TOTAL NITROGEN AND CARBON IN CULTIVATED LAND AND LAND ABANDONED TO GRASS AND WEEDS

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INTRODUCTION

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A deficiency of nitrogen in the soil so often becomes a limiting factor in crop production that any investigation which has as its object a determination of the cause of losses, or methods of increasing the supply, of this element, is of prime importance.

It is already well known that under continuous cropping nitrogen does disappear rapidly from cultivated soils, and that frequently the supply is not maintained even when fair amounts of nitrogenous fertilizers are applied annually (6). That the amount removed in the crop does not account for the total loss is likewise well known, but beyond the fact that a part of it is found in the drainage waters as nitrates, the information is not very definite.

In this connection Snyder (14) discussing the effect of the continuous growing of wheat on the same land for a period of years says:

When wheat was grown continuously upon the same soil for eight years, there was a loss of 1700 pounds per acre of nitrogen, about 300 pounds being utilized as plant-food and 1400 pounds lost by the decay of the animal and vegetable matter of the soil and the liberation of the nitrogen as gaseous and soluble compounds. During the eight years of continuous wheat cultivation there was a loss of over 21 per cent of the total nitrogen of the soil, equivalent to an annual loss of 175 pounds per acre in addition to that used as plant-food.

He found about the same loss when oats and barley were grown continuously. The same author in a later publication says: (15)

The loss of nitrogen from four grain farms in ten years amounted to three to five times more than was removed by the crops. This loss was due to the rapid decay of the humus and the liberation of the nitrogen, which forms an essential part of the humus. When clover was grown, crops rotated, live stock kept and farm manure used, an equilibrium as to the nitrogen content of the soil was maintained, the mineral plant-food was kept in the most available condition and maximum yields were secured.

Alway, who has made an exhaustive study of the loess soils of Nebraska, says (1): "Analyses show a great loss of nitrogen, humus and unhumified organic matter in the case of all fields long under 'cultivation.'" In their virgin condition he finds these soils rich in the constituents mentioned.

Under a consideration of the nitrogen problem Russell (11) says:

No element of plant-food is so liable to waste as nitrogen. If a farmer applies potash or phosphoric acid to his land he may reasonably expect to get most of it back again, but when he applies nitrogen he is almost certain to lose a good proportion of it. The sound practice is therefore to keep the nitrogen circulating, to crop it out and replace it, rather than to aim at leaving it in the soil.

Shutt (13) calls attention to the unusually high nitrogen content of some of the soils of Manitoba and Saskatchewan (0.2 per cent to 1.00 per cent) but points to the fact that the system of grain growing now in practice on some of the lands results in a large loss of nitrogen annually.

On the other hand, it has been claimed that land allowed to run wild increases in fertility. In this connection Hall (4) calls attention to the fact that a piece of land at Rothamsted which was allowed to run wild contained, at the end of 20 years, 2200 pounds more of nitrogen than it contained at the beginning of the period. This means an increase of more than 100 pounds per acre annually. Hall thinks this increase may be due to symbiotic and non-symbiotic fixation, absorption of ammonia, rise of nitrates from the lower subsoil, and nitrogen compounds brought down in rain water.

Another (2) writer claims that plants derive much more plant-food from soils than chemical analysis accounts for. He says:

A large amount of incidental plant-food, is evidently conveyed by rain water. It appears probable also that the fertility given by the deposited excreta of small animals, birds, insects and worms and reptiles, and the decay of their bodies upon the ground and also the decay of vegetable matter, dust deposited by the wind, leaves, flowers and seeds and branches, etc., is largely in excess of what has previously been estimated, and in fact it is of as much importance as food obtained from the reserves held by the soil itself. This must be known as the incidental increment and must be taken into full account in all agricultural operations.

Hall (5) in a later publication calls attention to the fact that

with every system of farming a certain position of equilibrium will be reached (viewed over a term of years long enough to smooth out seasonal effects) when the natural recuperative agencies and the additions of fertilizing materials in the manure are balanced by the removals in crops and stock and the inevitable waste.

The higher the level of production, the greater will be the waste, and in consequence, the addition of fertilizer must be doubly increased to maintain the balance.

Schneidewind (12) conducted experiments which gave indication that under ordinary methods of intensive culture with liberal use of manure and fertilizers there was a marked depletion of the nitrogen and potassium supply of the soil. There was a relative increase of the phosphoric acid under such a system. Perotti (10) discussing gain of nitrogen, considers bacteria, molds, algae and legumes; and under loss, volatilization of ammonia and denitrification. Shutt (13), by analyses of virgin and cultivated soils, has called attention to the exhaustion of soils by continuous cropping without manure and has shown by experiment that a soil successively cropped to clover continues to increase in nitrogen under this treatment.

Moore, Hampton and Hunter (9) have shown that land in sod for a number of years, suffered a serious loss of nitrogen during five years' cultivation with a double crop rotation of cowpeas and wheat. In this connection they say:

The fact, therefore, that the soil content of nitrogen was not even maintained where a leguminous green crop equal to more than a ton per acre of thoroughly cured hay, on the average, not to mention the fallen leaves, stubble and roots, was turned under each year is almost startling and shows the necessity of a superior system of management if anything like high fertility of the soil is to be maintained without recourse to outside supplies of nitrogen, such as would be furnished by nitrogenous fertilizers and commercial feeding stuffs.

In summing up their conclusions they say further:

By taking the nitrogen removed by the crop into consideration, there was found to be, at the end of five years, (1) where the cowpea crop was turned under, a gain per acre on the unlimed sections of 67 pounds, to be accounted for in sources outside of the 8-inch depth of plowing, but on the limed sections none; (2) where the cowpea crop was removed, a gain per acre of 181 pounds on the unlimed and 177 pounds on the limed, to be accounted for as before.

Swanson (18) states that the soils of Kansas show an average decrease in crop-producing power in spite of the fact that farmers use good seed and improved methods of tillage. Results based on the analysis of cultivated and uncultivated soils in seven representative counties, show that carbon and nitrogen have disappeared from the cultivated to a greater extent than from the uncultivated soils. In round numbers they have lost from one-fifth to two-fifths of their nitrogen and from nearly one-fourth to one-half of the carbon.

Somerville (16) in making a study of the effect of applications of phosphatic manures (notably basic slag) took portions of soil from treated and untreated plots that have been under observation in different sections of England for the past 20 to 30 years and with this soil conducted pot experiments using oats as the first crop. He reports notable increases in yield from the treated soil over the untreated soil. He says:

While it would appear, that the accumulated fertility is partly due to phosphate residues, it is certainly due in most part to the secondary effects of the phosphates, of which the accumulating of humus, including the accumulation of atmospheric nitrogen, is probably the most important.

In a second article (17) he attributes the accumulated fertility largely to nitrogen stored up by leguminous plants, but believes the increase in n. n. leguminous humus is not without influence.

In an article on the chemical composition of virgin and cropped Indiana soils, Connor (3) says:

In spite of the fact that the tendency of nature is to build up and replenish the fertility of the soil, there is no question but that the destructive system of cultivation that has been followed by the farmers of this country has more than counter-balanced nature's tendency to upbuild, and as a consequence the soil has become more or less depleted.

In this connection Connor reports analyses of a number of virgin and cropped soils, and these analyses, he believes, indicate certain changes in the chemical composition of the soil which sixty to eighty years of cropping have brought about. He finds:

that although most of the soil ingredients have not changed enough to make any great difference in the chemical composition of the virgin and cropped soils, there are some notable exceptions.

The most serious losses from the standpoint of soil fertility are those of nitrogen, which shows a loss of 28 per cent, and the organic matter which shows a loss in the volatile matter of 26 per cent and in the humus of 47 per cent. These losses are without doubt the main reason why our cropped soils are no longer as fertile as they formerly were.

If one may judge by the references cited there seems little room to doubt that under continued cropping soils are rather rapidly depleted of their nitrogen and organic matter, and that there may be an actual loss of nitrogen and carbon even when leguminous crops are turned under and manures applied. With uncultivated soils, on the other hand, the losses are not so great and in some instances there are pronounced gains.

EXPERIMENTAL

One of the objects of this experiment was to study the changes which occur in the vegetation on abandoned land and especially the effect of commercial fertilizers on the appearance or disappearance of certain species of plants on such land. The experiment also includes a study of the composition of the soil on the abandoned land as compared with the composition of soil from adjoining plots which are under a 5-year rotation of corn, oats, wheat and two years of grass (originally two years of oats), and the determination of the percentage of applied nitrogen that is recovered in the crop. The soil is a loam inclining to the gravelly phase, with a sandy loam subsoil. Previous to 1908 this land had been neglected for a number of years. The plots were laid out one-twentieth acre in size, one-half to be under cultivation and the other half to remain uncultivated. Beginning with the corn crop of 1908 the plots received a dressing of ground limestone at the rate of 1 ton per acre and beginning with the second five-year period in the spring of 1913 they received a further application of this material at the rate of 2 tons per acre. The uncultivated halves have received the same fertilizer and lime treatment as the cultivated halves. The plots are arranged in pairs with reference to the fertilizer treatment as indicated in the accompanying diagram.

The nitrogen is supplied in the form of ground fish at the rate of 600 pounds per acre, the phosphoric acid as acid phosphate at the rate of 600 pounds per acre and the potash as muriate of potash at the rate of 300 pounds per acre. These materials have been applied annually in accordance with the plan, except for the oat crop in 1911 when no fertilizers were applied. Also, through an error the nitrogen was omitted from plots 63 and 64 in 1914.

Each year a record is made of the kinds of weeds and grasses found on the uncultivated part of the plots, and the number of such plants recorded or the area which they cover measured. It is thus possible to say whether certain species are disappearing and others taking their places under the different treatments. In the late summer the weeds and grass are cut down on these plots but nothing is removed.

It is not the intention to give in this paper a detailed statement of the crop yields on the cultivated section nor to give a complete record of the vegetation on the uncultivated section (the latter is reserved for a later publication) but rather to compare the nitrogen and carbon content of the soils from the two sections, and, taking into consideration the nitrogen removed by the crops on the cultivated sections, determine whether the net result with reference to this element has been loss or gain. No account has been taken of the carbon in the crop so that a comparison so far as this element is con-

CULTIVATED HALF							
57	58	59	60	61	62	63	64
Phos. Acid Potash	Phos. Acid Potash	Nitrogen Potash	Nitrogen Potash	Nitrogen Phos. Acid	Nitrogen Phos. Acid	Nitrogen Phos. Acid Potash	Nitrogen Phos. Acid Potash
57	58	59	60	61	62	63	64
UNCULTIVATED HALF							

cerned is with reference to the amount in the soil of the two sections, cultivated and uncultivated.

Unfortunately no samples were collected from these plots when the work was begun.

Table 1 gives the results of nitrogen and carbon determinations made on samples taken from the cultivated and uncultivated sections of plots 57 to 64 in 1913 and also in 1916. In taking the samples 6 borings, to a depth of 6 $\frac{3}{4}$ inches, were made with a tube cutting a core about 2 inches in diameter, and these cores were made into one sample, dried, passed through a 3-mm. sieve to remove coarse material and finally ground to pass a 0.5 mm. sieve.

Nitrogen determinations were made by the Kjeldahl-Gunning method, five or six determinations being made on each sample.

A study of this table brings out the fact that without exception both nitrogen and carbon are now higher in the uncultivated sections than in the cultivated. The average difference in nitrogen content between the two sections for the

nitrogen-treated plots, was 0.02 per cent in 1913, and 0.0234 per cent in 1916, the former being equivalent to 400 pounds of nitrogen per acre 6 $\frac{2}{3}$ inches (2,000-000 pounds of soil) and the latter equivalent to 468 pounds. The average difference between the cultivated and uncultivated sections of plots 57 and 58, the plots that receive no nitrogen, was in 1913, 0.0123 per cent, which makes a difference in favor of the uncultivated section of 226 pounds of nitrogen per acre, whereas the difference in 1916 was 0.0258 per cent or 516 pounds per acre.

TABLE 1
Nitrogen and carbon in soil, 1913 and 1916

TOTAL NITROGEN					TOTAL CARBON			
1913			1916		1913		1916	
	Cultivated	Uncultivated	Cultivated	Uncultivated	Cultivated	Uncultivated	Cultivated	Uncultivated
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
57	0.0913	0.1054	0.0749	0.1003	1.028	1.320	1.003	1.275
58	0.0787	0.0891	0.0715	0.0977	0.995	1.130	0.995	1.269
Average.	0.0850	0.0973	0.0732	0.0990	1.012	1.225	0.999	1.272
59	0.0809	0.0949	0.0802	0.0985	1.047	1.265	1.048	1.300
60	0.0913	0.1034	0.0824	0.1063	1.142	1.279	1.086	1.311
61	0.0795	0.1041	0.0841	0.0981	0.972	1.245	0.960	1.231
62	0.0874	0.1106	0.0773	0.1134	1.022	1.459	0.999	1.533
63	0.0806	0.1053	0.0802	0.1067	1.028	1.281	1.017	1.440
64	0.0876	0.1108	0.0856	0.1072	1.042	1.364	1.106	1.228
Average.	0.0846	0.1049	0.0816	0.1050	1.042	1.316	1.036	1.341

This accords well with the view that liberal applications of the minerals favor the appearance of volunteer leguminous plants on abandoned land and also the fixation of atmospheric nitrogen by non-symbiotic bacteria, and no doubt accounts for the fact that on the uncultivated sections of these plots the nitrogen supply is fairly well maintained. On the other hand, the cultivated sections are gradually being depleted of their supply of nitrogen, the volunteer leguminous plants not being permitted to come in to restore the losses.

Taking an average of all the nitrogen-treated plots, the cultivated portions show slightly less nitrogen in 1916 than in 1913, in spite of the fact that they have received fair annual applications of nitrogenous fertilizers. For the uncultivated sections the average is essentially the same in 1916 as in 1913, that is, the gain during the three years has not been sufficient to make an appreciable difference in the analyses. It is evident that the total carbon is being gradually decreased on the cultivated sections. This is shown by an average percentage of 1.042 in 1913 and 1.036 in 1916. It is further emphasized,

however, by the fact that determinations made on samples collected in 1909 from nearby plots, where the soil is the same as the soil of the plots under consideration, show 1.21 per cent of total carbon (6). From this it would appear that the cultivated plots have lost nearly 0.2 per cent of carbon during the period 1909 to 1916. On the other hand, the carbon is undoubtedly

TABLE 2
Yields of nitrogen in a five-year rotation, 1908 to 1916 inclusive
(Calculated on the acre basis)

	CORN 1908	OATS 1909	WHEAT 1910	OATS 1911	TIMOTHY 1912	TOTAL NITROGEN FOR FIRST FIVE YEARS	CORN 1913	OATS 1914	WHEAT 1915	TIMOTHY 1916	TOTAL NITROGEN 1913-1916 IN- CLUSIVE	TOTAL NITROGEN 1908-1916 IN- CLUSIVE
57	52.76	19.44	25.48	17.80	5.64	121.12	30.44	14.76	18.60	18.55	82.35	203.47
58	45.60	17.28	28.12	18.16	2.16	111.32	28.64	12.14	19.20	17.49	77.47	188.79
Average.....						116.22					79.91	196.13
59	74.40	28.48	47.80	21.20	5.28	177.16	50.44	23.04	30.00	23.71	127.19	304.35
60	76.40	33.52	55.88	33.16	6.76	205.72	53.68	36.42	37.44	24.83	152.37	358.09
Average.....						191.44					139.78	331.22
Average increase over check.....						75.22					59.87	135.09
61	90.28	31.20	52.12	34.52	7.12	215.24	36.88	23.42	38.52	28.42	127.24	342.48
62	41.12*	33.76	46.72	30.00	6.44	158.04	51.40	25.92	32.38	27.14	136.84	294.88
Average.....						186.64					132.04	318.68
Average increase over check.....						70.42					52.13	122.55
63	77.04	30.24	51.92	33.84	7.00	200.04	58.40	22.48	29.72	29.01	139.61	339.65
64	74.36	28.88	53.44	36.12	9.84	202.64	54.64	21.22	35.42	26.26	137.54	340.18
Average.....						201.34					138.58	339.92
Average increase over check.....						85.12					58.67	143.79
General												
Average....	72.27	31.01	51.31	31.47	7.07	193.14	50.91	25.41	33.91	24.90	136.80	329.94
Average increase over check.....						76.92					56.89	133.81

* Very low yield of stalks for some reason.

increasing in the uncultivated plots, as is shown by an average of 1.316 per cent in 1913 and an average of 1.341 per cent in 1916, and by the further fact, already mentioned, that the samples collected in 1909 from nearby plots show only 1.21 per cent of carbon. Thus it would appear that during the period 1909 to 1916 the carbon content of the uncultivated soils has increased by about 0.13 per cent, which would be equivalent to slightly more than 1¼ tons

of carbon per acre $6\frac{2}{3}$ inches. This is as one might expect, since each year there has been a fair growth of weeds and grasses on these plots and nothing has been removed.

Table 2 shows the amount of nitrogen removed by the crops on the cultivated portion of the plots for the years 1908 to 1916 inclusive, and the average amount for each crop on the eight plots. It will be observed that the corn crop of 1908 yielded the largest amount of nitrogen. This is followed by the corn crop of 1913 and the wheat crop of 1910, both of which furnished approximately 20 pounds less of nitrogen than the corn crop of 1908. The lowest yield was with the timothy of 1912. This is accounted for in part at least by the small crop of that year. With only two exceptions there was less nitrogen recovered from plots 57 and 58—the two that receive no nitrogen—than from those that receive an annual application of nitrogen. The average yield from plots 57 and 58 may be taken as the check, and if this is deducted from the average yields from the plots that receive nitrogenous fertilizers, the remainder may be taken as the amount of the applied nitrogen that was recovered in the crop. The nitrogen-treated plots have received the dried fish at the rate of 600 pounds per acre, but on account of the omission in 1911 the total for the five years was 2400 pounds instead of 3000 pounds. This, on the basis of 8 per cent nitrogen for the fish, would mean a total of 192 pounds of nitrogen per acre for the first five years and also 192 pounds for the last four years, excepting plots 63 and 64 which, on account of the omission in 1914, received only 144 pounds, thus making the average for the four years 176 pounds instead of 192 pounds. This gives a total for the nine years of 368 pounds.

These figures divided into the increase over the check for the respective periods, with the proper pointing off, give the percentages of nitrogen recovered in the crop.

The results calculated for the different treatments are as follows:

PLOTS	FIRST PERIOD, FIVE YEARS	SECOND PERIOD, FOUR YEARS
59.60	39.18	31.18
61.62	36.67	27.15
63.64	44.33	40.74
Average.....	40.06	33.02

Stated in another way the average increase over the check is, for the nine years, 133.81 pounds of nitrogen per acre (bottom figure in last column of table 2) and the total amount of nitrogen applied per acre during that time was 368 pounds. From these figures it is found that there was an average annual recovery for the nine years of 36.36 per cent of the applied nitrogen; that is, a recovery of only a little more than one-third. The highest average recovery for 9 years is from plots 63 and 64 which receive the complete fer-

tilizer, and the next highest from lots 59 and 60 which receive nitrogen and potash.

The average recovery for the first period is a little higher than for the second period. These figures correspond quite closely with recoveries obtained from dried blood in cylinder experiments previously reported (7) and also for the most part with recoveries from fish scrap used in field experiments (6) where the rotation was the same as the one here considered. Slightly higher recoveries were obtained where fish was used as a source of nitrogen in pot experiments (8). The average total recovery from plots 59 to 64 for the nine years is 329.94 pounds (acre basis) while the total amount applied to each plot during the same period was 368 pounds if 8 per cent is taken as the analysis of the fish. During this period the crops on plots 57 and 58, without commercial nitrogen, were able to take from the soil an average of nearly 200 pounds of nitrogen per acre.

From the results it seems quite clear that nitrogen is the limiting factor in crop production on this soil, otherwise plot 60, where no potash has been applied, and plot 61, where no phosphoric acid has been applied, would hardly have given yields of nitrogen in excess of plots 63 and 64 where all three constituents were used. It is true that the averages for 59 and 60 and for 61 and 62 are not quite as high as the average for 63 and 64, but the difference is so small that one could hardly say that the yield was limited by a lack of potash in the one case or of phosphoric acid in the other.

That nearly two-thirds of the applied nitrogen should be unaccounted for is discouraging and does not plead very strongly for the use of commercial nitrogenous materials of an organic nature, if those of mineral origin are available.

SUMMARY

It is here pointed out that the average nitrogen content of land which was allowed to run wild from 1908 to 1916, and which during that period received annual applications of dried fish amounting to 600 pounds per acre, was essentially the same in 1916 as in 1913. (No samples were collected previous to 1913.)

The carbon content of this same land was increased slightly during the period 1913 to 1916.

The average nitrogen content of adjoining cultivated plots, under a 5-year rotation, was 0.02 per cent less in 1913, and 0.023 per cent less in 1916, than the nitrogen content of the corresponding plots that were allowed to run wild.

The average nitrogen content of the cultivated plots was slightly less in 1916 than in 1913.

The average carbon content of the cultivated plots was approximately 0.27 per cent less in 1913 and 0.30 per cent less in 1916 than the average carbon content of the corresponding plots allowed to run wild.

The average carbon content of the cultivated soils was slightly less in 1916 than 1913.

The two cultivated plots which received no nitrogen (the check plots) yielded, in the crops from these plots, an average total of 196.13 pounds of nitrogen for the nine years.

The six nitrogen-treated plots yielded, during the same period, an average total of 329.94 pounds of nitrogen in the crops from these plots.

There was recovered from the six nitrogen-treated plots for the nine-year period, an average of 36.36 per cent of the nitrogen that was applied.

The percentage of nitrogen and carbon in the cultivated soils is decreasing, even where dried fish is applied at the rate of 600 pounds per acre annually.

The percentage of nitrogen in the soils allowed to run wild, and which have received annual applications of nitrogen, appears to run about constant, but the percentage of carbon is increasing slightly.

Much volunteer white clover is appearing on the two plots which receive minerals but no nitrogen.

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