10-1936

Bulletin No. 274 - Influence of Rotation and Manure on the Nitrogen, Phosphorus, and Carbon of the Soil

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Recommended Citation

Greaves, J. E. and Hirst, C. T., "Bulletin No. 274 - Influence of Rotation and Manure on the Nitrogen, Phosphorus, and Carbon of the Soil" (1936). *UAES Bulletins.* Paper 236.
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BULLETIN 274 OCTOBER 1936

INFLUENCE OF ROTATION AND MANURE ON THE NITROGEN, PHOSPHORUS, AND CARBON OF THE SOIL

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INFLUENCE OF ROTATION AND MANURE ON THE NITROGEN, PHOSPHORUS AND CARBON OF THE SOIL[1]

J. E. GREAVES and C. T. HIRST[2]

INTRODUCTORY

All agricultural plants require carbon, hydrogen, oxygen, nitrogen, calcium, potassium, magnesium, sulfur, phosphorus, iron, and probably traces of other elements for their normal growth and fruition. The growth of farm crops is dependent upon an available supply of these elements, and the extent of growth is governed by the one present and available in least quantity in proportion to the plant's needs. Of the essential elements, all plants secure two (carbon and oxygen) from the air, one (hydrogen) from the water, and the others from the soil. Most soils contain sufficient plant nutrients for normal plant production, with the exception of nitrogen, phosphorus, and potassium. These elements are used by the plants from the soil in the largest quantities and are generally the plant nutrients governing the productivity of a soil. In addition, the organic matter of the soil is of prime importance, for it is the matrix which holds the nitrogen and governs the structure and water-holding capacity of the soil. Probably most Utah soils contain sufficient potassium; consequently, the problem of Utah soil fertility resolves itself into maintaining an optimum concentration of nitrogen, phosphorus, and organic material in the soil. Therefore, this work represents a study of the influence of manure and crop rotation on the nitrogen, phosphorus, and carbon in the soil.

NATURE OF THE EXPERIMENTAL FIELD

Investigations were conducted on the Greenville Farm, belonging to the Utah Agricultural Experiment Station and located two miles north of the college campus. The soil is of a sedimentary nature, being derived from the weathering of the mountain range near by, which consists largely of limestone, quartzite, and dolomite. At the time of Lake Bonneville the mountain streams poured their waters, loaded with the weatherings of these rocks, in the various stages of subdivision (gravel, sand, and silt) into the still waters of the lake. When the swiftly running water of the stream met the quiet water of the lake, the stream began to deposit its load. The gravel and coarser material, being deposited first, gave rise to the well-defined deltas found at the mouths of all the larger streams. One of the best defined deltas is that on which the old college farm (now known as

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Acknowledgment: The authors are indebted to Professor D. W. Pittman for furnishing the samples used in this investigation and for the use of data on crop yields.

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Publication authorized by Director October 8, 1936.

the Greenville Farm) is located. The fine material, consisting mainly of fine sand, silt, and clay, was carried out farther into the lake, where it was gradually deposited. It is of this sedimentary material that the Greenville Farm is composed.

The soil is quite uniform in composition to a depth of 50 feet. Below this is a coarse gravel. The permanent water-table reaches a depth of approximately 100 feet; consequently, the soil has a perfect drainage. However, extensive work has shown that it is not uncommon for irrigation water to carry the soluble nitrates below the tenth foot (1).

At the beginning of this investigation a soil survey was made of the Greenville Farm in the following manner: Samples of soil were taken in foot-sections from each plot. The corresponding foot-sections of these samples were thoroughly mixed and taken to the chemical laboratory, where they were subjected to chemical and physical analyses.

Table 1 gives the chemical composition of the soil to the depth of 8 feet. The method of analysis followed was that advocated by the Association of Official Agricultural Chemists (3).

Table 1. Chemical composition of the soil of the Greenville Farm.

Constituent	Depth of Soil (foot-sections)							
	1st	2d	3d	4th	5th	6th	7th	8th
Insoluble residue	41.46	35.57	31.65	40.90	28.38	29.22	30.57	30.33
Soluble silica	0.62	0.84	0.41	0.75	0.34	0.42	0.57	0.42
Total	42.08	36.41	32.06	41.65	28.72	29.64	31.14	30.75
Potash (K_2O)	0.67	0.89	0.59	0.82	0.61	0.74	0.79	0.75
Soda (Na_2O)	0.35	0.47	0.47	0.62	0.37	0.42	0.45	0.74
Lime (CaO)	16.88	17.80	21.34	15.60	22.62	23.15	22.21	21.78
Magnesia (MgO)	6.10	9.46	7.57	7.48	9.36	5.89	6.06	5.63
Iron oxide (Fe_2O_3)	3.03	2.69	3.46	2.95	2.17	2.42	2.47	2.54
Alumina (Al_2O_3)	5.64	4.69	3.40	6.09	5.33	8.07	7.90	9.03
Phosphoric acid (P_2O_5)	0.41	0.29	0.34	0.19	0.12	0.06	0.07	0.11
Carbon dioxide (CO_2)	19.83	23.11	26.67	20.88	29.31	29.57	28.80	28.13
Volatile matter	5.60	3.38	3.93	4.23	0.91	0.95	.....	0.24
Total	100.69	99.29	99.93	100.51	99.52	100.91	99.92	99.68
Humus	0.53	1.00	0.61	0.47	1.13	0.60	0.44	0.57
Nitrogen	0.139	0.117	0.080	0.175	0.072	0.070	0.062	0.066

An examination of Table 1 will show that this, like other Utah soils, is exceptionally rich in the essential plant-foods (with the exception of nitrogen). Potassium is equally as high in the eighth and intermediate feet as in the first foot. Phosphoric acid is high in the first foot but gradually decreases in each succeeding foot. Humus and nitrogen, as is characteristic of soils of arid America, are both low. One of the most important considerations, however, from the view point of this investigation, is the fact that the calcium and magnesium carbonate content of the soil is exceptionally high. In fact, the results indicate that 43 per cent of the surface foot of soil is calcium and magnesium carbonate and that the amount increases with depth to the fifth foot, after which the magnesium content is practically the same as in the first foot; the calcium carbonate also increases with depth to a maximum in the fifth foot and then remains practically constant.

From the work of previous investigators on the magnesia content of soils one might conclude that the soil on the Greenville Farm would be sterile. The contrary is true, however; the soil is remarkably fertile and produces excellent crops without the addition of barnyard manure. With the single exception of its low organic content, this soil is ideally adapted both chemically and bacteriologically to support rapid bacterial action.

Table 2 indicates the physical composition of the soil of the Greenville Farm. Results show this soil to be a good loam of remarkable uniformity throughout the 8 feet.

Table 2. Physical analysis of the soil of the Greenville Farm.

Item	Depth of Soil (foot-sections)							
	1st	2d	3d	4th	5th	6th	7th	8th
Coarse sand	0.21	0.17	0.68	1.02	0.09	0.34	0.47	0.09
Medium sand	9.63	8.29	6.63	9.63	9.53	9.48	8.91	7.08
Fine sand	30.04	32.54	29.49	33.06	36.92	33.79	35.34	34.25
Coarse silt	32.25	32.81	32.62	28.51	28.65	30.49	31.65	32.65
Medium silt	12.30	10.46	10.89	10.95	10.46	10.85	9.92	9.89
Fine silt	6.25	4.81	7.27	6.94	4.85	5.86	5.56	5.84
Clay	7.62	7.12	10.13	7.52	7.82	6.78	6.52	7.57
Moisture	1.60	1.47	1.13	1.49	0.95	1.01	1.01	0.84
Soluble and lost	0.10	2.33	1.16	0.83	0.73	1.40	1.42	1.99
Specific gravity	2.67	2.72	2.80	2.69	2.76	2.79	2.71	2.76
Apparent sp. gr.	1.23	1.27	1.30	1.29	1.33	1.34	1.39	1.35
Water-soluble salts	0.06	0.11	0.14	0.16	0.08	0.09	0.15	0.09

METHOD OF INVESTIGATION

The rotation, which was started in 1915, was a seven-year rotation of oats, beets, beets, oats, alfalfa for three years, and repeat (4, 5, 6, 8).[3] The alfalfa was sowed with oats as a nurse crop. Farmyard manure was added at the rate of 15 tons per acre preceding the first beet crop and thereafter at the rate of 10 tons per acre preceding the beet crops, thus making two manurings in seven years. There were seven plots in the experiment, each consisting of 1/26.352th acre. All crops were irrigated as needed. The oats, straw, beets, and alfalfa were removed from the soil. The beet tops were plowed under. The plots were sampled to a depth of 3 feet in foot-sections in 1916, 1926, and again in 1934. At least five borings were made on each plot and a composite used for analyses. Total nitrogen, phosphorus, and organic carbon were determined according to the official methods (3). The results are reported as the elements nitrogen, phosphorus, and carbon, and represent the averages of several closely agreeing determinations.

ELEMENTS CONCERNED

Nitrogen

Nitrogen occurs in two forms—free and combined. In the free form it has no monetary value. It is a colorless, tasteless, odorless gas, and ex-

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[3] Numbers in parentheses refer to literature citations (References, page 15).

tremely inert and useless to all animals and plants, with the exception of a few bacteria. These change it into the combined form so it has a monetary value and can be utilized by higher plants. Nitrogen enters into the composition of many valuable compounds. The most beautiful dyes and perfumes contain it, as do also some of the most potent poisons and vilest smelling compounds. It is tucked away in the most powerful explosives and plays a profound part in living protoplasm. It is taken from the soil in large quantities by the growing plants and constitutes an integral part of every cell. Lack of nitrogen in the soil results in a reduction of leaf surface, stunted, abnormal growth, and yellowing of the leaf, especially in cold weather. Excessive nitrogen given to cereals causes overproduction of straw, with a great tendency to lodge. Beets produce excessive tops with small roots. Nitrogen-starved plants as well as plants receiving excessive quantities of nitrogen are especially susceptible to attacks of insects and fungous pests.

Nitrogen differs widely from the other essential elements in that it did not constitute a part of the original earth crust but occurred exclusively in the atmosphere to which it constantly tends to return. When in the soil it is rendered soluble and available to higher plants by bacteria; while in the soil as nitrates, if not taken up by the growing plants, there may be a tendency for it to leach from the soil by rain and irrigation waters. Most soils are deficient in nitrogen.

Table 3 shows the average number of pounds per acre of nitrogen contained in oats, sugar-beets, and alfalfa removed from an acre of the Greenville Farm soil.

Table 3. Average pounds per acre of nitrogen contained in oats, sugar-beets, and alfalfa removed from an acre of soil on the Greenville Farm.

Crop	Average No. Crops	Nitrogen in Annual Acre-Crop (Lbs.)	Value of Nitrogen in Yearly Crop
Oats	35	82	$12.30
Beets	35	59	8.85
Alfalfa	35	304	45.60

It is evident that oats remove greater quantities of nitrogen from the soil than do sugar-beets when the crowns are returned to the soil; otherwise, sugar-beets remove more nitrogen than do cereals. Both of these crops are dependent upon the soil for their nitrogen, as neither can use atmospheric nitrogen. Alfalfa, on the other hand, when forced to do so by a lack of this element in the soil, can, if properly inoculated, utilize atmospheric nitrogen.

Experiments which have been conducted at the Utah Station during a 12-year period have demonstrated that even on soils poor in nitrogen alfalfa first feeds upon the combined nitrogen of the soil. It is known that plant residues and other complex nitrogen compounds found in the soil are transformed by bacteria into ammonia and this in turn by another class of bacteria into nitric nitrogen, and it is mainly on this nitrogen that the growing plant feeds. The quantity of this found in the soil at different periods under different plants has been measured at the Utah Agricultural Experiment Station, the average results for twelve years being given in Table 4.

Table 4. Nitric nitrogen found under various crops at different seasons of the year (pounds per acre to a depth of 6 feet).

Crop	Season			Average
	Spring	Midsummer	Fall	
Alfalfa	22	16	33	23.7
Oats	36	14	21	23.7
Corn	25	19	22	22.0
Potatoes	81	61	54	65.3
Fallow	82	54	63	66.3

Here the legume (alfalfa) is found removing the nitric nitrogen from the soil just as fast as do the non-legumes. Yet this soil was well inoculated with the symbiotic bacteria, which undoubtedly assisted the alfalfa in obtaining free nitrogen from the air when needed, but not until the soluble nitrogen had been drained from the soil to its full extent. This is evidenced by the fact that alfalfa soil never contains more nitric nitrogen than does oats and corn land and further that it is extremely poor as compared with potato and fallow soil.

It may be argued that the small quantity of nitric nitrogen in the alfalfa soil is due to a lack of its production, as it may not be needed by the legume and hence not formed; but this conclusion is not warranted by the facts in the case, as may be seen from the results obtained where the speed of formation of nitric nitrogen (nitrification) was measured (Table 5). These also are the average results extending over a number of years and obtained at the Utah Experiment Station.

Table 5. Milligrams of nitric nitrogen produced in 100 grams of soil in 21 days.

Crop	Season			Average
	Spring	Midsummer	Fall	
Alfalfa	3.15	7.48	3.08	4.56
Oats	2.40	4.00	3.00	3.13
Corn	2.18	3.50	1.48	2.38
Potatoes	3.00	15.55	5.60	8.04
Fallow	1.30	5.50	2.48	3.09

Here the quantity of soluble nitrogen produced in the alfalfa soil is greater than that produced in either the oat or alfalfa soil, and there is no doubt but that this is one reason why an increased yield is obtained the year following the plowing up of an alfalfa field; this increased nitrification is observed for several years after an alfalfa field is planted to some other crop. The alfalfa plant stimulates bacterial organisms of the soil so they make available faster the nitrogen of the soil; this only depletes the soil of its nitrogen more readily than does the non-legume, for it is the nitrogen already combined in the soil on which the nitrifying organisms act.

Hopkins (2) of Illinois was able to measure the quantity of nitrogen taken from the soil and the quantity taken from the atmosphere. This was made possible by the fact that many of the Illinois soils do not normally contain the symbiotic bacteria, thus making it impossible for alfalfa to obtain nitrogen from the air. This being the case, a field was taken which had not grown alfalfa and hence did not contain the symbiotic nitrogen-gathering bacteria. This was planted to alfalfa, only one-half of it being inoculated with the legume organism. To some of the plots were added lime and phosphorus to make certain that these were not the limiting factors. Results thus obtained are given in Table 6.

Table 6. Fixation of nitrogen by alfalfa in field culture, Illinois.*

Plot No.	Treatment Applied	Pounds in Crop		Pounds Nitrogen Fixed by Bacteria
		Dry Matter	Nitrogen	
1a	None	1180	21.81	
1b	Bacteria	2300	62.04	40.23
2a	Lime	1300	26.20	
2b	Lime bacteria	2570	68.02	41.82
3a	Lime phosphorus	1740	35.40	
3b	Lime phosphorus bacteria	3290	89.05	53.65

*Illinois Agricultural Experiment Station Bulletin 76 (1902).

It is evident from these results that the alfalfa has obtained from 40 to 53 pounds of nitrogen from the air, depending upon the treatment. There was slightly more than one-third as much nitrogen in the alfalfa crop from the uninoculated as in the inoculated. Therefore, it is quite evident that the alfalfa in these plots had obtained one-third of its nitrogen from the soil and two-thirds from the air. Nitrogen is required for growth by the roots of the plant as well as for that part of the growth above the ground; there is every reason to believe also that the roots obtain their growth in the same proportion from air and soil as did the hay crop itself. If the percentages of the dry matter and nitrogen occurring in the roots and stalks of alfalfa are examined, it would be possible to decide whether more nitrogen is being returned to the soil in the roots and residues than is removed by the growing plants.

The results for this comparison come from a ten-year experiment conducted at the Utah Agricultural Experiment Station in which alfalfa was grown on the Greenville Farm soil. Part was inoculated and part was not inoculated. Roots and stocks were harvested separately and the dry weight and nitrogen determined in each case. Average results for the ten-year period are given in Table 7.

Table 7. Percentages of dry matter and total nitrogen in roots and stocks of alfalfa averages of 15 crops.

Crop (Alfalfa)	Percentage of Nitrogen			Percentage Total Dry Matter		
	Whole Plant	Plant above Ground	Roots	Whole Plant	Plant above Ground	Roots
Inoculated	100	60	40	100	54	46
Not inoculated . .	100	62	38	100	57	43

Inoculation of alfalfa slightly increased the root growth and the nitrogen of the roots. Approximately 40 per cent of the nitrogen of the alfalfa plant is in the roots. This represents the distribution of nitrogen in young alfalfa, and it is improbable that in the older plant a high proportion of the total nitrogen would be found in the roots. If only two-thirds of the total nitrogen of the plant is obtained from the air it is, therefore, evident that the quantity returned to the soil with the roots and plant residues does not exceed that removed from the soil by the growing plant, which leaves the soil neither richer nor poorer from the growth of alfalfa where the entire crop is removed. This assumes that the roots are allowed to remain and decay. Yet it is not uncommon to find farmers removing the roots from the soil, and at the same time expecting an increase in their soil nitrogen.

The 295 pounds of nitrogen removed by the five crops of sugar-beets and the 404.0 pounds of nitrogen removed by the oats come directly from the soil. Nitrogen to the extent of 587 pounds was returned to each acre of soil in the farmyard manure, which is 112 pounds less than was used by the sugar-beets and oats. Therefore, if alfalfa has received its nitrogen from the air, a loss of 112 pounds from every acre, due to cropping, is apparent. An inventory of the soil nitrogen at the beginning and end of this experiment is offered. The plots were carefully sampled to a depth of 3 feet at the begining (1916) and at the end of the experiment (1934), the average results being given in Table 8.

Table 8. Pounds per acre of nitrogen in the 3-foot section of soil, in 1916 and 1934, respectively.

Foot-section	Average No. Pounds per Acre-foot of Nitrogen		
	1916	1934	Loss (Lbs.)
First	5904	5400	504
Second	3726	3276	450
Third	3132	2592	540
Total	12762	11268	1494

The oats and sugar-beets removed 699 pounds of nitrogen from the soil, leaving a balance of 795 pounds, or an annual loss of 44 pounds per acre. This is higher than the amount (35 pounds) found to be lost from the

Rothamsted (England) plots in drainage water, much of which is probably taken up by the alfalfa. Just what proportion is being removed by the alfalfa and what proportion is being carried below the third-foot level by the water? This can be answered only by further investigational work, but it is evident that a seven-year rotation of oats, beets, beets, oats, and alfalfa for three years, in which 20 tons of farmyard manure is added during a rotation, is not sufficient to maintain the nitrogen content of the Greenville Farm soil.

This conclusion does not imply that crop rotation should not be practiced, for there are many reasons why crop rotation commends itself to the careful farmer, but rotation must not be used and the legume removed with the expectation of maintaining soil fertility. This may appear to be an unfortunate conclusion, but it is just the reverse. If its teachings are heeded it means a fertile soil and an economic gain to the farmer from the system of farming which he is required to adopt.

There are two practical methods of maintaining the nitrogen of the soil: (1) Planning systems of crop rotations with legumes, the legume being plowed under and allowed to decay, thus furnishing nitrogen to the succeeding crop; and (2) practicing a combined system of crop rotation and livestock farming. The alfalfa removed from each acre during the life of such a rotation contained 2400 pounds of nitrogen, all of which, it could be assumed, had come from the atmosphere, provided the quantity found in the roots had come from the soil. If the alfalfa is plowed under, some of the nitrogen is lost; even then, however, there would be more than enough to make up the nitrogen deficiency incurred in this rotation.

The second method of maintaining the nitrogen and organic matter of the soil — the combined rotation and livestock method — is the more practical, and if systematically practiced will not only maintain the nitrogen of the soil but will prove of great economic value to the individual following it. This method consists of a rotation in which the legume plays a prominent part — the legume to be fed and all manure returned to the soil. This would mean selling from the farm the entire hay crop in the form of butter, milk, or beef which carried from the soil only a fraction of the nitrogen stored by legume; moreover, it brings for the producer much greater returns than does the system in which the legume is completely removed from the soil.

It must, however, be remembered that in this system only about three-fourths of the total nitrogen of the feed is recovered in the dung and urine. Therefore, instead of the alfalfa adding 2400 pounds of nitrogen to the soil from the air, it would add only 1800 pounds, provided all of the liquid and solid excrements are collected and returned to the soil. Where the alfalfa is to be fed and the manure returned to the soil, however, the legume can occupy a much longer period in the rotation (and with greater economy) than where the legume is to be plowed under directly. However, three years out of the seven would be more than ample to maintain the nitrogen of this soil (4). If these principles which have been established for soils, even low in nitrogen, are systematically applied, greater revenue from an increased livestock industry will result and a soil rich in nitrogen and organic matter will be maintained rather than being depleted of its stored-up nitrogen, as is so often the case under many common practices.

Phosphorus

Phosphorus, the second element which is often the limiting factor in crop production, plays a highly important role in both plant and animal growth as well as in metabolism. Phosphorus is necessary for the production of chlorophyll. In its absence neither sugar nor starch is formed in the leaf. To the farmer of the arid districts this is especially important for two reasons: (1) In the early stages of growth phosphorus promotes root formation to a remarkable extent, which is especially noted in clay soils where there is a tendency for scant root formation; and (2) in the later stages of growth, phosphorus hastens ripening. In northern districts where frost is a menace this may be an important factor. At maturity the phosphorus has accumulated to a large extent in the seeds. Plants and grains grown on soils with a low phosphorus content are deficient in phosphorus. Where these in turn are fed to animals they often suffer from a deficiency of phosphorus, which first manifests itself by deficient growth, while in more severe cases defective bones result. An insufficient quantity of phosphorus in the diet has a profound effect on the animal, as phosphorus is required in every cell and fluid of the body. Phosphorus, together with calcium, plays a fundamental role in bone formation and enters into the buffering powers of the blood and other tissue. Phosphorus is intimately concerned with carbohydrate, fat, and some phases of protein metabolism. It is essential in muscular contraction and is vitally concerned in the functioning of the nervous system. The quantity of phosphorus removed from oats, sugar-beets, and alfalfa is shown in Table 9.

Table 9. Average pounds per acre of phosphorus removed by oats, sugar-beets, and alfalfa from Greenville Farm soil.

Crop	No. of Crops	Phosphorus Removed from an Acre-foot of Soil (Lbs.)	Value of Phosphorus in Yearly Crop
Oats	35	14	$0.84
Beets	35	15	0.90
Alfalfa	35	36	2.16

Alfalfa removes more than twice as much phosphorus from the soil as do either oats or sugar-beets. In the last columns of Tables 3 and 9 are given the costs of the nitrogen and phosphorus in the plants, if purchased as a commercial fertilizer in the cheapest available form. It is evident that one cannot profitably purchase nitrogen and use it as a fertilizer for the production of oats, beets, or alfalfa; one must rather depend upon the fixation by bacteria in the presence of a suitable legume. Phosphorus, however, if required, could be profitably used (Table 10).

During the life of this experiment 164 pounds of phosphorus were added with the manure. Consequently, the loss from the surface 3 feet during the 18 years of cropping was 720 pounds. The phosphorus in the crops accounts for 491 pounds, leaving a loss of 229 pounds, which represents an annual average phosphorus acre-loss of approximately 13 pounds. Some of this may have been leached below the third-foot level, but probably much is due to experimental error.

Table 10. Pounds per acre of phosphorus in Greenville Farm soil in 1916 and and 1934, respectively.

Foot-Section	Average No. Pounds per Acre-foot of Phosphorus		
	1916	1934	Loss (Lbs.)
First	2700	2448	252
Second	2528	2412	116
Third	2592	2404	188
Total	7820	7264	566

Alfalfa roots carry considerable phosphorus; since, however, they are slow in decaying the soil could not be sampled to measure the amount. Soil erosion may also have played a part in this loss; consequently, the complete loss from the soil is probably not as high as these figures indicate. To be on the safe side, admit an annual loss of 13 pounds of phosphorus from each acre of soil. During the 18 years this soil was cropped it had lost 11.7 per cent of its total nitrogen and 7.1 per cent of its total phosphorus. Hence, relatively speaking, the nitrogen is being depleted twice as fast as is the phosphorus. Moreover, if necessary, phosphorus could be added to these soils economically in the form of a commercial fertilizer (7); in the case of the nitrogen, however, the cost would be prohibitive. Therefore, insofar as this type of soil is concerned, the problem confronting the farmer is to grow legumes and to return their nitrogen to the soil (4, 6, 7). On decaying, the added organic manures yield acids which, in turn, render the phosphorus available. These soils are extremely rich in phosphorus, which is reflected in the phosphorus content of the crops grown upon them. This is reflected by the better growth made by animals fed upon them.

Carbon

Although plants do not use the organic matter (carbon) of the soil for food, it greatly influences the physical, chemical, and biological properties of a soil. Organic matter in various stages of decay gives to a soil its dark-brown or black color. The absorption of heat, and consequently the temperature, depends to a large extent upon the color of the soil. It is common knowledge that dark-colored soils are earlier than light-colored soils. Heat may be generated within the soil, due to the decay of the organic material. It also changes the structure of the soil. When added to a light clay it tends to spread the particles, whereas if added to a sand it has a tendency to cause the particles to adhere together. In either case, it increases the tilth of the soil. Organic matter acts like a sponge and, naturally, when applied to a soil increases its water-holding capacity. It is the great reservoir in which is held the nitrogen of the soil as well as considerable phosphorus and potassium; it is also the food for the principal bacteria which live in the soil and prepare the necessary food for the growing plants. Loose soil, low in organic material, is readily eroded by wind and water. The organic carbon of arid soil is low, and the careful farmer plans his systems of cropping so as to return as much organic material in the form of plant residues, farmyard manure, and green legumes to the soil as possible. The effects of this crop rotation on the organic matter of the soil are seen in Table 11.

Table 11. Pounds of organic carbon and carbon-nitrogen ratio in Greenville Farm soil, 1916 and 1934, respectively.

Foot-Section	No. Pounds of Organic Carbon		Carbon-Nitrogen Ratio		Gain (Lbs.)
	1916	1934	1916	1934	
First	48,096	65,376	9.9	12.1	17280
Second	24,840	42,804	6.7	13.1	17964
Third	16,726	32,508	6.6	12.5	15782
Total	89,662	140,688			51026

The organic carbon content of the three foot-sections of the soil was materially increased by this cropping system. Using Wolff's factor, cxl. 724, for converting the carbon into organic material, the soil in 1916 carried 154,577 pounds of organic material in one acre of soil taken to a depth of 3 feet. The same soil in 1934 carried 242,546 pounds, making an average annual gain of 4887 pounds. The quantity of organic material returned to the soil in the farmyard manure, oat stubble, alfalfa roots, and beet tops is approximately 5971 pounds. According to these figures, this soil annually decomposed more than 1000 pounds of organic material. This is considerably lower than the 3000 pounds usually conceded as being the annual loss from a good arable soil. This difference may be due to several factors: (1) This soil was supporting only two hoed crops in seven years, resulting naturally in low oxidation; (2) there might have been some slight error either in (a) the calculated amount of organic material returned in the stem and plant roots or in (b) results obtained in sampling and analysis. It is clear from these results, however, that the cropping system used was highly efficient in maintaining and even in increasing the organic material of the soil. It must be remembered, however, that all stubble and beet tops were plowed under. The story would have been far different if the stubble had been burned and the beet tops fed from the soil. During the 18 years of this experiment sugar-beet tops have added 40,000 pounds of organic material to each acre of soil; they have also returned appreciable quantities of nitrogen, phosphorus, and potassium to the soil. When considering permanent fertility, this seriously raises the question as to which is the most profitable—the feeding of the beet tops or plowing them under in order to increase the productivity of the soil.

The addition of manure and plant residues to the soil changed the carbon-nitrogen ratio from 9.9 in 1916 to 12.1 in 1934. In soils the ratio of carbon to nitrogen indicates the nature of the organic matter and the extent to which it has decomposed. The ratio of carbon to nitrogen in plants is 25-40 to 1, whereas in humus it is 10-15 to 1. The further the decay has progressed in a soil the narrower the carbon-nitrogen ratio. Other things being equal, a wide carbon-nitrogen ratio indicates a more productive soil than one having a narrow ratio.

During the process of decay carbon and hydrogen are readily liberated from partly decayed plant debris, but not from the old coal-like material, resulting in organic acids. These react with and render available to the growing plant the essential plant-food.

SUMMARY

A study has been made of the influence of a seven-year rotation of oats, beets, beets, oats, and alfalfa for three years, on the nitrogen, phosphorus, and organic material of an irrigated silt loam. It was found that oats remove more nitrogen than do sugar-beets when the crowns are returned to the soil; when the crowns are also removed, the two crops deplete the soil of its nitrogen to the same extent. Properly inoculated alfalfa feeds first on the combined nitrogen of the soil; when this is insufficient it draws on the nitrogen of the air. Hence, rotations in which the alfalfa is removed from the soil do not maintain the nitrogen of this soil. However, there are two practical methods of maintaining the nitrogen of the soil: (1) Planning systems of crop rotations with legumes, the legume being plowed under and allowed to decay, thus furnishing nitrogen to the succeeding crop; and (2) practicing a combined system of crop rotation and livestock farming, the legume being fed and the manure returned to the soil.

The rotation investigated in this work showed a loss of 83 pounds of nitrogen from each acre to a depth of 3 feet. Thirty-nine pounds of this was removed by the beets and oats. The balance was either removed by the alfalfa or leached below the third-foot level by the water.

Alfalfa removes twice as much phosphorus from the soil as do either oats or sugar-beets. During the life of this experiment (18 years) analysis showed a loss of 720 pounds of phosphorus from each acre of soil, only 491 of which was removed by the crops, the balance being held in the undecomposed plant residues carried below the third-foot level by irrigation water.

The rotation under consideration increased the carbon of the soil and widened the carbon-nitrogen ratio, thus rendering the soil more productive.

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(College Series No. 534)