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J. E. Greaves

C. T. Hirst

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The Influence of Cropping on the Nitrogen, Phosphorus and Organic Matter of the Soil Under Irrigation Farming

BY J. E. GREAVES AND C. T. HIRST

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BULLETIN 310

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THE INFLUENCE OF CROPPING ON THE NITROGEN, PHOSPHORUS AND ORGANIC MATTER OF THE SOIL UNDER IRRIGATION FARMING[1]

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

INTRODUCTION

MOST soils contain sufficient nutrients for normal plant growth, with the exception of nitrogen, phosphorus and potassium. These elements are used by plants in the largest quantities and the amounts of these in the soil govern its productivity. Soil organic matter is of prime importance for it is the matrix which holds the nitrogen and modifies the structure, temperature, and water-holding capacity of the soil. The organic matter is the very life of the soil, for it is in and on it that bacteria work and by so doing determine the kind and speed of reactions which occur. It is the bacterial activities in the soil that determine the available plant food. 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 matter. The present work represents a study of the phosphorus, nitrogen, and organic matter in the soil and the speed with which they are being removed by plants, erosion and leaching.

EXPERIMENTAL FIELD

THE work was conducted on the Greenville Experimental Farm, the soil of which is of a sedimentary nature, being derived from the weathering of the mountain range nearby, 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 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. The fine material, consisting mainly of fine sand,

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[1] Contribution of the Department of Bacteriology and Biochemistry—Report on Project 23—Adams.

[2] Research professor of bacteriology and biochemistry, and research associate professor of chemistry, respectively.

silt and clay, was carried farther out 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 and extensive investigations by Greaves, Stewart and Hirst (5) have shown that it is not uncommon for irrigation water to carry soluble nitrates below the tenth foot.

The chemical and physical analyses of this soil have been reported elsewhere (4). It, like many other Utah soils, is exceptionally rich in the essential plant foods with the exception of nitrogen. The amount of potassium is equally as great in the eighth and intermediate feet as in the first foot. The phosphorus content of the first foot is high but it gradually decreases in each succeeding foot. Amounts of humus and nitrogen are both small, as is characteristic of soils of arid America. An important consideration, however, is that the calcium and magnesium carbonate content of the soil is exceptionally high. In fact, 43 percent of the surface foot of soil is calcium and magnesium carbonate. The amount of magnesium increases with depth to the fifth foot, after which it is practically the same as in the first foot. Calcium carbonate also increases with depth to a maximum in the sixth foot and then remains practically constant. Humus and nitrogen are distributed throughout the ten feet with slightly more nitrogen in the surface two feet than in the lower foot sections.

The soil is remarkably fertile and produces excellent crops if small amounts of barnyard manure are applied to it. With the single exception of its low organic content, the soil is ideally adapted chemically, physically, and bacteriologically to support rapid bacterial action.

METHOD OF INVESTIGATION

THERE were eight plots in the experiment. They received the treatments outlined in table 1.

The work was started in 1916 on plots consisting of 1/26 acre, separated from adjoining plots by a four-foot walk. All crops were irrigated as needed. The oats, straw, beets and alfalfa were removed from the soil. The beet tops were plowed under. The cultivated plots were fall plowed and in the spring a mixture of fairly well rotted manure was added to the manured beet plots. The manure contained approximately 728 pounds of dry matter, 3.04 pounds of phosphorus, 13.7 pounds of potassium, and 16.08 pounds of nitrogen in each ton. The fallow plots were cultivated, watered, and kept free of weeds. All plots were sampled to a depth of 3 feet in foot sections in 1916 and again in 1934. At least five borings were made on each plot and composited for analyses. Total nitrogen, phosphorus and organic carbon were determined according to official methods (1). The results are reported as pounds of nitrogen, phosphorus, and organic matter in one acre foot of soil.

Table 1. *Treatment of plots in experiment*

Plot no.	Manure Tons per acre (annually)	Crop
31G	none	Continuous alfalfa
41G	none	Continuous fallow
42G	none	Alternate oats and fallow
43G	none	Continuous oats
44G	30 tons manure with beets	Continuous beets 11 yrs., continuous alfalfa last 8 yrs.
45G	10 tons manure with beets	Continuous beets 11 yrs., continuous alfalfa last 8 yrs.
46G	none	Continuous beets 11 yrs., continuous alfalfa last 8 yrs.
47G	none	Alternate corn and beets 17 yrs., alfalfa last 2 yrs.

There were no replicates, hence it is impossible to evaluate accurately the sampling error in the work. However, the care used in sampling and analyses together with work reported by Bracken and Greaves (2) on similar Cache Valley soils collected and analyzed in the same manner as were these soils suggests what the probable error may be. Bracken and Greaves found that the mean differences in the comparison of virgin and cropped soils at the one percent point for nitrogen in the first foot was 0.012 percent and for the second and third foot 0.009 percent. Applying these results to the present work, in order for the differences to be significant there would need to be a difference of 432 pounds of nitrogen in the first foot and 327 pounds in the second and third foot samples, and a difference of 1,086 pounds total for the entire three foot soil section. The same workers found it necessary to have a difference of 0.107 percent carbon for the comparison of virgin and cropped soil for the one percent point. Assuming that these results are applicable to the data under consideration there would have to be a difference between compared plots of 11,556 pounds of organic carbon to be significant.

LIMITING ELEMENTS IN CROP PRODUCTION

Nitrogen. The amounts of nitrogen in the first, second, and third feet of the variously cropped soils in 1916 and 1934 are given in table 2. An acre foot of soil is taken as weighing 3,600,000 pounds.

Although plot 31G had grown alfalfa continuously for 19 years, it lost 1,902 pounds of its original nitrogen. There was a small increase of nitrogen in the first foot but a large decrease in the second and third foot sections, hence this soil was decreasing in nitrogen even though alfalfa was grown continuously. However, this does not indicate that the alfalfa was not obtaining nitrogen from the air, for during the 19 years 4,526 pounds of nitrogen had been removed in the crop, assuming that all of the nitrogen which had disappeared from the surface three feet of soil was taken up by the alfalfa. Even under this assumption the alfalfa obtained 58 percent of its nitrogen from the soil. It is probable that even larger quantities were obtained from the air as there would be a loss by leaching and erosion.

Table 2. *Nitrogen content of the soil of variously treated plots in* 1916 *and* 1934

Plot	Treatment	Year	Pounds of nitrogen per acre foot of soil				Removed from soil
			1st ft.	2nd ft.	3rd ft.	Total	
31G	Continuous	1916	5,256	4,500	3,630	13,386	
	alfalfa	1934	5,652	3,312	2,520	11,484	1,902
41G	Continuous	1916	4,896	3,744	3,996	12,636	
	fallow	1934	3,090	2,808	2,196	8,094	4,542
42G	Alternate oats	1916	6,372	4,536	3,780	14,688	
	and fallow	1934	3,960	3,276	2,376	9,612	5,076
43G	Continuous	1916	6,192	4,896	4,104	15,192	
	oats	1934	4,572	3,060	2,232	9,864	5,328
44G	Beets, manure	1916	6,228	4,212	3,780	14,220	
	alfalfa	1934	6,624	3,672	2,520	12,816	1,404*
45G	Beets, manure	1916	5,724	3,492	2,772	11,988	
	alfalfa	1934	5,076	3,060	2,340	10,476	1,512**
46G	Beets no manure	1916	6,300	4,104	2,268	12,672	
	alfalfa	1934	5,220	3,348	2,088	10,656	2,016
47G	Alfalfa, corn	1916	3,852	3,852	3,312	11,016	
	beets	1934	4,104	3,204	2,448	9,756	1,260

*This is in addition to 5,306 pounds of nitrogen added in the manure

**This is in addition to 1,769 pounds of nitrogen added in the manure

Plot 41G, which was continuously fallowed for 19 years, lost 4,542 pounds of total nitrogen. Approximately 40 percent of this came from the first foot, 20 percent from the second and 40 percent from the third foot section. The nitrogen lost from this fallow soil was equivalent to that contained in the alfalfa harvested from plot 31G during 19 years. This quantity of nitrogen calculated at 15 cents a pound if purchased as a commercial fertilizer would cost $683. It is possible that some of this nitrogen may not have been lost to deep rooted crops if they were seeded on this soil later, however, the data clearly illustrate the wastefulness of fallow on irrigated soils.

The treatment of plot 42G was alternate oats and fallow for 18 years, and then in 1934, it was planted in sugar beets. Fallow and oats in alternate years apparently are as wasteful of nitrogen as is continuous fallow for in this system 5,076 pounds of nitrogen disappeared from the soil, only 11 percent of which was recovered in the oat crops, leaving a balance of 4,519 pounds completely lost. This is the quantity of nitrogen lost where continuous fallow was practiced. The losses of nitrogen in alternate oats and fallow were more evenly distributed in the surface three feet of soil than in the case of continuous fallow.

Where oats were grown continuously 5,328 pounds of nitrogen had disappeared from the surface three feet of soil, only 12 percent of this was recovered in the oat crop. Here again the loss was distributed throughout the surface three feet of soil. It is possible that nitrogen was also lost from the fourth and subsequent foot sections, for it has been shown elsewhere that nitrates are often leached to the tenth foot-section of soil (5).

Plot 44G was cropped continuously to sugar beets from 1916 to 1926, inclusive, and alfalfa from 1927 to 1934, inclusive. Manure was added to the soil at the rate of 30 tons per acre when sugar beets were grown. No manure was added when alfalfa was grown. Hence 5,306 pounds of nitrogen were added to this soil, in addition to 1,404 pounds which had disappeared from the soil, making a total of 6,710 pounds of nitrogen removed in 19 years. The crop carried 3,495 pounds of nitrogen, which in the case of the sugar beets came entirely from the soil, or that added with the manure. The alfalfa obtained large quantities from the air. If we assume that alfalfa obtained all of its nitrogen from the air, then 48 percent of the nitrogen which had disappeared from this soil was carried by the irrigation and drainage waters below the third foot or lost by erosion and denitrification. Whether this was a total loss cannot be answered from the data at hand as some of the nitrogen may remain in the fourth and subsequent foot sections and if properly handled may be later recovered.

Plot 45G produced beets from 1916 to 1926, inclusive, with continuous alfalfa from 1927 to 1934, inclusive. This soil likewise received barnyard manure, but at the rate of 10 tons per acre annually from 1916 to 1926, inclusive. The quantity of nitrogen removed from the soil by the crops in 19 years was 3,436 pounds. The quantity of nitrogen added to the soil with manure was 1,769 pounds; that removed from the original soil was 1,512 pounds. Hence there were 155 pounds more nitrogen in the crops than disappeared from the manured soil. This quantity together with that lost in drainage and erosion represents the nitrogen fixed by the legume.

Plot 46G produced beets continuously from 1916 to 1926, inclusive, and alfalfa continuously from 1927 to 1934, inclusive. During this time the soil lost 2,016 pounds of nitrogen. There had been removed from this soil by the crops 2,388 pounds of nitrogen. Hence the alfalfa crops had taken from the atmosphere at least 372 pounds of nitrogen. Although this soil had been continuously cropped to beets during the first 11 years to alfalfa the last 8 years, yet the soil contained 2,016 pounds less nitrogen in the first 3 acre feet, than it did 19 years previously.

Plot 47G was cropped alternately to beets and corn from 1916 to 1932, inclusive. During 1933 and 1934 the plot was in alfalfa. During this time 1,260 pounds of nitrogen had disappeared from the soil. This is the amount that was removed in the crops.

It is evident from these results that the quantity of nitrogen lost from these soils may exceed that removed by the growing crops. The loss is great in continuous oats, continuous fallow, and alternate oats and fallow. It is highly probable that the loss was also great in continuous sugar beets although this loss is masked to a degree by the later growth of alfalfa. Alfalfa reduces the apparent loss in two ways: (1) It feeds on the nitrates nearly as rapidly as they are produced, thus preventing their loss by drainage water. (2) When not furnished with available soil nitrogen, it obtains its nitrogen from the air.

It is interesting to compare the nitrogen in the harvested crops with that removed from the soil including that supplied with the manure. The summarized results are given in table 3.

The cropping systems, continuous alfalfa; beets 11 years, alfalfa 8 years, 10 tons manure per year with the beets; and beets 11 years, alfalfa 8 years, no manure, yielded more nitrogen in the crop than

Table 3. *Nitrogen lost from soil, applied in the manure and remaining in crops*

Plot no.	Crop	Nitrogen lost from soil	Nitrogen added in manure	Total loss	Nitrogen in crop	Loss or gain
				pounds per acre		
31G	**Continuous alfalfa**	**1,902**		**1,902**	**4,526**	**+2,324**
41G	**Continuous fallow**	**4,542**		**4,542**	**0**	**—4,542**
42G	**Alternate oats and fallow**	**5,077**		**5,077**	**759**	**—4,319**
43G	**Continuous oats**	**5,328**		**5,328**	**645**	**—4,683**
44G	**Beets 11 yrs., alfalfa 8 yrs.**	**1,404**	**5,306**	**6,710**	**3,495**	**—3,215**
45G	**Beets 11 yrs., alfalfa 8 yrs.**	**1,512**	**1,769**	**3,281**	**3,436**	**+ 155**
46G	**Beets 11 yrs., alfalfa 8 yrs.**	**2,016**		**2,016**	**2,388**	**+ 372**
47G	**Alternate corn and beets 17 yrs. Alfalfa last 2 yrs.**	**1,260**		**1,260**	**1,260**	**0**

disappeared from the soil and manure. This quantity together with the unknown lost by leaching, erosion and denitrification represents the quantity fixed by the alfalfa. Where alternate corn and beets with the two last years in alfalfa was the practice, the nitrogen of the crops equaled that removed from the soil.

Where alfalfa was grown continuously, 14 percent of the nitrogen which was in the surface three feet of soil in 1916 had disappeared during the 19 years of cropping. Where continuous fallow or continuous oats was the practice, 36 and 35 percent, respectively, of the soil nitrogen had disappeared, thus indicating the wastefulness of these methods of cropping. This wastefulness of nitrogen is brought out even more clearly if the annual loss of nitrogen is considered. On plot 45G, which had grown alfalfa and beets, there was a gain of 8 pounds of nitrogen annually which with the price of commercial nitrogen at 15 cents a pound is $1.20. Plot 43G which had grown oats continuously lost 246 pounds of nitrogen annually valued at $36.90. These values may exceed the market value of the crops grown.

These losses are considerably greater than those occurring in Utah dry farm soils and in other arid and semi-arid soils (2) and are usually higher than the losses reported for humid soils (6). This is because of several factors: (a) The large quantities of irrigation water applied to these soils. It has been shown elsewhere (2) that the soluble nitrates of this soil are rapidly leached below the feeding areas of the plants and consequently lost in drainage water. (b) The nature of the soil. This soil has good drainage, hence any soluble nitrogen is quickly carried away in the drainage water. The crop produced on irrigated soil is governed by the available plant food within the feeding area of the roots. This is often low in soils receiving excessive amounts of irrigation water, even though there is an abundance of nitrogenous material which is being rapidly nitrified (5).

The losses reported for this soil are probably greater than occur in most Utah irrigated soils, but they illustrate the potential and sometimes real danger of the waste of plant food which may occur in irrigated soils.

Phosphorus: Phosphorus is unevenly distributed in soils; some virgin soils contain enough for only a few crops, others contain sufficient for hundreds of crops. It exists primarily as phosphates both in the soil and as large natural deposits.

The total quantities of phosphorus in an acre foot of the variously cropped soil of the Greenville plots in 1916 and 1934 are given in table 4.

There is one practice in these systems of cropping that maintains the phosphorus content of the soil, that is the one in which beets and alfalfa were grown and manure applied to the beets at the rate of 30 tons per acre yearly. There was applied to the soil in the manure 1,003 pounds of phosphorus, 578 pounds of which were removed in the crops, 8 pounds remained in the soil, and 417 pounds were lost by drainage or erosion.

More phosphorus disappeared from the soil on which alfalfa was grown continuously than from any other soil. This was the result of the heavy phosphorus requirements of the plant. The greatest total loss of phosphorus occurred in plot 44G planted to beets for 11 years, alfalfa for 8 years with 30 tons of manure added annually when the beets were grown. This was the result of the rapid bacterial activity in this soil with the production of acids which rendered the phosphorus soluble, which in turn was leached from the soil by the drainage waters. The yearly loss of phosphorus from the several plots varied from 2.6 pounds per acre in the case of beets to 22 pounds per acre in the case of beets, manure and alfalfa.

The three surface feet of the soil of plot 31G lost 512 pounds of phosphorus during nineteen years. This is a yearly loss of approximately 1 percent of the phosphorus in the surface foot of the soil. At this rate it would require 100 years of cropping to alfalfa to remove the phosphorus from the surface foot. The time when phosphorus would be the limiting factor of crop production is even more remote than this figure indicates for it is evident that it is being removed from all three foot sections. Moreover, each year erosion constantly exposes underlying phosphorus, hence the problem confronting the tiller of this soil is not a problem of adding more phosphorus, but one of rendering the

Table 4. *Phosphorus content of Greenville soil after 19 years of cropping*

Plot	Treatment	Year	Pounds per acre			Total	Loss or gain	Added in manure	Removed in crop	Total loss	Yearly loss
			1st ft.	2d ft.	3d ft.						
31G	Continuous	1916	2,916	2,984	3,024	8,924					
	alfalfa	1934	2,880	2,736	2,796	8,412	—512		440	—72	—3.8
41G	Continuous	1916	2,952	3,024	3,060	9,036					
	fallow	1934	2,800	2,988	2,876	8,664	—372			—372	—19.6
42G	Alternate oats	1916	2,988	2,916	2,584	8,488					
	and fallow	1934	2,916	2,844	2,520	8,280	—208		103	—105	—5.5
43G	Continuous	1916	2,880	2,736	2,664	8,280					
	oats	1934	2,808	2,700	2,488	7,996	—284		119	—165	—8.7
44G	Beets, manure	1916	3,012	3,152	2,952	9,116					
	alfalfa	1934	3,028	3,182	2,914	9,124	+8	1,003	578	—417	—22.0
45G	Beets, manure	1916	3,024	3,134	2,916	9,074					
	alfalfa	1934	3,004	3,018	2,902	8,924	—150	334	435	—49	—2.6
46G	Beets, no manure	1916	2,988	2,988	2,664	8,640					
	alfalfa	1934	2,952	2,808	2,556	8,316	—324		266	—58	—3.1
47G	Alternate corn										
	and beets	1916	2,916	2,916	2,844	8,676					
	alfalfa	1934	2,836	2,796	2,656	8,288	—388		212	—176	—9.2

phosphorus available. This can be done by keeping the soil well supplied with organic material, which, when decomposed by bacteria, liberates organic and inorganic acids which react with insoluble phosphorus and render it soluble. Fresh manures and undecomposed plant residues are superior to well rotted manure for this purpose. However, where the quantity of manure available is limited, small applications to a large acreage are superior to large applications to a small acreage.

Table 5. *Organic matter (C x 1.724) content of Greenville soil after 19 years' cropping*

Plot	Treatment	Year	Pounds per acre			Total	Loss or gain	Without manure Total annual loss or gain in soil
			1st ft.	2d ft.	3d ft.			
31G	Continuous alfalfa	1916	76,463	62,809	51,265	190,537		
		1934	101,537	63,802	53,125	218,464	+27,927	+1,470
41G	Continuous fallow	1916	84,779	61,940	56,540	203,259		
		1934	53,809	51,451	35,563	140,823	—62,436	—3,286
42G	Alternate oats and fallow	1916	95,454	83,600	50,272	229,326		
		1934	88,183	64,484	47,045	199,712	—29,614	—1,559
43G	Continuous oats	1916	131,017	76,153	48,596	255,766		
		1934	91,048	61,754	38,535	191,337	—64,429	—3,391
44G	Continuous beets 30 T manure alfalfa	1916	118,108	62,436	44,003	224,547		
		1934	136,417	67,526	46,858	250,801	+26,254	+1,382
45G	Continuous beets 10 T manure alfalfa	1916	100,544	67,898	39,287	207,729		
		1934	105,074	58,030	38,231	201,335	—6,394	—336
46G	Continuous beets 1916-1926 alfalfa 1927-1934	1916	111,901	54,989	41,459	208,349		
		1934	99,861	50,540	39,000	189,401	—18,948	—997
47G	Alternate corn and beets alfalfa	1916	91,917	67,339	47,231	206,487		
		1934	84,655	58,030	41,662	184,347	—22,140	—1,165

Organic Matter. That there is a relationship between the organic matter of the soil and its productivity has been recognized for centuries. Virgin soils are highly productive, but they decrease in productivity as they are cultivated and there is a corresponding decrease in their organic content. Any permanent system of agriculture should maintain the organic matter of the soil.

The pounds of organic matter per acre in an acre foot of the soils receiving the various cultural treatments are given in table 5 and represent organic carbon times 1.724.[a]

The average organic matter of the surface three feet in 1916 was 108 tons. This was distributed throughout the soil as follows: 47 percent in the first foot, 31 percent in the second foot, and 22 percent in the third foot. In 1934 the average organic matter of the surface three feet of soil was 99 tons distributed as follows: 48 percent in the first foot, 30 percent in the second foot, and 22 percent in the third foot. This soil had lost 7.5 percent of its organic matter during the 19 years, but the distribution in the soil had not been materially changed.

The soil which had grown alfalfa continuously and the soil which had received 30 tons of manure per acre each gained an average of approximately ¾ ton of organic matter yearly. However, the manured soil had decomposed approximately 6 tons of organic matter annually which is nearly four times the organic matter lost by the continuously fallowed soil. This is because of the rapid decomposition of the fresh organic manures.

The loss from the continuously fallowed soil was twice as great as it was from the alternate oats and fallow. This was also true where the soil was planted to oats. The ten tons of manure added where the beets were grown were not sufficient to maintain the organic matter of the soil, but where 30 tons were applied and also where alfalfa was grown continuously the soil increased in organic matter.

Calculated in percentages of the total organic matter of the first foot of soil in 1916, we find that each plot lost or gained annually the following percentages of its organic matter:

	percent
Continuous fallow	—3.9
Alternate oats and fallow	—1.6
Continuous oats	—2.6
Continuous beets, 10 tons manure annually, followed by alfalfa	—0.3
Beets and alfalfa, no manure	—0.9
Alternate corn and beets	—1.3
Continuous alfalfa	+1.9
Beets, 30 tons manure annually	+1.2

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[a] The total organic carbon times the factor 1.724 equals the organic matter.

These losses do not appear large and one may be tempted to conclude that it would require from 25 to 100 years to deplete the first foot of soil of its organic matter. However, it must be remembered that long before the organic matter of the soil was gone the chemical, physical, and biological properties of the soil would be so materially changed as seriously to retard productivity. Moreover, it is the fresh organic matter which is active biologically hence in a few years the speed of decomposition decreases so rapidly that the plant food locked up in the soil is not rendered available. This would necessitate the use of commercial fertilizers even though large quantities of insoluble plant food occurs in the soil.

DISCUSSION

PERMANENT soil fertility implies that a soil be so tilled that it contains sufficient plant food for maximum crop production and that this plant food be maintained economically over an indefinite period. It is not sufficient to view it in the light of a few years, as a soil may be tilled for a short period and forced to yield large crops by intensive cultivation or by the use of soil amendments. These may liberate plant nutrients and in this way increase productivity; but if continued, the soil in time ceases to react, hence the productivity drops below the economic level. We may enunciate the fundamental principle: It is the duty of a farmer to obtain from his soil the largest return possible. In so doing he may remove the maximum of plant nutrients for the specific cropping system and when he uses fertilizers he should pay for both his work and the fertilizer applied and should also receive a fair return for the plant nutrients removed from his soil.

Nitrogen. Examining this soil in the light of the above principles we observe that the average nitrogen in an acre foot of soil to a depth of three feet was 13,225 pounds in 1916. This was distributed throughout the soil as follows: first foot, 42 percent; second foot, 32 percent; and third foot, 26 percent. During the nineteen years the soil was cultivated it lost 22.7 percent of this nitrogen. The loss came from the three feet and, including the nitrogen added in the manure, varied widely with the various cultural treatments as shown by the following:

	percent
Continuous alfalfa	14.2
Continuous beets, 30 tons manure	10.0
Continuous fallow	35.9
Continuous beets, 10 tons manure	28.0
Alternate oats and fallow	34.6
Continuous beets, no manure	15.0
Continuous oats	35.1
Alternate corn and beets	11.4

None of the systems maintained the nitrogen of the soil, and it is evident from these figures that in a comparatively short time these soils would be unproductive owing to a lack of nitrogen. If this loss were replenished with commercial fertilizers, the annual cost of the nitrogen removed from this soil by crops, erosion and drainage valued at 15 cents a pound is: continuous alfalfa, $15; continuous fallow, $35; alternate oats and fallow, $40; continuous oats, $42; beets 30 tons manure, $11; beets 10 tons manure, $12; beets no manure, $16; alfalfa, corn, beets, $10. From 11 to 100 percent of the nitrogen was recovered in the crop and undoubtedly better cultural and especially proper irrigation practices could materially reduce these losses. Assuming that they could be cut to one-half, even then the cost per acre annually for the commercial nitrogen necessary for the production would vary from $5 in the case of alfalfa and corn to $21 where oats were grown continuously. This cost is high and in many cases more economical ways might be found to maintain soil nitrogen.

The authors have shown elsewhere (4) (5) and it is borne out by this work that all that can be expected from alfalfa cultivation is to obtain the nitrogen needed by this crop from the air. This implies that the growth of alfalfa on a soil leaves the soil equally poor in nitrogen after the crop has been removed. Moreover, it has been shown that a seven year rotation consisting of oats, beets, beets, oats and alfalfa + 20 tons manure for three years will not maintain the nitrogen of the soil (8).

Two practical methods of maintaining the nitrogen of the soil which may be used to a limited extent are: (1) Practicing systems of crop rotations with legumes, the legume to be 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 a seven-year rotation, three years of which is alfalfa, contained approximately 600 pounds of nitrogen, all of which, may be assumed, had come from the atmosphere and the quantity occurring in the roots came from the soil. When 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 a seven year's rotation.

A second method of maintaining the nitrogen and organic matter of the soil—the combined rotation and livestock method—is the more practical. 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 implies selling from the farm the entire hay crop in the form of livestock or livestock products which would carry from the soil only a fraction of the nitrogen stored by the legume.

In the latter system only approximately three-fourths of the total nitrogen of the feed is recovered in the dung and urine. Therefore, instead of the alfalfa adding 600 pounds of nitrogen to the soil, it would add only 450 pounds, provided all of the liquid and solid excrements are returned to the soil. Where the alfalfa is to be fed and the manure returned to the soil, 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 the soil (3) (7) (8) (9) (10). If these principles which have been established for soils 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 one depleted of its nitrogen, as is so often the case under many common practices.

Phosphorus. If the time required for each cropping system to remove the equivalent of the phosphorus in the surface foot of soil is used, the following results are obtained: Where beets were grown continuously with the addition of 30 tons of barnyard manure per year the phosphorus would last forever. Where beets were grown continuously with the addition of 10 tons manure per acre yearly the phosphorus in the soil would be sufficient for 382 years. With alternate oats and fallow the phosphorus would be sufficient for 274 years. Where oats were grown continuously the phosphorus would be sufficient for 192 years. Where beets were grown continuously with no manure the phosphorus would be sufficient for 158 years. Where alternate corn and beets were the practice the phosphorus would be sufficient for 143 years. Where alfalfa was grown continuously the phosphorus would be sufficient for 108 years. It is evident from the data presented in table 4 that the various crops remove the phosphorus from the first, second and third foot sections. Hence the phosphorus in the soil would last even longer than is indicated by the above figures. Moreover, there is a constant erosion which exposes lower sections of soil containing phosphorus. Hence it is evident from these results that the phosphorus problem for this soil is not a problem of adding more phosphorus but one of rendering available that already in the soil. This may be done where a system of rotation containing legumes is practiced and the crop residues or barnyard manure returned to the soil.

Organic Matter. The average organic matter in three feet of this soil in 1916 was 108 tons and in 1934 it was 99 tons, hence there was a loss of approximately 7.5 percent. The distribution of this organic material throughout the three foot sections was practically the same at the beginning as at the end of the experiment. The first foot carried 47 percent of the organic matter, the second foot 31 percent, and the third foot 22 percent. However, the annual loss or gain from the soil from the different plots varied greatly as is seen from the following figures:

	Tons, loss or gain annually
Continuous alfalfa	+0.7
Continuous fallow	—1.6
Alternate oats and fallow	—0.8
Continuous oats	—1.7
Continuous beets 30 tons manure	+0.7
Continuous beets 10 tons manure	—0.2
Continuous beets no manure	—0.5
Alternate corn and beets	—0.6

There was a gain in organic matter where alfalfa was grown continuously and where 30 tons of manure were applied annually to the soil. Ten tons of manure per acre annually was not quite sufficient to maintain the organic matter of the soil, but it is probable that 11 tons per acre would be sufficient, and this quantity of fresh barnyard manure would be sufficient to maintain available phosphorus. If the loss of nitrogen from leaching is cut to a minimum, 11 tons of manure is sufficient to provide the needed nitrogen for most crops. Hence insofar as this soil is concerned the application of 11 tons of barnyard manure per acre annually would approach optimum for maintaining nitrogen, available phosphorus and organic matter of this soil under better cropping systems.

SUMMARY

A STUDY has been made of the influence of cropping under irrigation upon the nitrogen, phosphorus and organic matter of the soil. This was done by determining the quantity of each of these constituents in the surface three feet of soil in 1916 and again in 1934. The cropping methods used were: Continuous alfalfa; continuous fallow; alternate oats and fallow; continuous oats; continuous beets 11 years, 30 tons manure annually with beets, alfalfa 8 years; beets 11 years, 10 tons manure annually with beets, alfalfa 8 years; beets 11 years, no manure, alfalfa 8 years; alfalfa, alternate corn and beets, alfalfa.

Continuous alfalfa removed 1,902 pounds of nitrogen from this soil during nineteen years. This loss was caused by removal by plant growth, leaching and erosion. The data do not permit a statement as to the relative importance of the latter two.

The continuously fallowed plot lost 4,542 pounds of total nitrogen during the nineteen years, all of which was caused by erosion and leaching. Where alternate oats and fallow were practiced the loss was even greater, 5,076 pounds from the first three feet of soil. This was practically the same when oats were grown continuously on the soil.

The soil on which sugar beets were grown and to which 30 tons of manure were applied annually lost 1,404 pounds of nitrogen. This, together with the added nitrogen makes a total loss of 6,710 pounds in the nineteen years. When sugar beets and alfalfa were planted the loss was not so great as when oats were grown continuously on the soil. The gross loss of nitrogen from the soil when sugar beets and alfalfa were grown was less where 10 tons of manure were added than where 30 tons per acre were added. Hence 10 ton applications of manure to this soil under these cropping systems appears to be more economical than 30 tons per acre. From 11 to 100 percent of the nitrogen disappearing from the soil was recovered in the crop.

Fallow or continuous oats is wasteful of soil phosphorus. If the time required for each cropping system to remove the equivalent of the phosphorus in the surface foot of soil is taken as a basis for comparison the following results are obtained: Where beets were grown continuously with the addition of 30 tons of barnyard manure per acre the phosphorus would be sufficient for an indefinite cropping; where beets were grown continuously with the addition of 10 tons of barnyard manure per acre annually the phosphorus in the soil would be sufficient for 382 years; where alternate oats and fallow was the procedure the phosphorus would be sufficient for 274 years; where oats were grown continuously the phosphorus would be sufficient for 192 years; where beets were grown continuously the phosphorus would be sufficient for 158 years; where alternate corn and beets were grown the phosphorus would be sufficient for 143 years; and where alfalfa was grown continuously the phosphorus would be sufficient for 108 years.

During the life of this experiment the soil annually lost the following percentages or organic matter from the surface foot: Continuous fallow, 3.9 percent; alternate oats and fallow, 1.6 percent; continuous oats, 2.6 percent; beets and no manure, 0.9 percent, alternate corn and beets, 1.3 percent. The soil that was planted in alfalfa gained 1.9 percent, and that in beets and receiving annually 30 tons per acre of manure gained annually 1.2 percent of organic matter, and that in beets with 10 tons of manure per acre gained 0.3 percent of organic matter. That is, the soils which decreased in organic matter lost annually from 0.5 tons to 1.7 tons per acre. The soil which produced continuous alfalfa and that which had received 30 tons of manure per acre annually gained 0.7 tons of organic matter per acre annually.

LITERATURE CITED

(1) Association of Official Agricultural Chemists. Official Methods of Analysis. Washington, D.C., 1940.

(2) Bracken, A. F., and Greaves, J. E. Losses of nitrogen and organic matter from dry-farm soils. Soil Sci. 51:1-15, 1941.

(3) Burnham, C. Observations on the use of commercial fertilizers on the arid soils of Utah. Utah Agr. Exp. Sta. Bul. 233. 1932.

(4) Greaves, J. E. and Hirst, C. T. Influence of rotation and manure on the nitrogen, phosphorus and carbon of the soil. Utah Agr. Exp. Sta. Bul. 274. 1936.

(5) Greaves, J. E., Steward, R. and Hirst, C. T. Influence of crop, season, and water on the bacterial activities of the soil. Jour. Agr. Res. 9: 293-341. 1917.

(6) Hopkins, C. G. Soil fertility and permanent agriculture. New York, Ginn and Co., 1910.

(7) Pittman, D. W. Fertility maintenance by rotation and manure. Utah Agr. Exp. Sta. Bul. 271. 1936.

(8) Pittman, D. W. Maintaining the productivity of irrigated land. Utah Agr. Exp. Sta. Bul. 188. 1924.

(9) Pittman, D. W. Rotations and cropping systems. Utah Agr. Exp. Sta. Cir. 103. 1934.

(10) Stewart, G., and Pittman, D. W. Twenty years of rotation and manuring experiments at Logan, Utah. Utah Agr. Exp. Sta. Bul. 228. 1931.