MISSOURI

Agricultural College Experiment Station.

BULLETIN NO. 19.

SOILS AND FERTILIZERS.

Part I.

COLUMBIA, MISSOURI,

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PART I.

INTRODUCTORY.

In carrying out the objects of the organization of an "Agricultural Experiment Station," we cordially invite the co-operation of all persons interested in its success. Suggestions as to lines of experimental work, problems to be solved, inquiries relating to agriculture, horticulture, stock, and the dairy will be cheerfully received and answered as far as possible; but no work will be undertaken unless of public value, and the results of which we are at liberty to use for the public good.

Specimens of grains and grasses; seeds of fruit and forest trees; vegetables, plants and flowers that are true to name; varieties of beneficial and injurious insects; samples of mineral waters and ores, and whatever may illustrate any department of agriculture will be gladly received and due acknowledgments made in annual reports. Directions for collecting, packing and shipping such specimens will be furnished on application.

Bulletins will be issued at least quarterly, giving the results of experimental work as fast as completed, together with such suggestions and information as may be thought valuable to the farmers of Missouri.

The bulletins and reports of this Station are sent free to every citizen of Missouri who applies for them. Copies are sent as soon as issued to every newspaper in the State, to every Grange, Farmers' Alliance or other agricultural organization whose address can be obtained. Bulletins and reports are also sent to the leading agricultural papers of the country, and will be sent to any paper that may desire to exchange.

Letters relating to any special line of work should be directed to the officer in charge of that division, but all general correspondence relating to the work of the Station should be addressed to

EDWARD D. PORTER,
Director of Experiment Station.

COLUMBIA, Boone County, Mo.

SOILS AND FERTILIZERS.

PART I.

P. SCHWEITZER, *Chemist.*

The passing of a fertilizer inspection law by the General Assembly of the state of Missouri was intended to afford protection to the farmer against attempted frauds on the part of manufacturers or dealers in fertilizers, and is a beginning in the right direction. The law is imperfect, however, and needs amendment which it will doubtless receive at the proper time. Its very passage is an indication of growing interest by progressive farmers in manures and fertilizers as the best means for increasing soil fertility and for obtaining larger crops. To afford correct information on the principles of manuring, upon the knowledge of which success so largely depends, is the aim of this bulletin. May it answer its purpose.

THE SOIL.

Formation. The soil is primarily a product of the disintegration of rocks. Weather and chemical agencies break these down and the floating power of running water, grinding and pulverizing the material, carries the particles to lower levels. There the broadening of the streams checks the velocity of the current and the material, so far buoyed up and carried along by the moving water, subsides and forms land. This grows by accretion from year to year until it pushes through the water where occasional overflows add to its height until it escapes eventually even these and becomes the fit abode of man.

In this way most of the soils of our state have originated. The process still continues and hundreds of thousands of tons of valuable material are carried yearly by the turbid floods of the Mississippi and its tributaries to the ocean, there to build at some future time a continent to be the seat of an empire like our own. The fine material in this process of transportation is naturally carried further than the coarse, the proportion between the two being determined by the nature of the rock from which it is derived, the length of time and character of the atmospheric agencies working upon it and the velocity of the water rolling and pushing it along. The great variety existing in all these conditions produces, of course, a great variety of soils. In our own state the fine clay-like material, that covers so large an area of it, bespeaks a remote source north of the great lakes. The rocks from which it is derived must have been largely feldspathic as otherwise such vast quantities of clay and clay-like earth, as exists in the Mississippi valley could not have been produced; but all rocks containing feldspar, no matter what their structure and origin contain, besides what eventually will be clay, potash and phosphoric acid, the two elements without which no agriculture is possible.

How vast the quantity of these substances is in our soils will appear further on; but as both of them, as mentioned, are soluble, they would be washed away by the rains and carried into the ocean if in the disintigration of the original rock, combinations of them did not exist or were formed that prevented this leaching process. These combinations, while yielding up to the growing plants from year to year a certain amount from their stores, thereby rendering continuous growth possible, are yet in their totality preventive of waste and retain enough of these most valuable ingredients of a soil to preserve to it a moderate degree of fertility for hundreds of years to come.

Alteration. Upon this soil of a purely mineral character plants begin to grow; first, lichens and plants of simple structure and low organization which, in time, die and make room for others, leaving behind their bodies. Then, as the soil becomes richer in carbonaceous and organic matters, higher organized plants occupy it, passing through the same phases of life as the former, and enriching it at an increased rate by the greater number as well as the greater bulk of their bodies that fall victims to organic law. Lastly, the highest type of plants makes its appearance preparing and leaving in the course of time the soil in the condition of virgin fertility in which our forefathers found it and of which, through ignorance of the laws of vegetable growth, they speedily despoiled it.

But the bodies of plants becoming incorporated in the soil are not the only causes of the alterations which it undergoes by their growth. Many other factors are active in changing a purely mineral to a fertile agricultural soil. The roots penetrate it in all directions and often to a great depth, leaving after the death of the plant, a net-work of narrow channels, through which air and water with their concomitant actions, aided by heat and frost, work a change in the character of the soil, that is helped along by the roots themselves, which by their acid secretions attack and dissolve mineral matter previously insoluble. This enters the plant subserving the physiological processes of its development and returns at its death to the soil from which it was originally taken, but in altered forms, in combinations not previously existing, more soluble, and, therefore, more readily accessible to subsequent plants that may need it.

How considerable this factor is even for a single season in modifying the character of a soil, will appear further on; and be it remembered it is not only the carbonaceous matter of the plant, not only its altered mineral combinations that produce the change, but also the nitrogen, originally absent from the purely mineral soil and collected successively from the atmosphere that works a modification in a most important direction. Heat and cold, dryness and moisture, chemical action of the roots of the plants upon the minerals of the soil and the incorporation into it of their bodies with their multiform proximate components including their nitrogenous constituents and air with its oxygen and carbonic acid, bring about finally a result as beneficial to us as it is natural; and one withal, that is lasting if knowledge and prudence recognizes and deals with it in the proper manner.

Composition. The soil, then, as it results by the processes indicated, is a mixture of fine and coarse material mixed with a greater or smaller amount of organic humus-like substance, holding a variable but large quantity of moisture in its composition. The percentage of this organic matter is usually low, amounting in our soils rarely to more than ten in a hundred, being more frequently only four to five. The water reaches a higher figure, and though fifteen per cent. of it in a soil will support a ripening crop, double the amount is preferable in the early season and more for a limited time advantageous rather than otherwise. The nitrogen, through the accumulation of ages, is but a fraction of one per cent. and the average composition of our soils during the summer season as follows:

4.0 per cent. organic matter.
0.1 per cent. nitrogen.
20.0 per cent. water.
75.9 per cent. mineral matter.

The mineral matter is the matter derived from the rocks that originated the soil modified, as suggested, by the action of weather and the growth of plants. It consists of particles of quartz sand, feldspar, mica, and a variety of mineral species, easily recognized under the microscope, and, in addition, of clay, soluble silica, simple and double hydrous silicates, the result of the alteration of soil and the addition to it of the ash constituents of the plants that grew upon it. These latter, the hydrous double silicates, are of the utmost importance to the fertility of a soil as in them really resides the power of holding and storing up for future use the substances for the lack of which a soil is wholly sterile. In all discussions of agricultural problems relating to mineral fertilizers but three substances need to be considered: potash, phosphoric acid and available nitrogen. Our soils, as the result of a careful investigation, published in Bulletin No. 5, of the Missouri Experiment Station, contain when perfectly dry (dust-dry, *i. e.*, with about 2.5 per cent. of water) the following amounts of these in pounds to the acre:

One acre contains in pounds in:

a. First 10 inches.
b. Second 10 inches.
c. At depth of 3 feet in 10 inches.
d. At depth of 12 feet in 10 inches.

	a		*b*		*c*		*d*	
Water..........	79497	pounds	97980	pounds	166980	pounds	181500	pounds.
Potash	70863	"	59653	"	50094	"	21054	"
Phosphoric acid...	2541	"	2662	"	2178	"	726	"
Nitrogen	4840	"	2299	"	726	"	not determined.	
Carbon..........	58927	"	27709	"	15972	"	not determined.	

One cubic foot of air dried soil, weighs about 100 pounds and will retain, when moistened, from 35 to 50, even 80 pounds of water.

It is seen that vast quantities of plant-food are stored up in our soils, which, if judged by chemical analysis alone, would have to be pronounced as extremely fertile; yet it is well known that their fertility at the present day is but moderate and certainly much less than it was fifty or thirty, or even twenty years ago, and that chemistry as a means for estimating the quality of a soil must tell us more than merely its composition. This is owing to certain properties of a soil regarding the absorption of plant food and the manner in which plants derive from it their essential mineral constituents.

Properties. When it was first discovered that chemical analysis was not, in every instance, a trustworthy guide by which to judge the fertility of a soil, the search for the causes of this apparently exceptional conduct soon made it clear that the greater or less solubility of the potash and phosphoric acid compounds of the soil must contain the key to the solution of the difficulty; for it stands to reason that such compounds, if perfectly insoluble, could furnish to a plant no nutriment whatever and might as well be looked upon as altogether absent. It is therefore not so much the *existence* of potash and phosphoric acid in a soil but the *manner* in which it exists or as it is sometimes called its assimilable form that renders the latter productive. If chemistry by a mere soil analysis cannot enlighten the farmer about the fertility of his land, a solution of the soil by leaching it out with water and analyzing it might furnish the desired information. But the result proved otherwise and just as unsatisfactory as a complete soil analysis and for the reason, as finally ascertained by numerous and laborious investigations, that soil possesses the property of retaining and holding back these valuable constituents, so that percolating water cannot remove them, while at the same time they are sufficiently soluble to be taken up and appropriated by the roots of the growing plants.

This property of the soil, then, which prevents, on the one hand, the deterioration of our fertile lands by the washing away by rain and in drain waters of their valuable constituents, lends itself on the other hand to their fixation and retention when given in the form of soluble mineral fertilizer. Soluble potash and phosphoric acid worked into a soil remain there not to be washed away by rains; they are held as in a bank which honors the legitimate drafts of the plants made through their roots, but refuses payment to the demands of the never resting and ever dissipating moving water.

The large quantities of potash and phosphoric acid in our soils are therefore of value; but insoluble at present to a large extent their value is hypothecated to the future. By their gradual conversion through atmospheric and other agencies of insoluble into soluble compounds they furnish a steady though limited supply of plant food for a moderate crop, but the demands of modern agriculture for large and salable annual harvests sufficient to yield a satisfactory return over and above their cost of production is not responded to. True, improved methods of cultivation will insure better returns, but only up to a certain point beyond which artificial, *i. e.*, mineral fertilizers become a necessity. The readily available plant food, the accumulation of centuries, has been gleaned by our forefathers of their fertile acres; to us the choice is left of having time unlock similar treasures yet in our soil and in the mean time quit harvesting, or to supply the deficiencies by becoming buyers with the certainty of becoming to a much larger extent sellers of our products.

THE PLANT.

Every plant as also every part of it leaves on burning a certain amount of ash. This incombustible material represents the mineral constituents of the plant's body and is different in amount as well as in composition not only for different species of plants but also for different individuals of the same species. Oats or wheat or, in fact, any other cultivated or uncultivated crop yields results in this direction that vary between widely distant limits and appear to depend to a high degree on the condition of soil and season. Confusing as were these results, two facts have been established beyond any question of doubt: first, that *the plant derives its ash constituents from the soil;* and second, that *a certain amount of each of about thirteen substances is so absolutely necessary to its development, that complete absence of any one of them not only checks but actually prevents growth.* Potash, phosphoric acid and nitrogen in available form are the only three, however, that need consideration as the other ten are never wanting in an arable soil and discussion of them can lead to no practical result.

Potash, phosphoric acid and available nitrogen, that is nitrogen in the form of nitrate enter the plant through the roots and from the soil, and as these substances are intimately connected with the production within the plant of the two great classes of foods on account of which we carry on agriculture, viz., starch and proteids, it is plain that greater quantities of the former in the soil will mean greater production of the latter in the plant; and since cultivated differ from uncultivated plants mainly in being richer in starch and protein it follows that the removal of cultivated crops deprives land of a greater proportion of these valuable mineral constituents than does the gathering and removal of plants that were the natural growth. Increasing of one's crop means, therefore, plainly first increasing of the plant food in the soil; the one depends upon the other, and to expect continuous and large crops of any kind from land inherited or bought by its cultivator is as reasonable as to expect continued payment of checks on the strength of a deposit that at some former time had been made in a bank. In both cases the drafts upon the available resources as a means of continued profitable business relations must be made good: fertilizers must be put upon the land and money be placed in the bank.

It may, then, be taken for granted that *potash, phosphoric acid and nitrates in the soil in certain amounts are necessary to insure satisfactory crops and that they must be in soluble, that is available form to become active.* The large quantities of the two former that have been mentioned before as existing in our soils are, however, soluble only to a limited extent and though certainly valuable they are not sufficiently and immediately available for the demands of a large crop; for such a one additional and proper fertilizing material must be supplied regularly and intelligently. This necessity is emphasized by the fact that *plants absorb the greater share of these mineral matters during the early stages of their growth and do so in a special and peculiar manner.*

This truth has, in fact, a most important bearing upon the whole question of manuring; for it is plain that if the absorption of the larger part of the ash constituents takes place during early growth and before full development of the root system a much larger amount of soluble plant food must be present in the soil than merely suffices for a single crop, because it has to be where the roots are and these have not penetrated yet and spread through the whole mass of cultivated soil. The food must seek the roots, rather than the roots the food and stinting the plant at this early stage of growth is fatal to its full development and a sure way to a short crop. Abundance of plant food at the beginning is prudent husbandry at the end, a truth which becomes plainer yet when we examine the mechanism of root absorption.

The soluble plant food, which we have called available, forms no real solution, in fact, as the term solution is usually understood. To be sure we can grow plants in water alone, but to do so requires unusual skill and constant attention to a multitude of minor details, which renders the growing in this manner of our cultivated plants a practical impossibility. All such plants require air in the soil as well as above it and would speedily perish if their roots remained for any length of time in a water logged medium, be this filled with water alone or a solution of plant food of the proper concentration. The nutritive solution which is meant, whenever the name is used in this connection, is a solution of about one part of nutritive substance in a thousand parts of water, moistening every particle of earth with a film of liquid ready to be sucked up by the tender roots of the plant as soon as they touch it, but yet leaving the earth as a whole, moist it is true, but filled with abundance of circulating air and certainly free from any visible or running water. With such a solution and under such conditions absorption, assimilation and growth occurs, vigorous, normal, healthy growth. That such growth implies also greater power to resist disease and recover from injury is to be presumed and represents a quality in the plants of our crops which, in the light of the tremendous losses from fungus diseases and depredations of insects, can not be valued too highly. On the other hand we must suppose, however, that plants may imbibe, at times, greater quantities of mineral matter than they actually need for their development, just as animals often swallow amounts of food much in excess of their necessities; but the waste is difficult to prevent in both instances and especially difficult in the case of plants. And,what, now, are the quantities of plant food that are required by our crops? An examination of their weight and composition will give the information!

THE CROPS.

In discussing the quantities of mineral matter that are removed by our crops from the soil it would lead too far to consider all the plants that are raised by the farmers of our state; a few of the more important ones which are at the same time typical must suffice to illustrate the principle which, once understood and appreciated, could be amplified and applied by every agriculturist.

Many analyses have been made of the ash of plants by this and other experiment stations, which furnish the data upon which the following calculations and deductions rest; they are given for more ready comprehension in the form of tables which deserve close inspection and intelligent interpretation:

TABLE 1.

One hundred pounds of dry weight (water free) contains the following amount in pounds of plant food:

	POUNDS.
Wheat, Kernels:	
Potash	0.63
Phosphoric Acid	1.05
Nitrogen	2.05
Wheat, Straw:	
Potash	0.69
Phosphoric Acid	0.28
Nitrogen	0.61
Oats, Kernels:	
Potash	0.54
Phosphoric Acid	0.85
Nitrogen	2.11
Oats, Straw:	
Potash	1.12
Phosphoric Acid	0.28
Nitrogen	0.70
Corn, Kernels:	
Potash	0.64
Phosphoric Acid	0.81
Nitrogen	1.82
Corn, Cobs and Shucks:	
Potash	0.71
Phosphoric Acid	0.04
Nitrogen	0.49
Corn, Stover:	
Potash	1.34
Phosphoric Acid	0.03
Nitrogen	0.92
Timothy:	
Potash	1.41
Phosphoric Acid	0.85
Nitrogen	1.31
Red Clover:	
Potash	2.31
Phosphoric Acid	0.62
Nitrogen	2.52
Alfalfa:	
Potash	2.35
Phosphoric Acid	3.75
Nitrogen	2.74
Potatoes:	
Potash	2.70
Phosphoric Acid	0.90
Nitrogen	1.62
Carrots:	
Potash	3.08
Phosphoric Acid	1.06
Nitrogen	1.62
Cabbage:	
Potash	5.18
Phosphoric Acid	2.96
Nitrogen	4.02
Cucumbers:	
Potash	5.75
Phosphoric Acid	3.25
Nitrogen	3.25

The foregoing table, as the basis, served for the computation of the next; in it the fourteen plants or parts of plants were assumed to be in the ordinary condition of merchantable material, that is material which holds a certain and well known amount of moisture in its combination. This amount in the case of grain and straw, including all kinds of fairly air-dry hay was taken to be 10 pounds in 100, and in potatoes, cabbage, carrots and cucumbers, as sold in open market, as respectively 75, 85, 85 and 95 pounds of water to 100 pounds of green weight.

TABLE 2.

One hundred pounds of marketable produce, that is, wheat, oats, corn, both as grain and straw, and timothy, red clover and alfalfa, as hay, each with 10 per cent. of water, and potatoes, carrots, cabbage and cucumbers, each respectively with 75, 85, 85 and 95 per cent. of water, contain the following amounts in pounds of plant food:

	POUNDS.
Wheat, Kernels:	
Potash	0.57
Phosphoric Acid	0.94
Nitrogen	1.84
Wheat, Straw:	
Potash	0.62
Phosphoric Acid	0.25
Nitrogen	0.55
Oats, Kernels:	
Potash	0.49
Phosphoric Acid	0.76
Nitrogen	1.90
Oats, Straw:	
Potash	1.01
Phosphoric Acid	0.25
Nitrogen	0.63
Corn, Kernels:	
Potash	0.58
Phosphoric Acid	0.73
Nitrogen	1.64
Corn, Cobs and Shucks:	
Potash	0.64
Phosphoric Acid	0.04
Nitrogen	0.44
Corn, Stover:	
Potash	1.21
Phosphoric Acid	0.03
Nitrogen	0.83
Timothy:	
Potash	1.27
Phosphoric Acid	0.76
Nitrogen	1.18
Red Clover:	
Potash	2.08
Phosphoric Acid	0.56
Nitrogen	2.27
Alfalfa:	
Potash	2.11
Phosphoric Acid	0.67
Nitrogen	2.47
Potatoes:	
Potash	0.67
Phosphoric Acid	0.22
Nitrogen	0.40
Carrots:	
Potash	0.46
Phosphoric Acid	0.16
Nitrogen	0.24
Cabbage:	
Potash	0.78
Phosphoric Acid	0.44
Nitrogen	0.60
Cucumbers:	
Potash	0.29
Phosphoric Acid	0.16
Nitrogen	0.16

To determine what is a fair average crop was a more difficult matter; the values given in table three were finally decided upon, omitting those for cucumbers as too widely divergent in different sections of country.

TABLE 3.

WEIGHT OF CROP FROM ONE ACRE OF GROUND.

	BUSHELS.
Wheat	25
Oats	30
Corn	60
Potatoes	100
Carrots	150
Cabbage	3600 head

	POUNDS.
Wheat, Kernels	1500
Straw	5100
Oats, Kernels	960
Straw	2200
Corn, Kernels	3360
Cobs and Husks	840
Stover	3000
Timothy Hay	4000
Red Clover Hay	5000
Alfalfa Hay	4000
Potatoes	6000
Carrots	6000
Cabbage	10800

It is plain, now, that knowing the number of pounds of merchantable produce obtained from each acre of land and also the number of pounds of potash phosphoric acid and nitrogen which each one hundred pounds of such produce contains, we can readily calculate the total weight of the three substances which exist in the product of an acre, and as this has been derived from the land itself it is also the weight of the plant food which each acre loses by such crop.

TABLE 4.

WEIGHT IN POUNDS OF PLANT FOOD REMOVED FROM ONE ACRE BY THESE CROPS:

	POUNDS.
Wheat, Kernels:	
Potash	8.55
Phosphoric Acid	14.10
Nitrogen	27.60
	50.25
Wheat, Straw:	
Potash	31.62
Phosphoric Acid	12.75
Nitrogen	28.05
	72.42
Whole Crop:	
Potash	40.17
Phosphoric Acid	26.85
Nitrogen	55.65
	122.67
Oats, Kernels:	
Potash	4.70
Phosphoric Acid	7.30
Nitrogen	18.24
	30.24
Oats, Straw:	
Potash	22.22
Phosphoric Acid	5.50
Nitrogen	13.86
	41.85
Whole Crop:	
Potash	26.92
Phosphoric Acic	12.80
Nitrogen	32.10
	71.82
Corn, Kernels:	
Potash	19.49
Phosphoric Acid	24.53
Nitrogen	55.10
	99.12
Corn, Cobs and Husks:	
Potash	5.37
Phosphoric Acid	0.34
Nitrogen	3.70
	9.41
Corn, Stover:	
Potash	36.30
Phosphoric Acid	0.90
Nitrogen	24.90
	62.10
Whole Crop:	
Potash	61.16
Phosphoric Acid	25.77
Nitrogen	83.70
	170.63
Timothy:	
Potash	50.80
Phosphoric Acid	30.40
Nitrogen	47.20
	128.40
Red Clover:	
Potash	104.00
Phosphoric Acid	28.00
Nitrogen	113.50
	245.50
Alfalfa:	
Potash	84.40
Phosphoric Acid	26.80
Nitrogen	98.80
	210.00
Potatoes:	
Potash	40.20
Phosphoric Acid	13.20
Nitrogen	24.00
	77.40
Carrots:	
Potash	27.60
Phosphoric Acid	9.60
Nitrogen	14.40
	51.60
Cabbage:	
Potash	84.24
Phosphoric Acid	47.52
Nitrogen	64.80
	196.56

A comparison of the individual and total weights of the three substances removed from each acre of land brings out interesting facts. Of the regular farm crops red clover and alfalfa stand foremost in their demands upon the soil; they require more potash, more phosphoric acid and more nitrogen, though a large part of this is derived from the atmosphere, than any other. That they grow upon our lands without manuring as well as they do is proof of the inherent fertility of the latter; continuous cropping would, of course, be impossible, but that a crop of clover in proper rotation can find more than twice the amount of potash and a little more than the same amount of phosphoric acid in the soil than does a crop of wheat might at first glance be taken to prove manuring of our land altogether unnecessary; the plant food is certainly present and if one crop can find it, why might not another be made to do so by proper cultivation? There is some prospect for beneficial results in this direction, but as the powers of the different plants for absorbing mineral matters from the soil are limited by the extent of their root systems, and as in clover and alfalfa this is vastly greater and penetrates far deeper than that of other cultivated plants, they are enabled to get not only from the upper but also from the lower stratum of soil whatever plant food they require, while others are mainly depending upon the former. Facts are stubborn realities and cannot be ignored; over ride them we may, but not with profit to ourselves; far better to guide and direct them by knowledge and ingenuity into useful and profitable channels.

Corn, timothy and wheat, the three staple crops of our state, stand close together in their demand for phosphoric acid and, in the order in which they are mentioned in that for potash, of which they contain in round numbers sixty, fifty and forty pounds to the acre; they would stand, therefore in need of a potash fertilizer in the order named, while their requirements for phosphoric acid are about equal and nearly those of alfalfa and clover; in nitrogen, corn, wheat and timothy, requiring 84, 55 and pounds per acre, reveal their dependence upon the most deficient and consequently the most valuable of the three plant foods in our soil; but while all these crops represent a demand upon our soil of the quantities of plant food mentioned, it must be born in mind that only corn and cobs and wheat kernels are actually sold and the stover and straw remains; this makes the selling of timothy off a farm a much more exhausting and unwise practice than that of corn or wheat, supposing of course, that care be taken of the straw in connection with the manure heap. "*A penny saved is a penny earned*," must be learned by farmers as by other people to become successful in their life occupations.

Of cabbage, potatoes and carrots in common with all truck farm crops may be said they need plenty of fertilizer; much potash, much phosphoric acid and much nitrogen are demanded by them and will pay; their season of growth is short, their root system meagre, and plant food must abound to utilize the tremendous powers of these plants for absorbing and assimilating it; crops two and three times as great as those assumed may be obtained without difficulty.

The value of plant food, then, has a double meaning: to the plant, as without it no growth, and that is no crops, are attainable, to the farmer, as at some time he is bound to buy and restore what he takes from his land; he cannot eat his cake and have it still. He would buy, of course, in open market, and at as low a rate as competition will allow, and when he does he will readily ascertain the value of the number of pounds of the three fertilizing substances which his crops have removed; for evidently that value would be equal to the price which he has to pay for them in the market. Such calculation has been made in the following table, under the term of manurial value:

TABLE 5.

MANURIAL VALUE OF THIS CROP.

The trade value of potash, phosphoric acid and nitrogen, or the price at which each can be bought in open market, is five and one-half cents per pound of potash, five cents a pound of phosphoric acid, and seventeen and one-half cents per pound of nitrogen. At these prices the cost of returning to the land what is removed by the crops would be per acre:

Wheat, kernels	$6.00	Timothy	$12.57
" straw	7.29		
	$13.29	Clover	$26.98
		Alfalfa	$23.17
Oats, kernels	$3.81		
" straw	3.92	Potatoes	$ 7.07
	$7.73	Carrots	$ 4.52
Corn, kernels	$11.94	Cabbage	$18.35
" cobs and husks	0.96		
" stover	6.40		
	$19.30		

To take care, therefore, of straw and all other vegetable refuse and return it to the land in a proper manner, is a matter of great importance; to sell timothy, clover and alfalfa as such, rather than to feed it and sell it as flesh or milk, is bad policy and self-destruction. To value a crop simply by its market price is crude and unscientific. The price which the farmer pays for it is not only its cost of production, but in addition to it, its manurial value, which we have often neglected, and which the conditions of the case begin now to force upon us for serious consideration.

THE MANURES.

Manures, in the narrow sense in which the term is here used, are substances which, when put upon the land, increase its productivity by virtue of the plant food which they contain. This plant food is entirely of mineral origin and character and, though carbonaceous or so-called organic matter, is very important in modifying the properties of a soil, so as to render it better adapted for the support of plants, it is in reality only the mineral matter of the soil which these absorb. Plants, therefore, are manures in themselves, and having once gleaned from the soil and taken up their needed amount of mineral matter, hold it of necessity in the condition in which other plants may, without difficulty, absorb it. The bulk of such manure, however, is great, and the handling and hauling of it troublesome and expensive; other forms of it, the sò-called mineral or chemical fertilizers, may with advantage take its place, and it is of them that we speak here.

These mineral manures, many brands of which are in the market, are in reality only of three kinds, each containing one of the fertilizing materials that have been mentioned before; all others are made up from these or are, at least, comparable to them as to price and value. A compound or complete fertilizer is, on the whole, unscientific, and though buying it may save the farmer some thinking, he is charged a good round sum for the thinking which the manufacturer does for him. No one supposes that all the land of a state, of a county, or even a township needs the same proportions of plant food in its fertilizers. A complete fertilizer could, therefore, apply only to a perfectly sterile land, and would have to differ with each crop raised on it. On any other it must be wasteful, since, if one ingredient be in excess, it would be left behind and not enter the plant, and, if it fell short of the crops' capacities for it, the others would be useless to the extent of their exceeding it. Far better to apply potash, phosphoric acid and nitrogen separately, as the needs for each may manifest themselves to the farmer.

To be successful in his avocation, he must be able to give the same answer as the painter when questioned as to what he put in his paints to make his pictures so true and charming, viz: "brains;" *so the farmer must put brains in his soil*, if he wishes it to respond without waste to its full capabilities and render his business, for business it is, prosperous.

Before discussing now the individnal fertilizers, a summary statement of the quantity of each per acre might be made as far as the question can be decided on general principles. In table 4 the weights in pounds of the three important fertilizing materials removed per acre by a number of crops are given, and the crops themselves are, certainly, within the reach of our farmers in good years. The crops must, therefore, find this plant food in the soil, and if larger ones are not harvested on account of the absence of, or difficulty in, finding additional food supplies, fertilizers would remedy the matter easily. Doubling the crops should be our aim, and to approach it fertilizers sufficient to provide for the wants of this increase should be put upon the land. If this be done a full response must, of course, not be expected the first year; the solubility of the material will spread it throughout the soil, while the roots come in contact only with a limited portion of it; but in the end it is taken up and utilized. Upon this plan a table each for potash, phosphoric acid and for nitrogen will be constructed to facilitate the calculation of the farmer.

Potash. The accessible potash supply for this state consists of wood-ashes, and the products of the potash industry at Stassfurt, Germany. The former are limited in amount, and available only in certain places, and it is difficult to assign to them, on account of the differences in their composition, any certain value; where used, as in the southern part of the state, ten per cent. of potash in them may perhaps be a fair average, so that 100 pounds of good, dry wood-ashes would posses a manurial value of fifty-five cents.

An unlimited supply of potash salts reaches us, however, from Germany. The potash or *German Kali works*, as officially known here, produce and send out a yearly increasing quantity of their valuable products, which begin to find their way to our state and to our farms. Mainly four forms are imported, each containing a different but warranted quantity of potash, which may be trusted to be correct without state supervision. The four forms, together with their manurial value at five and one-half cents per pound of actual potash, are as follows:

Kainit with 12.4 per cent. potash, $0.68 100 pounds, $13.60 per ton.
Sulphate of potash, 50.0 per cent. of potash, $2.75 100 pounds, $55 per ton.
Carnallit with 9.0 per cent of potash, 0.49 100 pounds, $9.80 per ton.
Muriate of potash, 45–55 per cent. of potash, $2.47 to $3.02 100 pounds, $49.40 to $60.60 per ton.

Kainit may be said to be the raw material from which sulphate of potash, as carnallit that from which muriate of potash are made; both raw materials contain, in addition to the potash, magnesium salts and common or table salt, which on our soils are of some value and often prove quite beneficial. The prices at which these salts sell are close to their manurial value, both of which should really be identical, since manurial value means the price at which the specific manurial agent can be bought in open market; but railroad freights and the cost of manufacturing the crude into purer products causes the price to differ from, and to usually exceed, the value; where the difference is great either way; that is, when the price is much higher or much lower than the manurial value, investigation and caution in buying is called for.

TABLE 6.

Quantities of fertilizers in pounds per acre to supply a crop with potash.

	Pounds.
Wheat, $2.21.	
Wood Ashes	402
Carnallit	446
Kainit	324
Sulphate or Muriate	80
Oats, $1.48:	
Wood Ashes	269
Carnallit	299
Kainit	220
Sulphate or Muriate	54
Corn, $3.37:	
Wood Ashes	612
Carnallit	679
Kainit	493
Sulphate or Muriate	122
Timothy, $2.79:	
Wood Ashes	508
Carnallit	564
Kainit	410
Sulphate or Muriate	102
Red Clover, $5.72:	
Wood Ashes	1040
Carnallit	1155
Kainit	840
Sulphate or Muriate	208
Potatoes, $2.21:	
Wood Ashes	402
Carnallit	447
Kainit	324
Sulphate or Muriate	80
Cabbage, $4.63:	
Wood Ashes	842
Carnallit	936
Kainit	680
Sulphate or Muriate	168

Phosphoric Acid. The phosphoric acid supply for fertilizing purposes is more varied than that of potash; its four main sources are, *first*, bones either fresh or as spent boneblack; *second*, phosphatic deposits like those of South Carolina or the keys of the Carribean Sea; *third*, accumulations at certain places of fossil, chiefly excrementitious material; *fourth*, Thomas slag, a by-product recently brought into market, of the smelting of iron ores. In neither of these materials the phosphoric acid is readily available, and each requires to be ground into an exceedingly fine and impalpable powder, or else to be treated with oil of vitriol to render the phosphoric acid soluble. The first is a simple mechanical process which makes the product cheaper though less effective than the second, which is a chemical treatment with variable quantities of acid requiring both knowledge and skill. The prices paid, therefore, per pound of phosphoric acid are in accordance with its degree of solubility, and this, again, depends upon the treatment the raw material has received by the manufacturer. They are about as follows:

Raw material, ground moderately fine...	Phosphoric acid, 2 cents a pound.
Raw material, finely pulverized or floated..	Phosphoric acid, 4 cents a pound.
Superphosphate, (raw material treated with acid)	Phosphoric acid, 6 cents a pound.

It is, therefore, not a matter of indifference in what forms phosphatic fertilizer is brought, and careful and frequent analyses of the brands offered for sale are necessary to protect the buyer. Our present state inspection law is defective and does not secure it; no general standard brands like those of the Stassfurt potash salts or the Nitrate are accessible to the retail trade, whence the product of the unscrupulous and fraudulent concern stands upon an equality with that of the reputable and honest house, a condition which is unjust to the latter and confusing to the farmer who wishes to buy; no tabulation as to cost and amount per acre of the phosphoric acid in a crop is for that reason attempted.

Nitrogen. The term available so often used in regard to plant food implies solubility in water, since the roots of plants can suck up and absorb nothing but what is soluble. This applies to potash and phosphoric acid, whose insoluble compounds in the soil are nearly valueless and is still further limited in the case of nitrogen by additional conditions. Thus the vast amount of elementary nitrogen stored up in our atmosphere is completely unavailable excepting in those special cases to be described later; likewise does the available nitrogen in the soil suffer gradual but continued loss through surface washing or under drainage, by which this most desirable and costliest of all the plant foods demands more careful and more intelligent attention than the rest.

We know there are virtually but two classes of nitrogen compounds which, on account of their solubility and the experimental proof furnished therefor, can be taken up and assimilated by the plants; these are ammonia salts, and salts of nitric acid; we also know by practical trials with our cultivated crops that the latter are more effective than the former, and are, in all probability, that form of nitrogen which the plant can most readily utilize. All others can serve the needs of the plants only after conversion into nitrate, which takes time and renders their use much less effective. While, therefore, not excluding salts of ammonia, such as sulphate or muriate, there is no doubt but that nitrates are preferable and cheaper, and are in reality, the rational source of nitrogen supply for our crops, with which we compare all others as to price and efficiency; these others are of two main sources: animal or ground fish, bone, scraps and the multifarious refuse of our slaughter and packing houses and vegetable as f. e. cotton seed meal and similar articles whose nitrogen, to repeat it, is not immediately available to plants but must first pass through a series of changes within the soil into compounds of ammonia which the plant may take up but which it finds some difficulty in easily digesting. These changes precede in every instance the assimilation of nitrogen and since animal substances, containing it, decompose much more readily than vegetable ones, the former are more valuable to the farmer than the latter for manurial purposes, where quick responses are expected and demanded; from this statement, however, horn shavings and hide and leather scraps must be excluded as these produce scarcely any effect whatever unless previously subjected to a chemical treatment.

These facts are recognized in the prices at which a pound of nitrogen in different fertilizers can be bought, and as several find a sale only in eastern markets eastern prices are subjoined here:

PRICE OF ONE POUND OF NITROGEN IN THE FOLLOWING BRANDS:

Ground fish, meat, blood (containing 8 per cent. of nitrogen)	17 1-2 cents a pound.
Ammonium sulphate (containing 20 per cent. of nitrogen)	17 cents a pound.
Nitrate of soda (containing 15 3-4 per cent. of nitrogen)	15 1-2 cents a pound.
Fine ground bone and tankage (containing 6 per cent. of nitrogen)	15 cents a pound.
Fine ground medium bone and tankage (containing 4 per cent. of nitrogen)	12 cents a pound.
Medium bone and tankage (containing 4 per cent. of nitrogen)	7 cents a pound.

The high, and, in fact, the highest price of all paid for the first article is owing to the presence of other valuable constituents and does not invalidate the general statement made above; Peruvian Guano would, in all probability, rank alongside of it and for similar reasons.

The soil, then, is the medium in which the conversion of any form of nitrogenous compounds, whether animal or vegetable, into ammonia is effected; this is partly absorbed by the plants, partly fixed by the soil and partly also, if opportunity offers, carried away by running water. The action of the soil, however, does not stop there! multitudes of living and active organisms, constantly present in it, transform with great rapidity the ammonia into nitrate in which form cultivated crops greedily absorb and convert it to their uses, so that the choice of a nitrogenous fertilizer, whether organic, ammonia or nitrate, depends simply upon the time when it is expected to be of service to the crop; if immediately, then nitrate, if subsequently, with the chance of failure to come to time and during the interval to suffer loss by washing away, then ammonia or organic manures. The rational nitrogenous fertilizers, and all things considered the cheapest for intensive agriculture, are certainly the nitrates, of which nature has given us vast deposits in some parts of our globe.

The amounts in pounds of the various fertilizers per acre necessary to furnish the nitrogen of a crop have been calculated, and as the price of this differs, as already stated, in proportion to its availibility, the cost of each has been added:

TABLE 7.

Pounds and cost of fertilizer per acre to supply a crop with nitrogen.

WHEAT.

(55.65 pounds of nitrogen.)

700	pounds ground fish (8 per cent. of nitrogen)	$ 9.74
278	pounds sulphate of amonia (20 per cent. of nitrogen)	9.46
354	pounds *nitrate of soda* (15 3-4 per cent of nitrogen)	8.63
938	pounds fine ground bone and tankage (6 per cent. of nitrogen)	8.35
1391	pounds fine ground medium bone and tankage (4 per cent. of nitrogen)	6.68
1391	pounds medium bone and tankage (4 per cent. of nitrogen)	3.89

OATS.

(32.10 pounds of nitrogen.)

400	pounds ground fish	$ 5.62
160	pounds sulphate of ammonia	5.46
204	pounds *nitrate of soda*	4.97
535	pounds fine ground bone and tankage	4.81
802	pounds fine ground medium bone and tankage	3.85
802	pounds medium bone and tankage	2.25

CORN,

(83.70 pounds of nitrogen.)

1040	pounds ground fish	$14.65
419	pounds sulphate of ammonia	14.23
532	pounds *nitrate of soda*	12.97
1395	pounds fine ground bone and tankage	12.55
2092	pounds fine ground medium bone and tankage	10.44
2092	pounds medium bone and tankage	5.86

TIMOTHY.

(47.20 pounds of nitrogen.)

590 pounds ground fish	$ 8.26
236 pounds sulphate of ammonia	8.02
300 pounds *nitrate of soda*	7.32
787 pounds fine ground bone and tankage	7.08
1180 pounds fine ground medium bone and tankage	5.66
1180 pounds medium bone and tankage	3.30

POTATOES.

(24 pounds of nitrogen.)

300 pounds ground fish	$ 4.20
120 pounds sulphate of ammonia	4.08
152 pounds *nitrate of soda*	3.72
400 pounds fine ground bone and tankage	3 60
600 pounds fine ground medium bone and tankage	2.88
600 ponnds medium bone and tankage	1.68

CABBAGE.

(64.8 pounds of nitrogen.)

810 pounds ground fish	$11.34
324 pounds sulphate of ammonia	11.02
412 pounds *nitrate of soda*	10.04
1080 pounds fine ground bone and tankage	9.72
1620 pounds fine ground medium bone and tankage	7.78
1620 pounds medium bone and tankage	4.54

GREEN MANURING.

It is proper here to explain the principles of green manuring since they bear in an important manner upon the nitrogen question and are in explanation of some of the statements just made; the practice itself is old and has been followed with varying degrees of success for hundreds of years. To incorporate great masses of vegetable matter into a soil increases its water holding power, makes it more porous and richer in humus and imparts to it certain physical properties which are highly beneficial to plant life and the growth of crops; but the quantity of mineral matter in it is thereby not in the least affected; whatever amounts f. e. of potash and phosphoric acid a crop may contain, and, by plowing under, yield up to the soil, it is plain that it merely returned what it borrowed, and no art in manipulation can alter the fact.

The two bodies, however, have certainly become by green manuring, more available to plants than they were before; but the same thing might have been effected by plowing and cultivating the land without any crop, and, even though in a minor degree, by permitting it to lie fallow for a season, so that the practice could scarcely be either wise or profitable were it not for the power, formerly suspected and now known to exist in certain plants of fixing the elementary nitrogen of the air and converting it to their uses; this power the great majority of our cultivated plants lack; they need and depend upon nitrogenous manures for their nitrogen supply and require of the farmer either watchful care in saving and utilizing all vegetable and animal refuse of the farm or the purchase of chemical fertilizers in open market.

We distinguish thus between two classes of plants: *the nitrogen consumers* just now described, and *the nitrogen producers*, possessing the economically most important property of being able to live upon the nitrogen of the air; they produce not nitrogen, not something that did not exist before, but they convert the non-serviceable free nitrogen of the air into serviceable combined nitrogen of plant and soil. All nitrogen producers so far discovered are leguminous plants and it is probable that every member of this family possesses this power. Peas, beans, vetches, clover, serradella and lupines have in turn been the objects of experimentation, and, while much yet remains to be explained, the following facts are definitely known:

1. The power of leguminous plants to assimilate atmospheric nitrogen depends upon their roots showing numerous irregular, small swellings called tubercles.

2. The tubercles are caused by minute living organisms, existing in great numbers in the soil. (They are different from the bacteria spoken of before as the cause of the conversion of nitrogenous substances into nitrates).

3. Leguminous plants grow in a sterilized soil, that is a soil in which these organisms have been destroyed, like all other plants; they demand assimilable nitrogen as f. e. nitrates.

4. A sterilized soil, in which leguminous plants are grown by the aid of nitrates, and in which they would perish if these were cut off, may acquire the power of producing in them root tubercles by coming in contact with a minute portion of earth possessing it or with water, even only a few drops, that had percolated it; the plants then become able to live without nitrates and upon the free nitrogen of the air.

This living together of the leguminous plant and the adventitious organism for mutual benefit is frequently met with in the vegetable kingdom and is called *symbiosis;* it is a purely business relation and when either host or visitor overtakes and crowds out the other the death of both results speedily. The organism, it is to be presumed, demands for its development, the existence within the host of certain favorable conditions, which doubtless prevail in all leguminous plants and impart to them their important property of being able to live upon free nitrogen; may not other plants be made to acquire it also? Until then we have learned, however, which crops may and which may not be employed for purposes of green manuring; the knowledge must now be supplemented by actual trial to render it practical. Whether clover, peas and vetches, serradella or lupines answer best under our conditions of soil and climate, whether to grow them as main crops and lose the use of the land for the season or to sow with others and secure a crop along with a long period of growth, whether to plow in at all or to feed to cattle and save the manure to return to the land, and, lastly, whether to buy mineral fertilizers to stimulate an abundant growth of leguminous crops for feeding, followed by a grain crop or a crop of roots or tubers for two or three years to begin the rotation again, are all questions that practical and patient trial alone will answer; and such answer in the form of a few plain rules is the hope of agriculture, and, when formulated, the staff upon which the general farmer will lean with safety.