent. The best result, however, came from the addition of 6 per cent of sodium bisulphate, corresponding to 1.5 per cent of sulphuric acid, which reduced the loss to 1.3 per cent, thus keeping the manure practically unchanged.

An experiment similar to the above was made by Prof. William Frear at the Pennsylvania experiment station in 1901,* in which manure, allowed to accumulate during two months (April and May) under animals in cement-lined stalls, was compared with manure removed daily and stored in a heap under a covered shed. The outcome was that the trampled manure suffered but little loss of fertilizing constituents, while the covered shed manure lost one-third of its nitrogen, one-fifth of its potassium and one-seventh of its phosphorus. The loss of potassium and phosphorus is explained by seepage of the liquid manure into the clay floor of the storage shed, but the loss of nitrogen was chiefly due to the volatilization of carbonate of ammonia. The money value of the loss by the second method was computed at $2.50 for each steer stabled six months.

* Pennsylvania State College Experiment Station, Bulletin 63.

Dr. Frear's final conclusion is that "manure, if prepared upon a tight floor and with such proportion of litter that it can be trampled into a compact mass, loses very little, if any, of its fertilizing constituents so long as the animals remain upon it"—a conclusion which is in harmony with the general consensus of opinion of European investigators.

Preservation of hen manure—The Maine experiment station* reports an experiment in the preservation of hen manure in which one lot was stored in a barrel from May to November without any treatment, while other lots were mixed with kiln-dried sawdust, kainit, plaster and acid phosphate. The outcome of this test was that the untreated manure became moldy and lost more than half its nitrogen. The sawdust alone slightly improved the mechanical condition of the manure, but was of no service in conserving nitrogen. The manure stored with approximately an equal weight of plaster lost about one-third of its nitrogen; with nearly twice its weight of plaster there was no loss of nitrogen. The lots stored with kainit and acid phosphate retained practically all their nitrogen, even when these materials were used in but little more than half the weight of the manure. When these materials were used alone the manure was rather wet and sticky, but when they were used in connection with sawdust the physical condition was more satisfactory.

* Annual Report, 1903.

CHAPTER IX

THE REINFORCEMENT OF MANURE

Manure not a complete fertilizer—It is ordinarily assumed that the fertility of the soil may be indefinitely maintained by a sufficient use of manure; and while this is true for a limited area it is not the most economical way of maintaining fertility, for the animal necessarily withdraws from its food the elements required for the building of its tissues, and if it be a young animal, or a cow giving milk, the proportion of phosphorus and lime consumed will be much larger, relatively, than that of nitrogen or potassium. Hence the manure never carries back to the soil the full amount of any of the elements carried in the food, and in the case of growing animals or milk producers the ratio of these elements to each other is very different in the manure from that found in the food.

Fertility losses from permanent pastures—Take the case of a permanent pasture: Even when grazed by so perfect a manure producer as the sheep, it is evident that in the bones of the young stock grown upon it and sent to market there must be a steady drain of phosphorus and lime, which must ultimately become manifest in reduced production, and experience has shown that the use of phosphatic fertilizers upon such pastures produces a marked increase in the production of grass.

Fertility losses in grain production—Take the case of the grain farmer: A bushel of wheat carries about a fifth of a pound of phosphorus—a very small quantity it is true, and not a large quantity when multiplied by the average American yield of only about 14 bushels per acre—say three pounds of phosphorus per acre; but when the average annual addition of four pounds of phosphorus per acre to land that has grown wheat along with other crops for three-quarters of a century, or to land that has been in pasture for a third of that time, after previous cropping, will increase the value of the yield by 30 per cent, as it has done and is doing in the experiments of the Ohio station,* it means that the insignificant quantity of this element contained in the single bushel of wheat has become a very important matter within less than a century from the time when the soil was first brought under cultivation.

And when the addition of two pounds and a half of phosphorus to a ton of manure will add 20 per cent to its effectiveness, over and above the increase produced by such materials as gypsum or kainit, as indicated by the experiments reported farther on, it shows that manure alone is not a complete fertilizer for soils exhausted by long-continued cropping.

On soils deficient in lime the time will come, under ordinary management, when the supply of this constituent, as well as of phosphorus, will run short,

*See Bulletin 182, p. 154.

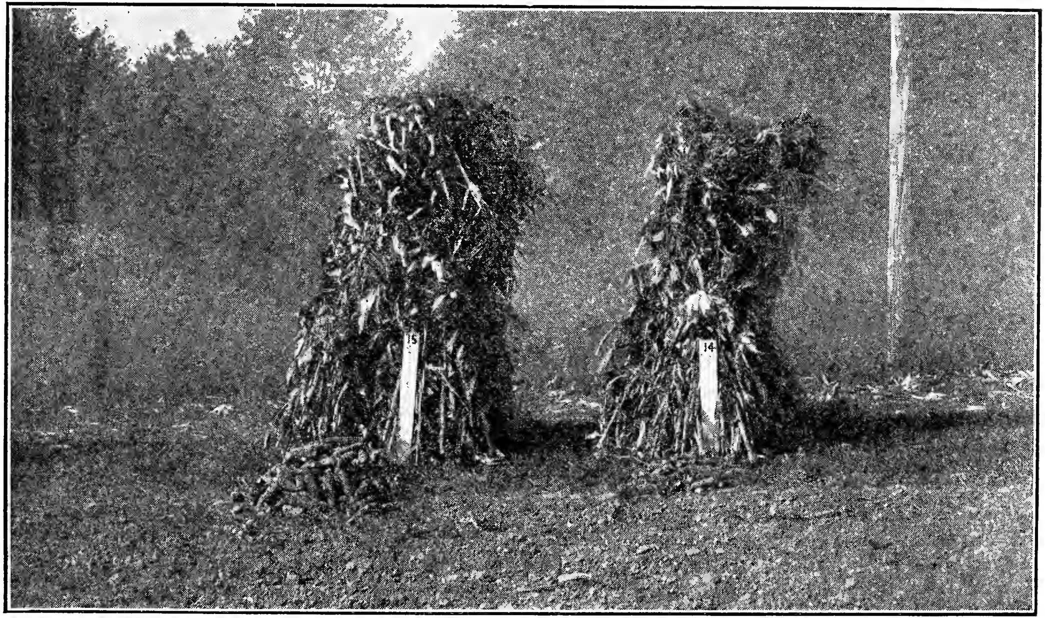
for the oxides of phosphorus and calcium—phosphoric acid and lime—are associated in the ratio of about 46 per cent of the former to 54 per cent of the latter in bone; hence there is a steady consumption of both in animal growth, so that manure alone will not maintain the lime supply, any more than it will that of phosphorus.

The effect of supplementing manure with lime has been discussed on previous pages. The experiments now to be described throw some light upon the reinforcement of manure with phosphates.

Experiments in the reinforcement of manure— Field and laboratory experiments with manure have been conducted at the Ohio experiment station since 1897, the object of which is to gain information regarding the losses suffered by manure on exposure to the weather and also to test the effect of adding certain preservative or reinforcing materials to the manure.

During the first years of these experiments five lots of cattle manure, of 1,000 pounds each, were taken in April from an open barnyard in which the manure had lain through the winter. One lot received no treatment, while with each of the other four 20 pounds, either of gypsum, kainit, acid phosphate or finely pulverized phosphate rock, was thoroughly mixed.

At the same time five similar lots were taken from box stalls where the manure had been trampled under foot during accumulation, and similarly treated. For the first two seasons this manure was



Corn in manure test at Ohio Experiment Station: Plot 15 (left), untreated yard manure; Plot 14 (right), nothing. See Table XLI for average yields.

produced by bulls, receiving a maintenance ration only, while the yard manure came from liberally fed dairy cows; but since then it has been the practice to have both yard and stall manure produced by fattening steers.

After lying a few weeks the manure was spread upon the clover in a three-year rotation of corn, wheat and clover, the clover being shortly afterward plowed under for the corn, the manure being applied at the rate of eight tons per acre.

Because of the uncertainty as to the quantity of fresh manure required to produce a ton of yard manure under this system, the method of selecting the manure was changed in 1903, and since then all the manure for the experiment is taken from the stable in December or January and subjected to the different treatments, after which one-half of each of the differently treated lots is spread in its place in the field, while the other half is piled in a flat, compact heap in an open yard, where it remains until April, when it is spread in its place and the whole is plowed under.

Three tracts of land are used in the experiment, in order that each crop may be grown every season, the tracts being arranged as shown in the diagram.

The corn is cut off in September and wheat is sown after it, clover being sown on the wheat the following spring. The results of this test, for the 15 years ending with 1911, are shown in Tables XLI and XLII.

Plots, One-sixteenth Acre

North

Section A.

11	Nothing	Nothing	1
12	Yard manure and gypsum	Yard manure and floats	2
13	Stall manure and gypsum	Stall manure and floats	3
14	Nothing	Nothing	4
15	Yard manure, untreated	Yard manure and acid phos.	5
16	Stall manure, untreated	Stall manure and acid phos.	6
17	Nothing	Nothing	7
18	Chemical fertilizer	Yard manure and kainit	8
19	Chemical fertilizer	Stall manure and kainit	9
20	Nothing	Nothing	10

Section B.

11	Nothing	Nothing	1
12	Yard manure and gypsum	Yard manure and floats	2
13	Stall manure and gypsum	Stall manure and floats	3
14	Nothing	Nothing	4
15	Yard manure, untreated	Yard manure and acid phos.	5
16	Stall manure, untreated	Stall manure and acid phos.	6
17	Nothing	Nothing	7
18	Chemical fertilizer	Yard manure and kainit	8
19	Chemical fertilizer	Stall manure and kainit	9
20	Nothing	Nothing	10

Section C.

11	Nothing	Nothing	1
12	Yard manure and gypsum	Yard manure and floats	2
13	Stall manure and gypsum	Stall manure and floats	3
14	Noth.ng	Nothing	4
15	Yard manure, untreated	Yard manure and acid phos.	5
16	Stall manure, untreated	Stall manure and acid phos.	6
17	Nothing	Nothing	7
18	Chemical fertilizer	Yard manure and kainit	8
19	Chemical fertilizer	Stall manure and kainit	9
20	Nothing	Nothing	10

Diagram III of Arrangement of Plots and Plan of Fertilizing in Experiments with Manure at Ohio Experiment Station.

TABLE XLI. BARNYARD MANURE ON CROPS GROWN IN THREE-YEAR ROTATION.
Average yield an acre for the 15 years 1897-1911.

Plot No.	Manure and treatment	15 years, 1897-1911				Hay 11 crops Lbs.	Plot No.
		Corn 14* crops		Wheat 14 crops			
		Grain Bus.	Stover Lbs.	Grain Bus.	Straw Lbs.		
1	None	37.92	2,300	12.58	1,516	2,911	1
2	Yard manure and floats	60.78	3,427	24.94	2.695	4,291	2
3	Stall manure and floats	64.39	3,668	26.50	2,876	4,824	3
4	None	31.48	2,055	10.99	1,283	2,315	4
5	Yard manure and acid phosphate	61.94	3,352	25.72	2,737	4,163	5
6	Stall manure and acid phosphate	65.62	3,548	26.54	2.918	4,829	6
7	None	30.89	1,986	9.85	1,198	2,301	7
8	Yard manure and kainit	55.51	3,258	21.31	2,393	3,520	8
9	Stall manure and kainit	60.39	3,543	22.89	2,672	4,280	9
10	None	33.54	2,050	10.36	1,259	2,489	10
11	None	37.83	2,382	13.80	1,672	3,182	11
12	Yard manure and gypsum	59.48	3,418	24.38	2,712	3,825	12
13	Stall manure and gypsum	61.53	3,564	24.19	2,677	3,887	13
14	None	31.95	2.051	10.60	1,223	2,364	14
15	Yard manure, untreated	52.53	2,952	20.20	2,222	3,263	15
16	Stall manure, untreated	59.46	3,369	21.70	2,413	3,955	16
17	None	37.86	2,373	10.95	1,326	2,659	17
18	Chemical fertilizer†	45.07	2.677	14.95	1,711	3,166	18
19	Chemical fertilizer§	45.02	2,514	15.20	1,804	3,377	19
20	None	34.08	2,047	10.40	1,303	2,738	20
	Average unfertilized yield	34.44	2,155	11.16	1,323	2,435	

* Excluding crop of 1909, which was so injured by grub worms that no comparison is possible.
† Acid phosphate, 80 pounds; muriate of potash, 80 pounds; nitrate of soda, 160 pounds.
§ Acid phosphate, 80 pounds; muriate of potash, 10 pounds; tankage (7-30), 100 pounds.

TABLE XLII. BARNYARD MANURE ON CROPS GROWN IN THREE-YEAR ROTATION. Average annual increase and its value (excluding corn crop of 1909).

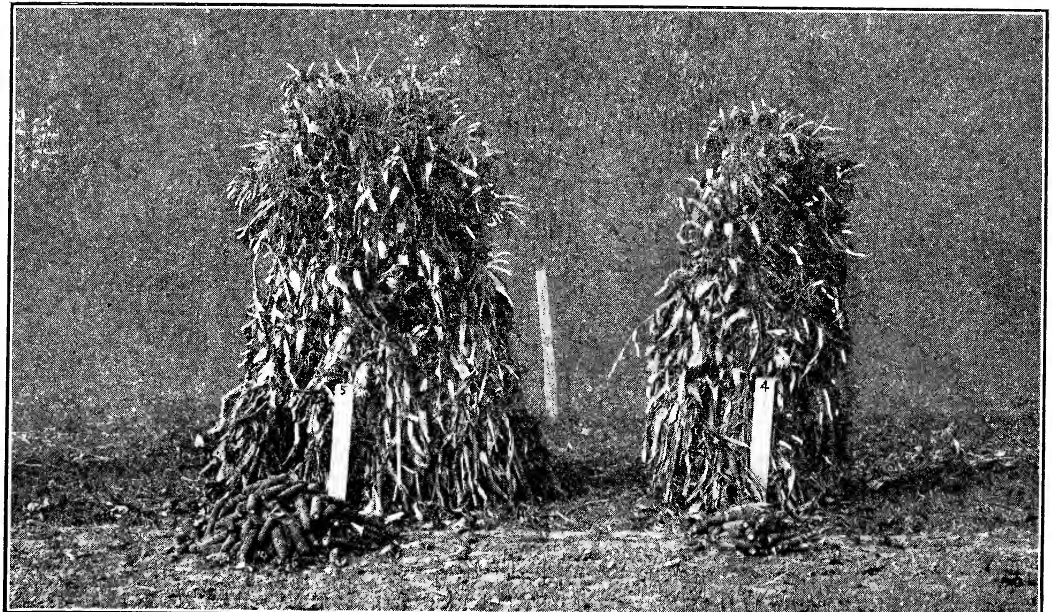
Plot No.	Manure and treatment	Average annual increase an acre					Cost of treatment an acre	Value of increase*	
		Corn 14 crops		Wheat 14 crops		Hay 11 crops Lbs.		Total an acre for one rotation	Net a ton of manure
		Grain Bus.	Stover Lbs.	Grain Bus.	Straw Lbs.				
2	Yard manure and floats	25.02	1,209	12.89	1,257	1,578	$1.40	$29.69	$3.54
3	Stall manure and floats	30.77	1,531	14.97	1,516	2,311	1.40	37.34	4.49
5	Yard manure and acid phosphate	30.66	1,320	15.10	1,482	1,853	2.40	35.21	4.10
6	Stall manure and acid phosphate	34.53	1,539	16.31	1,692	2,523	2.40	40.95	4.82
8	Yard manure and kainit	23.73	1,251	11.29	1,175	1,156	2.70	26.19	2.93
9	Stall manure and kainit	27.73	1,514	12.71	1,434	1,853	2.70	32.37	3.71
12	Yard manure and gypsum	23.61	1,146	11.66	1,190	916	1.00	25.35	3.04
13	Stall manure and gypsum	27.62	1,402	12.52	1,304	1,251	1.00	29.48	3.56
15	Yard manure untreated	18.61	793	9.49	965	801	....	20.39	2.55
16	Stall manure untreated	23.57	1,103	10.88	1,121	1,395	....	26.48	3.31
18	Chemical fertilizer †	8.47	412	4.18	393	480	7.45	9.65	....
19	Chemical fertilizer §	9.68	358	4.62	493	665	2.30	11.26	....

* Rating corn at 40 cents per bushel, wheat at 80 cents, stover at $3.00 per ton, straw at $2.00, and hay at $8.00.
† Acid phosphate, 80 pounds; muriate of potash, 80 pounds; nitrate of soda, 160 pounds.
§ Acid phosphate 80 pounds; muriate of potash, 10 pounds; tankage, (7-30) 100 pounds.

In this experiment every third plot is left continuously unmanured, and the manured plots are arranged in pairs, as indicated in the table, with an unmanured plot on each side of each pair, the increase on the manured plots being computed by comparison with the two unmanured plots between which they lie.

Superiority of stall manure over yard manure— Table XLI shows that in every case the average yield from the stall manure is decidedly greater than from the yard manure, excepting the wheat on the gypsum-treated plots.

The table also shows that each of the materials used in treating the manure has added to its effectiveness, and that in this respect the phosphatic materials have been more useful than the gypsum and kainit. These points are more clearly brought out in Table XLII, in which the relative value of the increase resulting from the variously treated manures is shown. Table XLI shows that the yields on plots 1 and 11 in this test have been larger than any other unfertilized yields except those of corn on plot 17. The details of the experiment show that these exaggerated yields are due chiefly to Section C. No sufficient explanation of this difference is found in the contour or other appearance of the land, and it is suspected that at some time the land covered by these plots which, it will be observed, stand end to end, may have been occupied by a fence row. Were we to calculate the increase on the basis of the general average of all the unfertilized



Corn in manure test at Ohio Experiment Station; Plot 5 (left), stall manure treated with acid phosphate; Plot 4 (right), nothing. See Table XLI for average yields.

plots, the results would be as shown in Table XLIII, which gives for the average of the two kinds of manure the net value of increase per ton of manure as compared (A) with the adjoining unfertilized plots, or (B) with the general average of all the unfertilized plots.

TABLE XLIII. NET VALUE OF INCREASE A TON OF MANURE AS COMPARED (A) WITH ADJOINING UNFERTILIZED PLOTS, OR (B) WITH THE GENERAL AVERAGE OF ALL THE UNFERTILIZED PLOTS.

Treatment	Value of increase a ton of manure	
	(A)	(B)
Floats	$4.01	$4.19
Acid phosphate	4.46	4.13
Kainit	3.32	3.05
Gypsum	3.30	3.63
None	2.93	2.96

Gypsum as a manure preservative—Gypsum has been used for a long time as a preservative of manure, and this experiment shows that it may be used with excellent effect, the gypsum-treated manure producing increase to the value of 49 cents per ton greater than the untreated, over and above the cost of treatment, in the case of yard manure, and 25 cents per ton greater in the case of stall manure, gypsum being rated at $6 per ton.

Kainit as a manure preservative—Kainit has also been highly recommended for this purpose, and the results of this experiment would have justified its use had not more effective materials been found. As compared with gypsum, the total increase from kainit has been greater, but the greater cost of kainit in Ohio, as compared with gypsum, has left the net gain practically the same, kainit being rated at $17 a ton. In the case of both materials the freight is so important a factor in the cost, that it would in many cases determine which of the two materials should be used.

On soils deficient in potassium kainit would serve to reinforce the manure in this element, and might be expected to produce a relatively greater increase than it has shown in this test; but here it seems that the chief effect of both the gypsum and kainit has been to arrest a part of the ammonia escaping from the fermenting manure, or to reduce the activity of fermentation, and thus conserve the ammonia.

Common salt as a manure preservative—Common salt has been found useful in reducing the ammoniacal fermentation of the manure heap and at the same time promoting its decay, an effect possibly due in part to the hygroscopic character of salt, by which it promotes the absorption of moisture in the heap, thus preventing the excessive heat resulting from the uncontrolled action of the ammonia-producing organisms, and giving the nitric ferments opportunity to convert the ammonia into nitrates before its escape.

Reinforcement of manure with crude phosphates—For an unknown period bones have been softened by mixing them, after pulverizing, with fermenting manure, and this fact suggested the use, in the experiment under consideration, of the crude phosphate rock from which acid phosphate is made, and which is known as floats. This material, it will be observed, has added more than $1 per ton to the net effectiveness of the manure, and the net increase per ton of manure for floats over gypsum has been more than half a dollar per ton of manure, floats being rated at $8 per ton, and gypsum at $5. In this case both the original cost and the freight affect the relative profit, but it will be seen that the net value of the increase from floats is greater, for both kinds of manure, than the total value of the increase from either gypsum or kainit. In other words, it has been more profitable to use floats at $8 per ton than to use gypsum or kainit, though they had cost nothing.*

Reference to Table XLI shows that the total yields of corn and wheat have been greater from the manures treated with acid phosphate than from those treated with floats, while the hay yields have been a little smaller on the yard-manure plot after the acid phosphate than after the floats. These differences, however, have been so small that the final conclusion respecting the relative efficiency of the

* The Dominion Experimental Farms have used "untreated mineral phosphate" in the treatment of manure since 1888; but whereas the treated manure was used at the rate of six tons per acre annually, the untreated manure was used at the rate of fifteen tons, thus leaving no opportunity for comparison of the effect of treated with untreated manure, nor of the effect of the manure on the phosphate; for while the six tons of treated manure has produced nearly as great an increase as the 15 tons untreated, the latter quantity is so far in excess of the capacity of the crop to utilize its constituents that no comparison can be made.

Corn in manure test at Ohio Experiment Station: Plot 16 (left), untreated stall manure; Plot 17 (right), no manure. See Table XLI for average yields.

two reinforcing materials rests upon whether the soil is assumed to be of uniform natural fertility, or whether we assume that there has been a progressive decrease in natural fertility from plot 1 to plot 7, as is indicated by the yields of all the crops, the indication being that the yield has fallen off more abruptly between plots 1 and 4 than between plots 4 and 7.

The ordinary retail price of acid phosphate, 14 percent grade, is $15 to $17 per ton, though it may be bought in carloads, freight paid, by those who are informed, at not exceeding one dollar per ton for each percent of phosphoric acid, or $14 per ton for the 14 percent grade. At this price the 40 pounds per ton of manure, or 320 pounds per acre, used in this experiment, would cost $2.24 per acre, thus leaving the net gain from the acid phosphate $32.97 per acre, or $4.12 per ton of manure, for the yard manure, and $38.71 per acre, or $4.84 per ton, for the stall manure.

The floats used in this test has analyzed about 27 percent total "phosphoric acid," so that it has carried nearly twice as much phosphorus to the soil as the acid phosphate, and if reinforcement of the soil with phosphorus were the only effect of the treatment of manure, it would be expected that in time the floats-treated manure would begin to show a greater effect than that treated with acid phosphate. That time, however, has not yet arrived, as the combination of manure with acid phosphate is still producing a larger yield than that treated with floats. This point is brought out by Table XLIV, in which the yields of corn and wheat are compared by six-year periods. It will be observed that the corn crop shows a diminished yield for the last period under every treatment except that of the fresh manure reinforced with floats and acid phosphate, but the wheat crop shows a large increase in yield for the last six-year period over the first in every case, and the rate of increase has been greater on the acid phosphate plots than on the floats plots for both kinds of manure

TABLE XLIV. COMPARISON OF STALL AND YARD MANURES, VARIOUSLY TREATED. FIRST SIX YEARS COMPARED WITH LAST SIX YEARS. AVERAGE YIELD IN BUSHELS AN ACRE.

Plot No.	Crop and treatment	Yield an acre		Gain (+) or loss (–) for second 6 years	
		First 6 years	Last 6 years	An acre	Percent
	Corn, unmanured	40.10	27.63	–12.47	–30
15	" yard manure, untreated	54.98	47.36	– 7.62	–14
12	" " " and gypsum	60.88	55.08	– 5.80	– 9
8	" " " " kainit	58.99	50.26	– 8.73	–15
2	" " " " floats	60.22	58.61	– 1.61	– 3
5	" " " " acid phosphate	61.46	59.08	– 1.38	– 2
16	" stall, " untreated	59.20	57.11	– 2.09	– 3
13	" " " and gypsum	63.50	57.83	– 5.67	– 9
9	" " " " kainit	61.05	59.08	– 1.97	– 3
3	" " " " floats	62.68	63.94	+ 1.26	+ 2
6	" " " " acid phosphate	63.46	65.29	+ 1.83	+ 3
	Wheat, unmanured	8.51	14.31	+ 5.80	+68
15	" yard manure untreated	15.63	24.03	+ 8.40	+54
12	" " " and gypsum	21.90	26.94	+ 5.04	+23
8	" " " " kainit	18.50	24.59	+ 6.09	+33
2	" " " " floats	22.39	28.83	+ 6.44	+28
5	" " " " acid phosphate	21.50	30.94	+ 9.44	+44
16	" stall, " untreated	17.59	25.10	+ 7.51	+42
13	" " " and gypsum	22.54	25.59	+ 3.05	+13
9	" " " " kainit	20.99	25.66	+ 4.67	+22
3	" " " " floats	24.28	29.72	+ 5.44	+22
6	" " " " acid phosphate	23.37	30.18	+ 6.81	+28

The land upon which this experiment is being conducted has been reduced to a very low state of fertility by many years of exhaustive farming, and while it shows a great lack of phosphorus, by its ready response to phosphatic fertilizers, yet it is equally hungry for nitrogen.

To illustrate: In the experiments with fertilizers, conducted on the same farm, the 18-year average unfertilized yield of wheat grown in rotation with other crops has been 10.72 bushels; where phosphorus has been given the yield has risen to 18.69 bushels; where potassium has been added to the phosphorus there has been a further increase to 19.91 bushels, and where nitrogen has been added to the combination of phosphorus and potassium the average yield has risen to 27.13 bushels.

This hunger of the soil for both phosphorus and nitrogen explains the fact that the acid phosphate has been more effective when used in combination with manure than when used alone; for whereas the quantity used with manure has increased the annual value of the total yield by $5.24 per acre over that given by the untreated manure, yet when the same quantity of acid phosphate has been used alone in the five-year rotation on the same farm its increase has amounted in value to only $3 annually. Each material has supplemented and reinforced the other, the phosphate supplying the element in which the manure was deficient, and the manure furnishing the nitrogen and potassium required to utilize the full effect of the phosphate.

CHAPTER X

METHODS OF APPLYING MANURE

Effect on manure of drying—A generation ago it was the general practice, in handling manure, to haul it from the barnyard to the field when convenient, pile it there in small heaps, 15 to 20 feet apart, and leave it in these heaps until the time came to plow the land, when the manure was scattered just ahead of the plow and turned under as quickly as possible; the idea being that the drying of the manure would cause a large part of its virtue to be lost.

Few farmers of that day knew that the pungent, invisible gas escaping from the manure heap was, in fact, its most valuable constituent. The great majority did not know that this gas was constantly being formed, so long as the manure lay in moist heaps, and was as constantly passing from the heaps into the air; they did not know that the drying of the manure took away only water, leaving all the actual plant food behind, and that, in fact, the complete removal of the water would leave the manure in better condition for preservation than before.

We now know that the decomposition of manure can only take place in the presence of moisture; that if we can withdraw all moisture, the residue will preserve all its fertilizing qualities indefinitely, and that when the moisture is evaporated from the manure heap it carries with it none of these fertilizing qualities, but goes into the atmosphere simply as watery vapor.

Everybody knows that when brine is evaporated all the salt is left behind, and this is equally true of manure water. There are two ways, and only two, in which manure loses its value; these are leaching and the heating which accompanies chemical action. When the manure is heaped in the field both these agencies of loss begin their action. The rain falls upon the heap and washes its more soluble, and, therefore, more valuable, constituents into the ground immediately under and around the heap, and chemical, or more properly, bacterial action begins in the heap, liberating its nitrogen and converting its phosphorus and potassium into more soluble forms, to be washed out by the next shower.

Of all the ways in which manure is handled, therefore, this old way of piling it in small heaps in the field is the most wasteful. It is worse than leaving it under the barn eaves and letting it leach out there, because of the waste of labor involved in hauling a lot of material to the field to be there thrown away, and because the excess of fertilizing material washed into the soil under the manure heaps is an actual injury to the soil, if the heaps be allowed to lie for any length of time. The overgrowth of lodged and half-filled grain over such spots ought to be sufficient to convince any observing man of the mistake of such a method, and yet there are thousands of farmers who still follow it.

Value of the liquid manure—If we would but stop and reflect that fully half the potential fertilizing value of the manure, as it is voided by the animal, is found in the salts dissolved in the liquid portion; that the full effect of neither the solid nor the liquid portion can be realized except when used in connection with the other; that when the liquid is permitted to flow away, in stable or yard, or when it is displaced by rain and separated from the solid portion, whether in yard or field, it carries with it these fertilizing salts; but that when it is merely evaporated they are left behind and still combined with those of the solid portion, it would be easy to realize that the only right way to handle manure is to collect the liquid by abundant absorbents, get it promptly to the field where its effect is wanted, spread it there at once and as perfectly as possible, and then let sunshine and rain do their work. The sunshine will evaporate the water, and that only, and the rain which follows will redissolve the salts and wash them into all the soil, where they are needed, and not simply into little spots here and there.

The manure spreader—When we come to understand the nature and value of manure, the need of thorough distribution becomes apparent. When it is spread with the fork there will inevitably be lumps here and bare spots there, thus losing part of the possible effect in one spot from excess and in another by deficiency. It is true that the distribution of manure with a fork may be very much improved by following with a smoothing harrow, but even with this extra labor the work cannot be so well done as with a manure spreader.

Another great advantage in the manure spreader is that it is always ready for its special purpose, and therefore, the manure is much more likely to be drawn promptly to the field than if a wagon, used chiefly for other purposes, must be gotten ready for this job every time a lot of manure is to be moved.

Not only is manure distributed more perfectly by the spreader than by hand, but the work is done more cheaply. With the steadily increasing cost of labor it becomes constantly more important to devise means for substituting the labor of horses for that of men, and with the spreader a team will unload a ton of manure in a small fraction of the time that would be required to do it by hand.

Considering the convenience, the perfection and the economy of its work, the manure spreader should be ranked next to the automatic harvester in importance as a farm implement.

Spreading manure in winter—Many farmers fear that if they spread manure on frozen ground, especially on hillsides, it will be in danger of being washed away by the spring freshets; but clay is a powerful absorbent, and the rain which would carry away the fertilizing salts of the manure would very soon thaw the surface of the soil so that it would extract these salts from the water flowing over it.

Admitting that there may be occasional small losses from this source, such losses are unquestionably insignificant as compared with those which occur in the average barnyard, or in the small manure heaps in the field.

Fresh vs. rotted manure—It has been commonly assumed that the effectiveness of manure is increased by rotting, and old books on agriculture, and especially on gardening, abound in advice to use only "well-rotted" manure, and in methods to bring it to this condition. The investigations which have been described in the previous pages show that the ton of rotted manure may sometimes contain as many pounds of fertilizing constituents as the ton of fresh manure, and so long as these investigations did not go into the question of the loss of fertilizing constituents suffered by manure in rotting, and of the comparative availability of the constituents in the two kinds of manure, it was easy to imagine that rotted manure might be more valuable than fresh manure. Prof. F. T. Shutt, of the Dominion Experimental Farms, says, on this point:

"The advantages gained by rotting may be enumerated briefly as follows: The manure becomes disintegrated and of uniform character throughout, allowing an easier and more uniform distribution in the field and a more intimate mixing with the soil; the coarse litter is decomposed and its plant food thus made more available; compounds are formed from the organic matter that more readily produce humus within the soil; the availability of the nitrogen of the solid portion of the manure is increased; the phosphates are made more assimilable; there is less weight of manure to haul to the fields; the large number of weed seeds that may be present are destroyed."

After thus stating the advantages of rotted manure Professor Shutt says:

"It has also been seen, on the other hand, that even under a good system of preservation, rotting must be accompanied by loss of fertilizing constituents. Weight for weight, rotted manure is more valuable than fresh manure, containing a larger percentage of plant food and having these elements in a more available condition, but the losses in rotting may, and frequently do, outbalance the benefits. Undoubtedly the safest storehouse for manure is in the soil. Once in the soil, the only loss that can occur is through draining away of the soluble nitrates, and this is usually very slight, indeed it is not to be compared with the loss of nitrogen in the fermenting manure heap. We, therefore, unhesitatingly say that the farmer who gets his manure while still fresh into the soil returns to it for the future use of his crops much more plant nourishment than he who allows the manure to accumulate in piles that receive little or no care, and which, therefore, must waste by excessive fermentation or leaching, or both."*

Whether the constituents of rotted manure are really more valuable, pound for pound, than those of fresh manure, however, has been shown by the work of Mr. Ames, of the Ohio station, quoted on page 147, to be dependent upon whether the rotting

* Central Experimental Farm Bulletin 31, pp. 23, 27.

has been conducted under such conditions as to avoid all loss of the more readily soluble portions, either by leaching or by seepage, so that under the conditions which usually attend the rotting of manure it not only loses in total quantity of plant food, but in the relative value of that which is left.

As a study of the comparative value of the two kinds of manure, an experiment was begun at the Dominion Experimental Farm at Ottawa in 1888, in which wheat, barley, oats, ensilage corn, mangels and turnips are grown continuously on land cleared from the forest for the purposes of the experiment, and in which one plot (No. 2) has received annually 15 tons per acre of a mixture of equal parts of fresh manure and cow manure, and another plot (No. 1) has received the same quantity of "well-rotted" manure from the same classes of animals.

This experiment was continued without change for 10 years; the manuring was then discontinued until 1905, in order to study the residual effect of the manures. The application of the manures was resumed in 1905. Table XLV shows the average yield per acre for the entire period of experiment, as computed from the annual reports of the director.

These experiments show practically no difference in the effectiveness of the two kinds of manure, ton for ton, the only decided advantage indicated for the fresh manure being that it has required more than two tons of fresh manure to produce one ton of rotted manure—a difference abundantly sufficient to justify the use of fresh manure.

TABLE XLV. COMPARISON OF FRESH AND ROTTED MANURE AT THE DOMINION EXPERIMENTAL FARM.

	Average yield an acre		
	No manure	Rotted manure	Fresh manure
Wheat, bushels	11.24	22.53	22.77
Barley, "	15.13	37.12	37.07
Oats, "	35.39	52.48	56.11
Silage corn, tons	6.33	14.92	14.22
Turnips, "	7.50	15.70	15.73
Mangels, "	8.21	22.18	21.21

But 15 tons of manure, applied every year, would carry such large quantities of fertilizing elements that there would have to be a very great difference in effectiveness if the crops were to show it. Taking the analyses of similar manures made by Professor Shutt in 1898 (see page 144), we find that 15 tons of the fresh manure would have carried 180 pounds of nitrogen, 56 pounds of available phosphoric acid and 200 pounds of available potash, or as much of each of these available constituents as would be contained in 90 bushels of wheat with its straw, or 26 tons of mangels. Of course, the total available plant food is never completely utilized by the crop, but the differences between the quantities supplied in the manure in this instance and those recovered in the increase of crop are so great as to show that the weight of crop was limited, not by the plant food supplied in the manure, but by seasonal, physical or physiological conditions.

CHAPTER XI

WHERE TO USE MANURE

Manuring corn—While all the crops ordinarily grown on the farm may be benefited by judicious applications of manure, there are some to which it is better adapted than to others, and which, therefore, should have the preference if there is not a sufficient supply for all, and of these corn easily stands first.

Of all the crops grown in the Temperate Zone none is capable of producing as much food to the acre as Indian corn. A crop of 80 bushels of corn to the acre is more easily attained than one of 40 bushels of wheat, and while the stover which produces this quantity of corn will weigh but little more than the straw carrying half as much wheat, yet it is practicable to convert a very much larger proportion of the stover into meat or milk than of the wheat straw, so that the corn crop will yield at least twice as much potential food to the acre as wheat.

If we compare corn with potatoes we would need to raise more than 500 bushels of potatoes to the acre to produce as much digestible dry material as is yielded by the grain alone of an 80-bushel corn crop, but the comparative rate of production of the two crops under the ordinary circumstances is less than three bushels of potatoes to one of corn.

The average rate of production of the different crops in Ohio, as shown by the statistics collected by the township assessors for the ten years, 1890-99, was as follows:

Corn,	33.68	bushels an acre
Wheat,	14.60	" " "
Oats,	29.34	" " "
Potatoes,	75.25	" " "

On an average, about 60 pounds of stover is required to carry a bushel of corn; about 110 pounds of straw to the bushel of wheat, and about 70 pounds to the bushel of oats.

This supremacy of corn as a food producer is due to its ability to secure and utilize immense quantities of soil nitrogen. Making its growth, as it does, during the summer months, when nitrification is most active, and under conditions of culture which favor the action of the nitrifying organisms, it has greater opportunity to obtain this element than those crops which make most of their growth during the cooler months.

Further than this, the corn plant is so constituted that it will reach its greatest perfection in a soil so rich in nitrogen that the small grains would lodge on it before reaching maturity, and, therefore, corn will thrive under doses of manure that would be fatal to wheat or oats.

Another reason for giving the corn crop the preference in the distribution of manure is that this crop is ready for the manure early in the spring, thus making it possible to avoid the waste which usually follows the keeping of manure through the summer. Moreover, corn is usually grown on sod land, on which the manure may be spread at any time during the fall or winter, if the land is reasonably level. Many farmers are now following this method, and they find that the manure spread during the fall or early winter produces larger crops than that spread later.

Of course, manures spread on steep hillsides may lose somewhat by leaching, but it is probable that the loss which occurs in this way is insignificant, as compared with that which takes place in the ordinary farmyard; for clay has a powerful affinity for manure, and a thin sheet of manure water flowing down a hillside will lose most of its manurial salts before it reaches the bottom.

Potatoes are also a spring crop which is usually grown on sod land, and while they produce less actual nutriment to the acre than corn, the average market value per acre of the potato crop is considerably greater than that of the corn crop, hence it is a very general and rational practice to deal liberally with this crop in the distribution of manure. In fact, it is a principle of general application that the higher the acre-value of a crop the more profitably it will respond to manuring or fertilizing; for this reason all crops known as truck crops may well receive first attention in the matter of manuring.

The oats crop is seldom directly manured, both because it is a crop of low acre-value, and because it is so easily lodged by excess of nitrogen in the soil.

Manuring wheat—In former days it was the general custom to leave the manure in the barnyard until after harvest, and then apply it to the land intended for the wheat. So long as the idea prevailed that manure must not be permitted to become dry it was the custom to deposit it in small piles in the field, these piles to be spread in advance of the plow, being careful not to get too far ahead of the plowing; and the writer, who has witnessed every step in the progress of agriculture, from that of reaping and threshing the wheat with such implements as Farmer Boaz may have used, to the enormous steam harvester of today, cutting a swath of 20 feet or more in width and threshing and sacking the grain as it goes, has spent many hours in scattering manure in this fashion.

But as the sickle gave place to the reaper, and the bonds of tradition, which had led the farmer in the footsteps of his father since man first learned to till the ground, began to weaken, it was discovered that the drying of manure was not so wasteful a process as had been imagined, and the practice of plowing the land first and then top dressing it with manure came into vogue, the farmer finding that this practice possessed the double advantage of permitting the plowing to be done earlier, thus securing the benefit of a short summer fallow, and of keeping the coarser portion of the manure on the surface, to serve as a partial protection to the growing wheat during the winter and a stimulus to the clover and grass seeds during the early spring.

Later on commercial fertilizers came into use, and these have proved so convenient and effective for improving the wheat crop that top dressing is much less practiced than formerly, and more of the manure goes to the corn crop. This disposal of the manure is an improvement on the former method, but unfortunately it has followed a large decrease in the number of live stock kept, so that much less manure is being produced in proportion to the area under cultivation than was a quarter of a century ago.

In the Ohio station's experiments corn, which has received eight tons of manure per acre, has given an 11-year average yield of 58 bushels per acre, an increase of 23 bushels over the yield of the unmanured land alongside, and the wheat which has followed this corn without any further manuring or fertilizing has yielded 19.7 bushels, an increase of 9.9 bushels over the unmanured yield; whereas, when the wheat land has been top-dressed with the same quantity of manure just before seeding, the manure having lain in the barnyard until drawn out for this purpose, the increase in yield has averaged but 11.1 bushels, or only one and one-fifth bushel more than that given by the wheat which has eaten at the second table after the corn.

In other words, *while this manure was lying in the barnyard waiting for the wheat it might have grown* *more than 20 bushels of corn without materially impairing its value for wheat production!*

Taking no account of the fact that much more than a ton of manure has to be thrown into the barnyard in the winter for every ton taken out in August, it seems evident that the proper way to handle the winter's accumulation of manure is to put it, as promptly as possible, upon the spring crops. Many farmers have learned this lesson, and the practice is steadily increasing, although there are still far too many who follow the old, wasteful methods.

The grass crops, both meadows and pastures, respond promptly to manuring. A familiar illustration of this point may be seen in meadows, the aftermath of which has been pastured the previous fall, in the superior growth around the animal droppings. It is easy to see that a liberal dressing of manure would have doubled the yield of many such a meadow.

In one of the experiments of the Ohio experiment station, clover and timothy occupy the land for two years, after corn, oats and wheat have been grown in succession. In this test one plot receives every five years a dressing of 1,060 pounds of chemical fertilizers, distributed over the three cereal crops, while another receives during the same period 16 tons of open-yard manure, divided between the corn and the wheat. The result has been an 18-year average increase in the cereal crops to the value of $29.72 per acre for each rotation, for the chemical

Scene in a southern Ohio orchard. Left hand row fertilized, right hand row unfertilized. Variety and spraying the same for both rows. Hundreds of orchards in the hill counties of southern Ohio are being starved to death in this manner. (From Bulletin 240, Ohio Experiment Station.)

fertilizers, as against a value of $25.56 from the same crops for the manure; but the clover and timothy have given a residual increase following the chemicals to the value of $9.50 per acre, as against a value of $14.04 for the same grass crops following the manured cereals. This relatively greater effect of manure on the grass crops has been partly due to the grass seeds carried in the manure, as shown by the thicker stand, especially of timothy, shown on the manured plots; but this is only an additional reason for using manure on meadows and pastures whenever practicable, for here its grass seeds give it additional value, whereas they are a disadvantage on the cultivated crops.

It is true that manure may carry weed seeds to the meadows and pastures as well as the more desirable grass seeds; but if the system of farming has been such as to avoid the production of weeds, this will not be a serious objection.

Meadows and pastures may be manured at times when it is not practicable to manure cultivated lands, and hence the system of farm management should contemplate the regular division of the manure produced between the lands in grass and those under cultivation.

Manuring the orchard—Another part of the farm which is too often overlooked in the distribution of manure is the orchard. It is probable that the seeds carried in a full crop of apples contain as large a quantity of the essential elements of fertility as an ordinary crop of corn or wheat, and the conditions of cropping in the orchard are similar to those of continuous culture on the same land. It is true that the fruit tree sends its roots deeper into the soil than the cereals, and thus has a larger foraging ground, but there can be no reasonable doubt that starvation is one of the prime causes of irregular crops and frequent failures in the orchard.

Orchardists are learning that conservation of moisture is another essential to successful fruit production, and the mulch system is making many converts; but a coarse, strawy manure is not only an ideal mulch, but a conveyer of needed soil enrichment as well. In using it for this purpose it should be kept well out under the ends of the branches, as it is there that the feeding roots are most active.

The only time in the year when manure is unacceptable to the orchard is the brief period during which the fruit is being gathered, and even then it might be spread and covered with straw, an operation which would involve no waste of labor, since more mulching material can be used to advantage than would be carried in a moderate dressing of manure.

CHAPTER XII

GREEN MANURES

Green manures are crops which are grown to be turned under for the purpose of enriching the land. The process of green manuring serves three principal functions: (1) The improvement of the physical texture of the soil by incorporating with it the fibrous roots of the manure crops, which separate the soil particles, permitting a more ready access of air and moisture; (2) the bringing up from lower depths and storing near the surface of fertilizing elements; and (3) the addition of nitrogen to the soil.

Two principal methods are employed in green manuring: First, the production and turning under of crops which require one or more season's growth, and, second, the sowing of so-called "catch" or "cover" crops after corn or potatoes, which occupy the ground only during the winter and are turned under the next spring.

The first method has been in use for many years, in the plowing under of clover, a practice which was more common half a century ago than at present. There can be no doubt that by this practice the fertility of the superficial soil may be greatly improved, both by the bringing up from the subsoil of mineral plant food and storing it in the surface, and by actual addition of nitrogen obtained from the air by leguminous crops. There is no doubt, moreover, that the improvement thus effected may be much greater than if the roots and stubble only are plowed under. According to average analyses, a yield of two tons of red clover hay should contain the following constituents:

Nitrogen,	79	pounds
Phosphorus,	10	"
Potassium,	62	"

If these constituents were purchased in nitrate of soda, acid phosphate and muriate of potash, their cost would be, at present market prices, freight paid to interior points, approximately as shown below:

WEIGHTS AND VALUES OF ELEMENTS

Nitrate of soda,	525	pounds	at	$55	a ton,	$14.43
Acid phosphate (14%),	114	"	"	14	" "	.80
Muriate of potash,	152	"	"	46	" "	3.50
Total,						$18.73

or $9.37 per ton for the hay. This value, however, would not be realized, under ordinary circumstances, by merely plowing under the clover, for experience has shown that on most soils phosphorus is needed in much larger proportion to nitrogen than it is found in the clover hay, which is relatively deficient in this element, as compared with wheat and corn, as shown below in the analysis of yields practically equivalent to two tons of clover hay:

WEIGHT OF ELEMENTS IN EQUIVALENT CROPS (POUNDS)

Elements	Corn 50 bushels with cobs and stover	Wheat 25 bushels with straw	Clover 2 tons
Nitrogen,	72	42	86
Phosphorus,	8	7	7
Potassium,	40	28	45

That is: 50 bushels of corn, with its cobs and stover, will carry a little more phosphorus and a little less nitrogen and potassium than two tons of clover hay, but 25 bushels of wheat with its straw, carrying the same quantity of phosphorus as two tons of hay, will contain only about half as much nitrogen and potassium as the hay. For the nitrogen and potassium of a clover crop to be efficiently used as a green manure for wheat, therefore, they must be reinforced with phosphorus.

If the hay be fed to live stock and the manure saved and returned to the land, there will, it is true, be some loss of fertilizing constituents, but under careful management it should be possible to recover in the manure three-fourths or more of the fertilizing value of the hay, after realizing its full market value as a feed. The question, therefore, for the individual farmer to decide will be, whether the additional value to be realized by feeding the clover will offset the cost of making it into hay, storing and feeding the hay and returning the manure to the field.

Other crops for green manuring—If a crop is to be grown expressly to be turned under as a green manure, the medium red clover is not the one that should be selected, under ordinary conditions. The mammoth clover will make a ranker growth and is hardier than the medium clover, and should be used for this purpose in preference; its treatment, as to seeding, being the same as for the medium red.

The soy bean and cowpea are both well adapted to this purpose, the soy bean for the region north of the Ohio river, and the cowpea for the territory south of that river. These are hot weather plants, and should not be planted until the ground is thoroughly warm, a little later than corn is usually planted. When grown for this purpose they may be sown with the ordinary grain drill, with all the runs open, using about a bushel and a half of seed to the acre. Both plants are killed by the first sharp frost, but they grow rapidly and under favorable conditions will produce as heavy a weight of crop as the clovers. They are especially adapted to serve as substitutes for clover, where the latter has failed from any cause. In more northerly latitudes the Canada pea might be used for the same purpose, but it should be sown early in the spring and plowed under in midsummer.

Either of these plants may be grown as a preparation for wheat. If the Canada pea is grown, it may be plowed under long enough before the wheat is sown to give time for compacting the soil; if the soy bean or cowpea is selected, the better way to man-age is to cut the crop into the surface with a disk harrow, instead of plowing it under, thus keeping the fertility which it has accumulated near the surface, where it is most needed, both by the wheat and by the clover following.

Sweet or Bokhara clover—One of the most valuable plants for soil improvement is sweet clover, *Melilotus alba.* This plant thrives throughout the entire range of climate from Michigan to Mississippi, and its one soil requirement is that there shall be an abundance of lime. Its special mission appears to be to occupy the waste places of the earth, and to prepare the way for other crops. When once introduced in a region where the soil is well supplied with lime, it speedily occupies the roadsides where the surface soil has been removed or where it has been puddled by the trampling of animals. An abandoned brickyard is to melilot what a clover sod is to corn, and in such a place it sends its roots deep into the hard clay and makes luxuriant growth.

A striking peculiarity of the melilot is the fact that, under ordinary circumstances, it does not become a weed, in the sense of invading cultivated land, or meadows and pastures. In California the complaint is made that it does become a weed in the alfalfa fields, and it is sometimes found growing with alfalfa in the East. In fact, the two plants are so closely related, botanically, that one who is not an expert may easily mistake one for the other during the earlier stages of growth; moreover the same root-nodule organisms are common to both plants, so that soil upon which melilot has grown serves to inoculate alfalfa with these organisms. At the Rothamsted experiment station, melilot, alfalfa and vetch were grown continuously on the same ground for a period of 12 to 14 years, beginning with 1878. Table XLVI shows the annual and accumulated yields of nitrogen secured in the crops harvested from these plants.

TABLE XLVI. MELILOTUS, ALFALFA AND VETCH GROWN CONTINUOUSLY AT ROTHAMSTED.

Year	Estimated annual and cumulative yield of nitrogen in pounds an acre					
	Melilotus		Alfalfa		Vetch	
	Season	Total	Season	Total	Season	Total
1878	53	53	...	....	51	51
1879	130	183	...	....	46	97
1880	36	219	28	28	58	155
1881	60	279	28	56	65	220
1882	145	424	111	167	146	366
1883	27	451	143	310	101	467
1884	56	507	337	647	113	580
1885	58	565	270	917	90	670
1886	...	565	167	1084	52	722
1887	82	647	247	1331	64	786
1888	32	679	161	1492	60	846
1889	23	702	153	1645	65	911
1890	...	...	124	1769	61	972
1891	...	...	147	1916	79	1051

The table shows that at the end of the third season the melilot had secured a total of 219 pounds of nitrogen, as against 155 for vetch and 28 for alfalfa. By the sixth season the vetch had passed the melilot, and the seventh season the alfalfa passed both the others, and from that time kept the lead, the total accumulation of nitrogen in 14 years amounting to 1,916 pounds for alfalfa, as against 1,051 pounds for vetch and 702 pounds for melilot.

This is but one experiment, and on different soils or under other conditions a different outcome might be reached; but the fact that the vetch and melilot are annual or biennial in habit of growth, thus requiring a frequent reseeding, while alfalfa is perennial, increasing in root growth for several years, makes it probable that this test gives a fair index to the comparative values of these plants, and that for immediate results in soil improvement alone, and as a preparation for other crops, the melilot is decidedly the plant to choose; whereas, if the primary object be the production of a large quantity of forage, with ultimate soil improvement as a secondary consideration, the choice would fall upon the other plants—alfalfa for conditions permitting a continuous occupation of the land by the same crop, and vetch for use in short rotations with other crops.

Seeding to melilot and alfalfa—Notwithstanding the readiness with which melilot spreads along the roadsides and waste places, many failures have resulted from attempts to cultivate it. Like alfalfa, melilot must have an abundance of lime. As already suggested, the only plant with which melilot appears to be willing to associate is alfalfa, and this point suggests, further, that the methods of seeding which succeed best with alfalfa are likely to be equally adapted to melilot.

Whether the melilot's apparent preference for soils which are inhospitable to other plants is an actual preference, or whether it merely signifies that the young melilot cannot endure crowding, is an undetermined question. The facts that it will grow luxuriantly on good land, if the land be kept clear of other plants, and that the slow growth of the young alfalfa plants gives the melilot a chance to get ahead, would seem to lend support to the latter view.

In the case of alfalfa, experiments have shown that the chance of securing a successful stand is much improved by preparing the land early in the spring and then spending a few weeks in encouraging the weed seeds near the surface to germinate, so that the plants they produce may be destroyed with the harrow before the alfalfa is sown, and it is highly probable that a similar method would be equally successful with melilot. Such a method has an additional theoretical support, in the fact that it brings the date of seeding to the time when the plant seeds itself under natural conditions.

Buckwheat as a green manure—Another plant frequently grown in earlier days as a green manure is buckwheat; but, with a wider knowledge of the function of leguminous plants in the capture of atmospheric nitrogen, the use of buckwheat for this purpose has become less common.

In experiments by the Ontario Agricultural College, reported in the circular of the Experimentalist for 1907, land on which field peas were used as a green manure yielded 6½ bushels of wheat per acre more than land on which buckwheat was so used, in the average of eight separate tests.

Catch crops—The conservation of fertility by catch crops depends upon the fact that the process of nitrification, by which the nitrogen of the decaying organic matter in the soil is converted into forms available to cultivated plants, is in constant operation whenever the temperature of the soil is above the freezing point. The result of this process is the formation of nitric acid, which may at once be absorbed by the roots of growing crops, or may be temporarily stored in combination with an alkali, such as lime, in the form of a neutral salt. Soda and potash serve the same purpose as lime where they are sufficiently abundant, and nitrate of soda and nitrate of potash are familiar examples of this combination. In humid climates, however, these alkalies have usually been leached from the soil to such an extent that not enough is left for this purpose, and lime is, consequently, the chief dependence. Nitrate of lime, however, like the nitrates of soda and potash, is a soluble salt, simply serving as temporary storage, and if the ground be not occupied by growing plants this nitrogen store will be dissolved out and carried away by the late fall and early spring rains.

The corn crop is grown under conditions especially favorable to the formation of nitrates. It makes its growth during the hottest months, when nitrification is most active, and the occasional stirring of the soil by cultivation re-distributes the nitrifying organisms and favors their work by loosening the soil so that air can penetrate more readily.

But the growth of the corn crop is stopped by the first frost, if not earlier, after which there are several weeks during which nitrification still continues, while the bare ground left by the corn is in just the condition to facilitate leaching, so that in time there must be considerable waste of nitrogen from corn-stubble land which is left bare through the winter.

The practice of following corn with winter wheat, which is quite generally followed in some sections, especially south of the latitude in which oats reaches its highest development, is supported by the fact that the wheat makes its start just at the opportune time for utilizing the nitrate residue left by the corn crop.

Whether such a rotation or a longer one is better depends largely upon the relative adaptability of the soil to different crops; upon the conditions of the local market, and upon the special preferences of the farmer. Where these conditions make it preferable to follow the corn with some other crop than wheat or other winter grain, it becomes desirable to sow a temporary crop in the corn at the last working, or on the stubble immediately after the corn is harvested, to save the nitrate aftermath which would otherwise be wasted.

Rye as a catch crop—A crop frequently used for this purpose is rye, which may be sown in the standing corn during August, or if the corn has been blown down so that it is impracticable to cover in the seed, the sowing may be delayed until the corn comes off, with a reasonable assurance of having a late fall and early spring growth which will serve the purpose in view even more perfectly than would be done by a wheat crop, because of the hardier nature and more vigorous growth of the rye.

A rye catch crop of this kind may be pastured when the ground is dry enough not to be injured by the trampling of stock, and in most seasons it may be made to yield enough in this way to pay for the cost of seed and labor, aside from the economy resulting from the saving of nitrates.

In an experiment of this kind, the pasturage of the rye crop, grown during the winter between two crops of corn, amounted to a value of $5 per acre, while the second corn crop was better than the first, the rye having filled the soil with a mass of fibrous roots which materially improved its physical condition, in addition to serving as a reservoir of available plant food, ready to be yielded to the growing crop as needed.

A later experiment on the same land, however, had quite a different result. In this case the rye was permitted to grow until time to plant corn, by which time it had headed out or nearly so, when it was turned under. Dry weather followed, and the corn following the rye was almost a total failure, an outcome due to the exhaustion of the water supply in the soil by the rye crop, leaving the corn to depend solely upon the summer rains for its supply.

It requires more than an average summer rainfall to furnish enough water for a good corn crop under ordinary conditions; but if the soil is pumped dry before the corn is planted the crop must inevitably suffer, unless the succeeding rainfall is greater than usual.

Had this last rye crop been turned under early in the spring and the ground left fallow for three or four weeks before planting the corn, giving it an occasional harrowing to fill up the crevices, compact the seed bed and destroy all germinating weed seeds, it is probable that the result would have been even more favorable than in the first instance.

"Souring" the land with green manures—It is probable that experiences similar to the above have given rise to the idea that the turning under of a heavy crop of green material may "sour" the soil. Such a green crop might amount to ten to fifteen tons to the acre, or less than such an application of manure as many farmers apply; it probably would not decompose in the soil any more rapidly than would manure, nor give rise to products containing any greater acidity. It would seem, therefore, that the occasional unfavorable effect observed from the turning under of green manures should be ascribed to previous exhaustion of the water supply, and not to any excessive production of deleterious acids.

The crop which is grown for a green manure fills the soil with a mass of fibrous roots which separate the soil particles and cause it to crumble when plowed. If the plowing be followed by dry weather and the ground be left without harrowing for a few days, the exhaustion of water supply caused by the growth of the plant will be completed by the evaporation of the small amount left in the soil, for the water contained in the crop which is turned under is as but a drop in the bucket as compared to the quantity required for crop growth, a point which will be realized at once when it is remembered that if the crop were mown and left upon the surface the greater part of its water would disappear during a day's sunshine, showing that a similar quantity of water has been transpired daily by its foliage during growth.

The rye crop adds nothing to the soil. It merely catches some of the soil nitrates that would otherwise be wasted, combines them with phosphorus and potassium already in the soil, and holds them to be given back again to succeeding crops. To accomplish this function perfectly the rye should have at hand a supply of quickly available phosphorus and potassium, otherwise it will not be able to capture the nitrates as fast as they are formed, hence the greatest effectiveness of this crop, or of any other green manure, will only be attained when it is reinforced with a light dressing of mineral fertilizers.

Catch crops should be fertilized—The catch crop, whatever it may be, is supposed to follow cultivated crops—corn, cotton, potatoes, tobacco or beets—which have grown through the summer under the stimulus of cultivation, and have largely exhausted the immediately available supply of the mineral elements of fertility. This point is strikingly brought out when turnips or rape are used as catch crops. If these crops are to be of any service, the land must either be in good heart to start with, or else they must be well fertilized.

Turnips and rape, like rye, will furnish excellent pasture in the fall, but in northern latitudes they will be killed down by the winter, and, therefore, will give no spring pastures. Like rye, these crops add nothing to the soil, merely working over and storing near the surface the plant food already there. These crops are more sensitive than rye to poverty of soil, and, therefore, it is useless to try to grow them except on rich land; but on such land they may be made to materially increase the income.

Leguminous catch crops—A crop which would not merely work over the old material in the soil, but would add new material as well, would be the ideal one for this purpose. In the southern states it has become a quite common practice to sow cowpeas in the corn, much as rye is grown in the North. Crimson clover has been successfully used in this way in the territory lying between the domains of King Cotton and King Corn, but it has not proved reliable in the corn belt proper.

The winter, or hairy, vetch comes nearer serving the purpose for this region, but there are two serious objections to it in the facts that the seed is expensive and the growth is so slow at the start that there is not a satisfactory quantity to turn under if the plowing is done early in the spring.

Vetch and rye may be sown together, using a bushel of each. Such a combination makes an excellent crop to turn under, or to cut green for soiling; while if it is desired to grow the vetch for seed, this is the best way to handle it, the rye supporting the vetch and both maturing together.

Soy beans and rye—Another combination which might be employed would be soy beans and rye, the beans to be sown in the corn at the last working, at the end of July or early in August, and then to be cut into the surface with a disk harrow, after the corn is taken off, and rye, or rye and vetch, sown to occupy the land through the winter. The cost of such a treatment would be considerable at present prices of vetch and soy bean seed. Whether it would be the most economical way of increasing fertility would depend upon the cost of manuring, or of fertilizing with chemicals, and this point applies to all forms of green manuring.

Experiments by the Illinois station—A comprehensive series of experiments in the use of catch crops and green manures has been inaugurated by Dr. C. G. Hopkins, agronomist and chemist of the experiment station of the University of Illinois, which will soon furnish a basis for more exact knowledge than we now possess.

In Bulletin 115 of that station is reported an experiment which is being conducted on worn land near Vienna, Johnson County, in the southern part of the state, the soil being a yellowish-red silt loam, commonly known as the red clay hill soil of southern Illinois. It is quite deficient in nitrogen, somewhat poor in phosphorus, but well supplied with potassium. As a rule the soil is too acid to grow clover successfully. The land on which the experiment is located has been cropped for about 75 years, with little or no manuring or fertilizing. The field is divided into three series of five fifth-acre plots, and is cropped in a three-year rotation. During the first four years the rotation was corn, cowpeas and wheat, after which it was changed to corn, wheat and clover. The soil treatment has been as follows:

Plot 1 of each series, no treatment, except as the cowpea stubble or the second growth of clover has been plowed under in the regular course of the rotation.

Plot 2, legume catch crops plowed under.

Plot 3, legumes plowed under and lime applied.

Plot 4, legumes, with lime and phosphorus.

The legume treatment consists of plowing under legume catch crops grown after the wheat and in the corn after the last cultivation. The first three crops of cowpeas in the regular rotation were also plowed under, one crop in each series on all the plots except the untreated check plot, No. 1. Since that time the regular cowpea crops have been harvested and removed from all the plots.

The primary object in applying lime is to correct soil acidity. In the spring of 1902 one ton of slaked lime per acre was applied, but it having been found that the sub-surface and sub-soil were more acid than the surface, the acidity increasing with the depth, an additional application of eight tons per acre of ground limestone was made in the fall of 1902. It is believed, however, that two to four tons per acre as an initial application might have given satisfactory results.

Once in three years 600 pounds per acre of steamed bone meal and 300 pounds of potassium sulphate is applied, carrying about 75 pounds of phosphorus and 120 pounds of potassium, or 25 pounds of phosphorus and 40 pounds of potassium per annum.

Oats were grown instead of wheat in 1902; since then four crops of wheat have been grown, while five crops each of corn and cowpeas have been grown. Taking the last three years, after the effect of the lime had been manifest, the effects of this

TABLE XLVII. EFFECT OF LEGUME-LIME TREATMENT ON SOUTHERN ILLINOIS SOIL.

	Treatment	Annual yield and increase an acre (Bushels)			
		Wheat		Corn	
		Yield	Increase	Yield	Increase
1	None	3.9	...	36.4	...
2	Legume	7.8	3.9	39.7	3.3
3	Legume, lime	15.4	11.5	53.3	16.9
4	Legume, lime, phosphorus	17.2	13.3	49.2	12.8
5	Legume, lime, phosphorus, potassium	20.8	16.9	47.4	11.0

treatment on the wheat and corn have been as shown in Table XLVII.

The table shows that the legume treatment has doubled the yield of wheat, and that the combination of legumes with lime has quadrupled it. This combination, apparently, has been all that was required to produce the maximum yield of corn, the addition of phosphorus and potassium, while increasing the yield of wheat, producing no further increase in that of corn (the slight falling off in the corn yield on plots 4 and 5 is probably due to the inequalities of the soil, rather than to the effect of the fertilizers).

It is evident that lime has been a most important factor in producing increase of crop on this soil, but probably the increase in the wheat and corn on the limed land is chiefly due to the indirect effect of the lime in increasing the growth of the legume crops.

Increase of soil nitrogen by leguminous crops— The following experiment, planned to show the increase of soil nitrogen from the growth of legumes, was made by Prof. Frank T. Shutt of the Dominion Experimental Farms.

A plot of 16 feet by 4 feet was staked off and the sides protected by boards sunk to the depth of 8 inches. The surface soil to this depth was then removed and in its place a strictly homogeneous but very poor sandy loam substituted—the nitrogen content of which was .0439 per cent. This was dressed with a mixture of superphosphate, used at the rate of 400 pounds per acre, and muriate of potash, at the rate of 200 pounds.

It was then sown with red clover, May 13, 1902. During each succeeding season the growth has been cut twice, and the material allowed to decay on the soil. At the end of every second season the crop has been turned under, the soil being stirred to a depth of approximately 4 inches, and the plot resown the following spring. Four samplings and analyses of this soil have been made since the experiment began, as shown in Table XLVIII; and each successive sampling has shown a marked increase in nitrogen—an increase which would seem to be very satisfactory for such an open, sandy soil.

TABLE XLVIII. NITROGEN ENRICHMENT OF SOILS DUE TO THE GROWTH OF CLOVER.

	Date of collection	Nitrogen	
		Percentage in water-free soil	Pounds an acre to a depth of 4 inches
Before experiment	May 13, '02	.0437	533
After 2 years	" 14, '04	.0580	708
" 4 "	" 15, '06	.0608	742
" 5 "	" 30, '07	.0689	841
Increase of nitrogen due to 5 years' growth clover	....	.0252	308

In two years this soil was enriched in nitrogen to the amount of 175 pounds per acre; in five years, despite losses, the land is richer by 308 pounds per acre.*

* "Science," Aug. 30, 1907.

CHAPTER XIII

PLANNING THE FARM MANAGEMENT FOR FERTILITY MAINTENANCE

Maintenance of fertility a complex problem—The experiments quoted in the previous pages would seem to furnish indubitable evidence that the successful solution of the problem of the maintenance of soil fertility rests upon the supply, in suitable proportions, of compounds carrying three or four chemical elements, to a soil which is maintained in such physical condition as to afford these elements, together with the organisms by which they are converted into available form, the most favorable environment for their reactions on each other and on other elements in the soil. In other words, the maintenance of fertility is a physico-chemico-vital problem, and these classes of agencies must all be considered in the planning of a permanent system of agriculture.

Manure alone not a balanced ration for plants—The practical experience of farmers, gathered through the ages since man first began to till the soil, has demonstrated that it is possible to maintain and increase the productiveness of the soil by a liberal use of animal manure. The average yield of wheat in England is more than 30 bushels per acre, and it has been brought up to within a few bushels of this point within 200 years from an average of about 12 bushels, by the use of manure alone; for while chemical fertilizers are now used extensively in that country, the average yield of wheat had reached 25 bushels or more before the use of such fertilizers began.

This result, however, has been accomplished through a lavish and wasteful use of manure, the drain of phosphorus from the land having been met by the use of manure in such quantity that much of its nitrogen and potassium was wasted in order to provide a sufficient quantity of phosphorus, the supply of manure having been kept up by the purchase of foreign-grown feeding stuffs.

There are many American farmers who say that they cannot produce enough manure to keep up the fertility of their soils. Strictly speaking, it is true that no farmer should depend upon manure alone for this purpose, but as a rule the farmers who make this assertion are neither producing as much manure as they might produce to advantage, nor using what they do produce in such a way as to secure its full effect.

Data now available on production and value of manure—The many careful experiments in feeding for meat or for milk which have been made by various experiment stations during recent years enable us now to form a close estimate of the direct effect which may be expected from a judicious combination of feeding stuffs, fed to selected animals, and the investigations reported on the preceding pages furnish data upon which we may base a similar estimate of the secondary recovery which may be secured in our feeding operations in the form of manure; these investigations giving not only practical information relative to the quantity of manure which may be produced under given conditions, but also showing the effectiveness of that manure for crop production, as compared with fertilizers which have a commercial value.

Systematic planning of farm management now possible—It is, therefore, now practicable to plan a system of management under which the farmer may calculate in advance, more closely than has ever before been possible, the probable outcome of his operations.

In planning such a system of management the points which require first consideration are the special choice and aptitude of the farmer himself; the character of his soil and climate; his market facilities and other environmental conditions.

The farmer may have a free choice—The first point is of prime importance. A man may succeed in a business which is more or less distasteful to him, because of general business ability, but the chances are that greater skill in management will be developed in a business in which one takes more than a perfunctory interest. This is especially true of the different branches of agriculture. The man who does not take delight in the management of domestic animals of some sort will not handle them as successfully as the one who does, and this is true, not only of live stock as a whole, but also of each class of animals. Some men prefer horses, others cattle, others sheep, hogs, or poultry, and fortunately there is room and opportunity for each to have his choice, and the conditions throughout the United States are now such that the man who makes a thorough study of the nature of these classes of animals and of the special conditions prevailing in the various sections, can profitably handle some one, if not all of them, in practically any locality in the humid regions, and over much of the arid area.

Some possible systems of farm management—Let us now compare a few possible systems of farm management, and for the purpose of this study let us take a farm of 160 acres, practically all tillable, well drained, with sufficient buildings for ordinary grain farming, but one from which the surface fertility has been skimmed by half a century or more of exhaustive cropping. Many farms may be found throughout the upper Mississippi Valley answering the above description in all points except the drainage, and occasionally this point will have been fairly well provided for, either by the natural drainage of underlying gravels or stratified rocks, or by artificial drains.

Let us assume that a farm of this character can be purchased for $10,000, or rented at six per cent on this valuation. Probably some farms of this character could be bought for less money, but many others, especially if well located with reference to market, are held at a much higher value.

To properly carry on the work on such a farm would involve an investment in teams and implements of at least $2,000. If the farmer is able-bodied he may perform most of the work with the help of one man for eight months, and the equivalent of two months' additional help in harvest. At present rates of wages the cost of this help, including board, would amount to at least $300 per year.

To the interest on investment it would be necessary to add an estimate for maintenance of teams and implements. The average working life of a horse probably does not exceed 10 years, which means that an allowance of 10 per cent annually must be made on the investment in teams to cover depreciation in value. Under most conditions the teams must be shod at least part of the time. The cost of keeping a horse shod the year round will average $10 or more. Implements wear out, so that 15 per cent of the original value would not more than cover the cost of maintaining the inventory of teams and implements. Including all these items, and including taxes in the items of interest and maintenance of inventory, the cost of conducting such a farm as that under consideration, exclusive of the labor of the owner or tenant, would be approximately as below:

COST OF FARMING 160 ACRES

Interest or rental on land, 160 acres,	$600
Maintenance of inventory, at 15 per cent,	300
Wages and board of help,	350
Total,	$1,250

Of the 160 acres we will allow 10 acres for woodland and waste, five acres for pasture and building lots, and 10 acres for production of crops for support of teams, leaving 135 acres to be cropped for commercial purposes.

Since 1894 the Ohio experiment station has conducted experiments with fertilizers and manures on a farm answering the above description, and while this work has been done on plots containing only one-tenth of an acre each, yet one who has inspected the work and observed the regularity with which similar treatment has produced similar results, on widely separated plots, cannot doubt that it would be possible to reproduce on larger areas the results which have been obtained on these small plots.

TABLE XLIX. EIGHTEEN-YEAR AVERAGE YIELD OF UNFERTILIZED LAND IN FIVE-YEAR ROTATION.

Crop	Grain Bushels	Stover, straw or hay Pounds
Corn	29.7	1,668
Oats	30.8	1,287
Wheat	10.7	1,093
Clover hay	...	1,921
Timothy hay	...	2,698

Farming without fertilizers or manure—In one of these experiments, the five-year rotation previously mentioned, corn, oats and wheat have been grown in succession, followed by two years in clover and timothy, five tracts of land of three acres each being included in the test, so that each crop has been grown every season. Each tract contains 30 plots, and every third plot has been left continuously untreated, thus giving 50 unfertilized plots. The average yield of these plots for the 18 years, 1894-1911, is shown in Table XLIX.

At the prices heretofore employed in such computations the above produce would be worth $53 per acre for each rotation, or $10.60 per acre annually, amounting to a total for our farm of $1,430, from which, deducting the cost of production, as computed above, $1,250, a balance of $180 would be left.

Let us assume now that our farmer is a renter, who feels that he cannot afford to purchase fertilizers to be used on another man's land, and that this particular farm has been occupied by renters of similar mind for a quarter of a century, as had apparently been the case with the farm on which the experiment we are now considering is being conducted. On this assumption it will be seen that the tenant's net income will be about half that of the man whom he hires by the month, for the farmer must work twelve months in the year, instead of only eight or ten.

If the farmer be so fortunate as to own the farm and to be free from debt, his income will be increased by the amount above allowed for interest or rental; and if he has the further good fortune to have a rugged boy or two, so that he will not have to hire help outside his family, he may make a fairly comfortable living; otherwise he will find it necessary to move off the farm to avoid starvation.

Effect of addition of phosphorus—The soil on which the experiment under review is being conducted is hungry for phosphorus, as are most soils that have been under cultivation for many years, and the application of 320 pounds of acid phosphate per acre for each rotation—80 pounds each on corn and oats and 160 pounds on wheat—has increased the average yields by the amounts shown in Table L.

TABLE L. EIGHTEEN-YEAR AVERAGE INCREASE FROM ACID PHOSPHATE.

Crop	Grain Bushels	Stover, straw or hay Pounds
Corn	7.48	208
Oats	8.54	356
Wheat	7.95	740
Clover hay	...	534
Timothy hay	...	265

This increase would have an average annual value of $3.30 per acre, or a total value of $445 for the farm under consideration, which, added to the value of the unfertilized yield, amounts to a total of $1,875. At $15 per ton the acid phosphate would cost $65; adding this to the cost of production, we have a total of $1,315, which leaves a net balance of $560—more than three times the net earnings of the farmer who will not fertilize.

Effect of addition of potassium—When potassium has been added to the phosphate, in the form of muriate of potash, applied at the rate of 80 pounds per acre each to the corn and oats and 100 pounds to the wheat, and increasing the cost of the fertilizer to $8.90 for each rotation, or $1.78 per annum, there has been the further increase in yield shown in Table LI.

TABLE LI. EIGHTEEN-YEAR AVERAGE INCREASE IN YIELD FROM ACID PHOSPHATE AND MURIATE OF POTASH.

Crop	Grain Bushels	Stover, straw Pounds
Corn	14.22	554
Oats	12.03	582
Wheat	9.03	779
Clover hay	....	970
Timothy hay	....	473

The value of this increase would be $4.90 per acre annually, or a total sum of $660 for the farm, which added to the value of the unfertilized yield would amount to $2,090. The cost of the fertilizer would be $240, which would increase the cost of production to $1,490, and would leave a net balance of $600, or $40 more than that resulting from the use of acid phosphate alone.

Farming with complete chemical fertilizer—When a complete fertilizer has been used, containing the quantities of acid phosphate and muriate of potash above given, reinforced with 480 pounds of nitrate of soda, 160 pounds on each of the cereal crops, the average increase has been raised to the quantities shown in Table LII.

TABLE LII. EIGHTEEN-YEAR AVERAGE INCREASE IN YIELD FROM COMPLETE FERTILIZERS.

Crop	Grain Bushels	Stover, straw or hay Pounds
Corn	18.46	688
Oats	18.40	928
Wheat	16.25	1,791
Clover hay	....	1,408
Timothy hay	....	966

The total value here amounts to $4.93 per acre annually, or to $1,056 for the farm, increasing the value of the total produce to $2,486. The nitrate of soda, however, has raised the cost of the fertilizer to a total for the farm of $594, thus increasing the cost of production to $1,844, and leaving a net balance of $642, or $82 more than that recovered from the acid phosphate alone.

There is reason to believe that the potassium salt has been used in this experiment in larger quantity than necessary. At the two southern test farms of the station, experiments were begun in 1904 in which corn, wheat and clover are grown in a three-year rotation, acid phosphate being applied at the rate of 120 pounds per acre to the corn and wheat on plot 2, and the same quantity of acid phosphate, reinforced with 20 pounds of muriate of potash, on plot 3, while plot 8 has received the same application as plot 3, together with 160 pounds of nitrate of soda, 80 pounds each on corn and wheat.

In Table LIII the results of these tests are compared with those attained at the main station on the basis of the average annual value of increase.

TABLE LIII. EFFECT OF REDUCING THE PROPORTION OF POTASSIUM IN THE FERTILIZER.

Treatment	Annual value of increase		
	Wooster*	Germantown†	Carpenter†
Acid phosphate alone	$3.31	$3.29	$2.43
Acid phosphate and muriate of potash	4.90	4.65	3.68
Complete fertilizer	7.83	5.60	5.35

*18-year average; †8-year average.

In the experiment at Wooster there has been a marked gain in the rate of increase with the progress of the work, the increase for the second five years being nearly twice as great as for the first five years, and that for the third five years greater than for the second. Whether this accelerated rate of gain is in part due to the liberal fertilizing of the earlier years, and whether a similar acceleration will be experienced at the southern farms remains for future results to determine. At present, however, the gain at the southern farms is greater than it was at Wooster during the earlier years of the test.

It may be questioned whether nitrogen also has not been given in excess. A direct answer to this question is given by the experiments at Wooster, in which one plot (No. 17) receives only half the nitrate of soda given to the one heretofore considered (No. 11), but receives 480 pounds acid phosphate instead of 320. The average annual value of the increase on these plots and the cost of the fertilizer for the 18 years are as below:

VALUE OF INCREASE IN EIGHTEEN YEARS

	Plot 11	Plot 17
Average value of increase an acre,	$7.83	$6.98
Cost of fertilizers an acre,	4.40	3.33
Net gain,	$3.43	$3.65

This comparison shows that the total yield has been considerably greater from the larger application of nitrate, but the net gain has been slightly greater from the smaller application. It seems probable, therefore, that the net gain may be increased, for a considerable period at least, by reducing the proportions of nitrogen and potassium in the fertilizer.

Fertilizer nitrogen too costly—But fertilizer nitrogen is a very expensive commodity. At current prices a pound of phosphorus may be purchased at retail in its most effective carrier, acid phosphate, for about 11 cents; and a pound of potassium in the muriate, at 6 1-3 cents, while a pound of nitrogen, in nitrate of soda, costs about 18 cents, freight paid to interior points in each case. It is true that a pound of nitrogen may be purchased in tankage for a little less money, but it is also true that such nitrogen is less valuable, because less promptly available, than that of nitrate of soda. In the ordinary mixed fertilizer, however, with its fancy name, the pound of nitrogen, though usually derived from tankage, or muck, is sold to the farmer at a much higher price than he would pay for it in nitrate of soda, so that in using nitrate of soda in these experiments nitrogen has been applied in the cheapest, as well as the most effective carriers.

Of the total $594, which the fertilizer on plot 11 would cost, if applied at the same rate on the farm under consideration, $353 would be paid for nitrogen, $175 for potassium and $65 for phosphorus. If this expenditure for nitrogen and potassium could be avoided, without reduction in yield of crops, it would add very materially to the farmer's income. And this may be done.

Maintaining fertility with clover only—In another experiment on the same farm with the one we have been considering, corn, wheat and clover have been grown since 1897 in a three-year rotation. In this case also each crop is grown every season, and one-third of the land is left continuously without any other amelioration than that which it gets from the clover. The yield on this untreated land has averaged as shown in Table LIV, for the 15 years, 1897-1911:

TABLE LIV. FIFTEEN-YEAR AVERAGE YIELD OF UNTREATED LAND IN CORN-WHEAT-CLOVER ROTATION.

	Grain Bushels	Stover, straw or hay Pounds
Corn (14 crops)	34.44	2,155
Wheat (14 crops)	11.16	1,323
Hay (11 crops)	....	2,435

The value of this yield, using our previous scale of prices, would be $37 per acre for each rotation, or $12.33 per annum, as against an annual value of $10.60 for the unfertilized yield in the five-year rotation.

Applying these results to our 160-acre farm, we would have a total annual value of produce amounting to $1,665, from which, deducting the cost of production, $1,250, there would be left to the farmer a net balance of $415, or $235 more than that resulting from the practice of the longer rotation, but this balance is still too low to give living wages to the man who manages the farm. It is true that in both cases the clover hay has been removed from the land and only the roots turned under. What might have occurred if the whole plant had been plowed under we can only guess at, as there are as yet no reported experiments on this point which have been continued a sufficient length of time to furnish definite information on this point.

A ton of average clover hay contains about 43 pounds of nitrogen, seven pounds of phosphorus and

23 pounds of potassium, or nitrogen, worth $6.45, phosphorus worth 75 cents and potassium worth $1.40, a total of $8.60, which is a larger value than has been given to the hay as a feeding stuff in the computations on the preceding pages, saying nothing of the additional cost of harvesting and marketing the hay. To realize this value, however, it would be necessary to reinforce the clover with phosphorus on the great majority of soils, otherwise much of the nitrogen would be wasted; eventually it would become necessary to add potassium and lime also, because clover only turns over the mineral elements already in the soil, nitrogen being its only actual addition to the soil.

Farming with manure—A part of the land in this last experiment has received each spring a dressing of open-yard manure, such manure as would be produced by cattle fed in open feed lots where the manure is exposed during the winter to the action of the weather. This manure has been applied at the rate of eight tons per acre, and has produced the increase over the unmanured land alongside shown below:

TABLE LV. FIFTEEN-YEAR AVERAGE INCREASE AN ACRE FROM EIGHT TONS OF OPEN-YARD MANURE.

	Grain Bushels	Stover, straw or hay Pounds
Corn	18.61	793
Wheat	9.49	965
Hay	....	801

The value of this increase would be $23.39 per acre for each rotation, or $6.80 annually, which would amount to $918 for our farm.

There being 135 acres in our rotation, exclusive of land set aside for support of teams and other purposes, there would be 45 acres in each crop every season, thus requiring 360 tons of manure each year to give a dressing equivalent to that used in the experiment.

Passing the farm crops through the open feed lot—The Ohio station's experiments show that an average 1,000-pound steer, on a well-balanced fattening ration, will consume in six months feeds containing about 4,000 pounds of dry substance, on which he should make a gain of about 360 pounds in live weight, and that in this time he will produce about five tons of manure, inclusive of bedding, or about 2½ pounds of manure with bedding to each pound of dry substance consumed.

To produce 360 tons of manure in six months' feeding would therefore require the feeding of 72 cattle of 1,000 pounds average weight, and to feed these cattle would require feeds containing 288,000 pounds of dry substance.

Including the wheat, on the assumption that it may be exchanged for bran and oilmeal or similar feeds; omitting the straw, and discarding one-third of the stover as waste, the crops receiving this dressing of yard manure have yielded dry substance at the rate of about 7,600 pounds per acre for each rotation, or 340,000 pounds for our farm, which would be more than sufficient to provide the required manure, were there no waste. But these and other experiments have shown that there is always a large loss of manurial elements when manure is exposed in this manner, and usually a loss of total weight, although sometimes the liquid manure is replaced by water from the clouds, so that there is apparently little if any reduction in total weight.

The above estimate assumes that the corn is fed in the shock without husking, a method which involves less labor than that of husking and handling the corn and stover separately, before hauling to market. The hay, also, is fed with less expense than it can be marketed, as if marketed it must be baled; so that this rough method of feeding, with hogs following the cattle, which is practiced by occasional farmers throughout the territory known as the "corn belt," puts the crops into market at the least possible expense.

This method of management, however, involves the handling of feed daily throughout the winter, and the hauling of a large amount of manure in the early spring; hence it will be necessary for our farmer to keep help the year round, instead of only through the eight months of crop production. Capital will also be required for purchasing the cattle, on which interest must be allowed for six months each season. These two items would raise the cost of production on a feeding farm by $150—$60 for labor and $90 for interest—or to a total of $1,400.

The expert stock feeder expects to get at least as much for his feed as it would bring in the market, without reference to the manure. Sometimes he will fail to accomplish this, but at other times he will make up the deficit. We are, therefore, justified in rating the produce fed to stock at the same price it would have brought if sold in the market. Adding, therefore, the value of the increase produced by the manure, $918, to the value of the unmanured yield, $1,665, we have a total of $2,583, from which must be deducted $1,400, as the cost of production, leaving a net balance of $1,183.

Passing the crop through sheltered feeding pens—In another of the Ohio station's tests the manure has been hauled directly from the stable to the field instead of first passing through the barnyard. The increase from this manure, applied also at the rate of eight tons per acre, has been as follows:

TABLE LVI. FIFTEEN-YEAR AVERAGE INCREASE AN ACRE FROM EIGHT TONS OF STALL MANURE.

	Grain Bushels	Stover, straw or hay Pounds
Corn	23.57	1,103
Wheat	10.88	1,121
Hay	....	1,395

The increase in this case amounts in value to $26.48 per acre for each rotation, or to $8.83 annually, or to a total of $1,192 for our farm, which, added to the unfertilized yield, gives a total value of production amounting to $2,857.

To produce this kind of manure requires feeding under shelter, but the building for the purpose need not be very expensive. A roof overhead, and a cemented floor under foot to hold the manure are the essentials; additional storage room for feed, including a silo and other conveniences, will pay a good interest on the investment. We may assume that the necessary addition to the buildings of our farm will cost $4,000, the interest on which will increase the annual expense account to $1,640, leaving a net gain of $1,217.

Shock corn may be fed in a properly arranged feeding shed, and with much greater satisfaction than out of doors. It is true that the stalks will interfere with the easy handling of the manure, and for this reason it will pay, when the feeding operations are large enough to justify equipment for cutting by power, to cut or shred the stover. In fact, the question may well be raised whether the cost of storing and cutting the stover would not be much more than offset by the saving of labor in hauling in the crop from the field from day to day, as is generally practiced in open-yard feeding.

There is but one more disagreeable job on the farm than that of handling shock corn during a January thaw, when each step sinks to the ankles in mud, and the team must be doubled to get out of the field with even part of a load, and that is the one of moving the same crop when the blizzard following the thaw has come, and the stalks have sunk into the ground and frozen there, so that they must be cut loose with a mattock.

Considering the extra labor and exposure involved in this method of handling the crop, the injury to the land resulting from trampling it when soft, and the loss in value from exposure of the shocks for two or three months to the weather, there can be little doubt that the easiest and cheapest way to take care of the crop is to get it in during the dry weather of the fall, and house it or stack it near to the place of feeding.

Farming with reinforced manure—In still another of the tests under consideration the manure has been treated with acid phosphate during accumulation, using the phosphate at the rate of 40 pounds to the ton of manure, or approximately a pound per day for each 1,000-pound animal; this manure has then been spread directly upon the land, as in the test previously described, and has produced the following increase:

TABLE LVII. FIFTEEN-YEAR AVERAGE INCREASE AN ACRE FROM EIGHT TONS OF PHOSPHATED STALL MANURE.

	Grain Bushels	Stover, straw or hay Pounds
Corn	34.53	1,539
Wheat	16.31	1,692
Hay	....	2,523

The value of the increase in this case has reached a total of $40.95 per acre for each rotation, or of $13.65 per acre annually, or of $1,842 for the farm, which, added to the value of the unfertilized yield, gives a total value amounting to $3,507.

The total cost of the phosphate would be $65, which added to our previous estimate of $1,640 raises the total cost of production to $1,705 and leaves a net income of $1,802.

To recapitulate, the foregoing calculations are collected for comparison in Table LVIII.

TABLE LVIII. ESTIMATED ANNUAL INCOME FROM FARM OF 160 ACRES UNDER VARIOUS SYSTEMS OF MANAGEMENT.

TREATMENT	Total value of produce	Total cost of production	Net gain
Five-year rotation			
No fertilizer nor manure.....	$1,430	$1,250	$180
With acid phosphate........	1,875	1,315	560
" phosphate and potash..	2,090	1,490	600
" complete fertilizer.....	2,486	1,844	642
Three-year rotation			
No fertilizer nor manure.....	$1,665	$1,250	$415
With yard manure..........	2,583	1,400	1,183
" fresh "	2,857	1,640	1,217
" " " phosphated	3,507	1,705	1,802

Of course, the outcome deduced from the above calculations would never be exactly realized. Farms differ in their state of fertility—or of exhaustion; farmers differ in their capacity for management; seasons differ, so that no two successive seasons, nor two successive 10-year periods, will give the same results; the point is, that under the same conditions, land which has been farmed under the common five-year rotation—which, by the way, is a better plan than that pursued on a great many farms—is yielding at such a rate that the tenant who will not buy fertilizers for fear he may enrich another man's land will probably receive on the average less for his year's work than the laborer whom he employs by the month gets for 8 months' work; whereas the one who has not this fear may, on the same farm and under the same system of cropping, realize fair wages, while the man who has the capacity for handling live stock may double or treble the net income of the best fertilizer farmer, or multiply that of the one first mentioned by ten.

It is very true that the successful management of live stock requires ability of a much higher order than is necessary for fertilizer farming; to know how to buy and how to feed involves judgment, training and practical experience, and even the most skillful stockman will sometimes find that he would have done temporarily better if he had sold his crops instead of feeding them; but in the long run there can be no question that the farmer who understands and practices the keeping of live stock, and the production, preservation and use of manure, will secure a very much better income from the land, whether he owns it or rents it, than the one who depends upon chemical fertilizers alone for the maintenance of the fertility of the soil; while as for the farmer who undertakes to take everything from the land without making any restitution, his liberty will eventually be taken from him and he will become the servant of wiser men, either on the farm or elsewhere.

Sweet clover on a test field of the Illinois Experiment Station.

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