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The Nitrate Nitrogen in the Soil as Influenced by the Crop and the Soil Treatments

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The Nitrate Nitrogen in the Soil as Influenced by the Crop and the Soil Treatments

W. A. ALBRECHT

INTRODUCTION

The crop production on many soils depends largely on the supply of nitrogen these offer the plant. This supply is present mainly as organic matter nitrogen, which is in the plant residues, manure, and similar nitrogenous materials undergoing decay in the soil. During this decomposition the activities of the soil micro-organisms transform the nitrogen from the organic to the ammonia and nitrate or mineral forms, both of which are used by the plants. The amount present in the ammonia form is small, since in most cultivated soils this is quickly converted into the nitrate which is removed by plants, or leached out by the rains. The nitrate may also be consumed by microbiological activity, most noticeably so when excessive amounts of carbonaceous matter as straw, for example, are turned under. Though the ammonia form may serve to supply nitrogen, the nitrate form is the main supply in cultivated soils, and plant growth generally increases as the supply of nitrate nitrogen increases. For this reason, the nitrate supply of the soil becomes of decided importance in crop production.

The study reported herewith was undertaken in order to become familiar with the nitrate supply of the soil during several years as related to the kind of crop, the soil tillage, the straw mulch, the fertilizer treatments and other possible factors, as a partial help in solving the problem of providing sufficient "nitrogen turnover"* for higher crop production.

PLAN AND METHODS OF THE STUDY

General Plan—This study deals with regular determinations of the nitrate nitrogen in the soil of a series of eleven plots of silt loam,† a rolling phase of Shelby silt loam, having different crops and cultural variations during six years, 1920-1925 inclusive, with different soil and fertilizer treatments along with different cropping practices during the succeeding seven years, 1926-1932 inclusive. The scheme of crops, of cultural, and of fertilizer treatments followed is given in Table 1.

*Attention is directed to the term "nitrogen turnover." This term is used to represent the nitrogen in the course of transformation, by microbiological activity of the soil, from organic to other forms from which the plant obtains a portion. This term is used in distinction from the term "nitrogen supply" suggesting a stock of more or less permanent nitrogenous organic matter of the soil from which nitrogen is withdrawn for the plant needs.

†This is a rolling phase of Shelby silt loam in a transition area approaching Lindley loam.

During the last seven years there were added six nearby plots undergoing additional manurial treatments. Four of these six represented a corn-legume rotation, including (1) a legume crop, (2) a legume crop with residual fertilizer effects following corn, (3) corn given a legume green manure, and (4) corn given 300 pounds of 2-10-2 fertilizer in addition to green manure. Two of these six additional plots represented a corn, wheat and clover rotation on limed land. One was under the livestock system of farming, applying two tons of manure and 200 pounds of phosphate ahead of the wheat, and turning under clover ahead of the corn. The second represented the grain system of farming using 250 pounds of a 2-12-2 fertilizer on the corn and on the wheat with additional nitrogen as sodium nitrate on the wheat in the spring.

After the close of the nitrate studies, the eleven plots which had been under study for thirteen years, were given treatments of fine limestone, fine limestone and phosphorus, and fine limestone along with both phosphorus and potassium, and seeded to a red and sweet clover mixture. This permitted the observation of the clover crop as it reflected the lowered fertility levels suggested by the lower levels of nitrates at the close of the study.

TABLE 1.—CROPS AND SOIL TREATMENTS OF PLOTS UNDER NITRATE STUDY.

Plot No.	1920-1925 Incl.		1926-1932 Incl.		
	Crop	Treatment	Crop	Treatments	
		Cultural		Cultural	Fertilizer
1	Corn	Unplowed Scraped	Fallow	Seedbed (a) Cultivated	
2	Corn	Seedbed (a) Scraped	Corn	Seedbed Cultivated	
3	Corn	Seedbed Cultivated	Corn	Seedbed Cultivated	N (b)
4	Fallow	Seedbed Cultivated	Corn	Seedbed Cultivated	N, Limestone (c)
5	Fallow	Seedbed Scraped	Corn	Seedbed Cultivated	Limestone
6	Fallow	Seedbed Straw Mulch (d)	Corn	Seedbed Straw Mulch	Green Manure (d)
7	Fallow	Seedbed Straw Mulch (e)	Fallow	Seedbed Straw Mulch (e)	Green Manure
8	Wheat	Plowed Sept. 15	Wheat	Plowed Aug. 15	N, P, K (f)
9	Wheat	Plowed Aug. 15	Wheat	Plowed Aug. 15.	N, P
10	Wheat	Plowed July 15	Wheat	Plowed Aug. 15	N
11	Grass	Sod	Wheat	Plowed Aug. 15	

(a) This denotes plowing with a moldboard plow to a depth of 6 inches, disking and harrowing to produce a good seedbed in the spring, usually April.

(b) Ammonium Sulfate was broadcast at the rate of 50 pounds per acre ahead of corn planting.

(c) Limestone (mill run 10-mesh) was applied, broadcast at the rate of 2 tons per acre in the Springs of 1926 and 1927.

(d) The straw mulch was put on in April at the rate of 2 tons per acre 1920-1925, and 6 tons per acre 1926-1932. The green manure consisted of chopped sweet clover, applied at the rate of 2 tons per acre ahead of the plowing in Spring as the seed bed was prepared.

(e) Six tons of straw per acre.

(f) N represents ammonium sulfate 20 pounds; P represents super phosphate 150 pounds; and K represent muriate of potash 8 pounds, per acre, all broadcast in advance of wheat seeding.

Chemical Methods—Samples of at least nine borings per plot to a depth of seven inches were taken every two weeks (except when frozen soil prohibited) for nitrate determinations. They were thoroughly mixed and moisture determinations made on triplicate 100-gram samples.* These were then extracted with dilute acid, the extracts were boiled with alkali to remove the ammonia, and their nitrate content was then reduced with DeVarda's metal during distillation into standard acid for titration. All calculations were made as nitrate nitrogen per acre of two million pounds of water-free soil. The extensive accumulation of data makes possible the presentation of only the average figures per plot by months or by years. These are reported in graphical rather than tabular forms and for the growing season in most cases rather than for the calendar year.

EXPERIMENTAL RESULTS

Nitrate Accumulation Under Grass Followed by Wheat—The data for sod (6 years) show a correlation during the growing season, of the nitrate accumulation with the rainfall as shown in Figure 1, which gives the pounds nitrate nitrogen per acre and the rainfall in inches by months for the six years in question. The similarity of the curves is readily noticeable. There is an increase in nitrates with the increased rain and also with the rising temperature of the spring until the maximum is reached in May. A decline follows until August, probably because of the nitrate removal by the grass growth and decreasing moisture. A rise occurs again in September, when the increased moisture gives increased nitrates and the seasonal conditions may reduce the rate of its removal by slower grass growth. Regardless of the increases in nitrates in the spring and autumn, the figures never become very high. Grass evidently keeps the nitrate nitrogen exhausted to the low levels ranging between approximately six and twelve pounds per acre as the average of the six years on this soil.

When put into continuous wheat for seven years following the sod of six years, this plot showed no great nitrate content in consequence of turning under the sod and putting it into cultivation. Even though the figures for the first year following the sod were higher than those for the adjoining plot (Number 10) which had been in continuous wheat for the preceding six years, yet when averaged for the seven wheat

*The author is indebted to many students for help in taking the samples, and in making the chemical determinations. Acknowledgment of this help is hereby made to L. F. Wainscott, Helen Lemert Wainscott, Harold F. Rhoades, George Browning, Wm. T. Hearne, Albert Trowbridge, and T. Raymond Smith. The care of the plots by Mr. L. B. Stuckey is also gratefully acknowledged.

years they are lower than was true for sod in all twelve months except in the two winter months of January and February, and the one summer month of August (Figure 1). Cropping this plot to wheat reduced the general nitrate level below that of sod, as shown in this figure where are given as a curve the monthly averages under the wheat for seven years following the six years of sod.

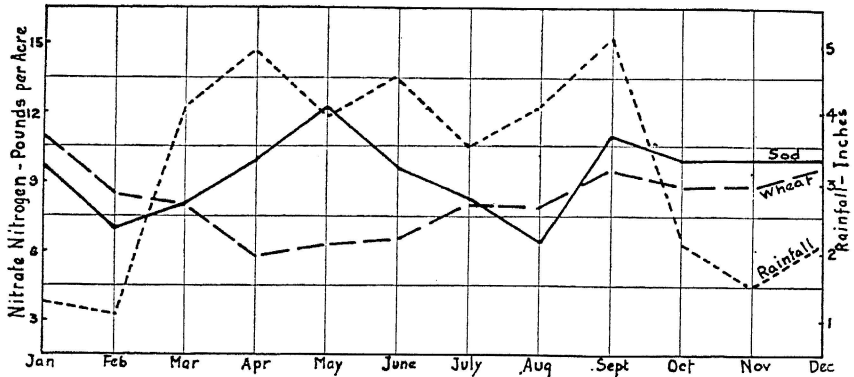


Fig. 1.—Seasonal nitrate nitrogen content of soil in sod (6 years) as related to rainfall. Seasonal nitrate nitrogen in the same soil in wheat (7 years) following the sod.

Nitrates Under Corn and Wheat—The results under sod and wheat raise the question as to whether the lower nitrate content under wheat is due to the particular ability of this crop to deplete it below the level possible by grass, or whether to the decline with time as it brings on nitrogen exhaustion. The influence of these two crops on the same plot, is shown in Figure 2, which gives the five year advancing averages over the period including the six years of sod followed by the seven years of wheat. This curve fails to show any lower levels during

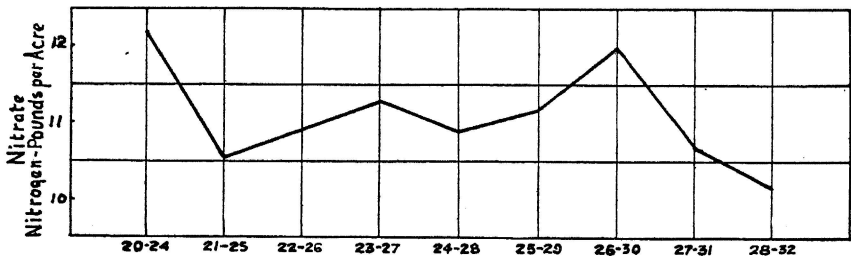


Fig. 2.—Advancing five-year averages of annual nitrate nitrogen level in sod (6 years) followed by wheat (7 years).

the last periods to suggest a greater depletion by the wheat than was true for the grass in the first periods. It even suggests a possible rise during the last seven years. Since the nitrate level was so low during the entire thirteen years, and since the fluctuation is within a range of three pounds per acre, it is difficult to discriminate between the effects of the two crops as reducers of the nitrate supply.

The influences of the corn crop on the nitrate level in comparison to the influence by wheat is shown in Figure 3 in which the monthly averages for the growing season are given for these two crops. For

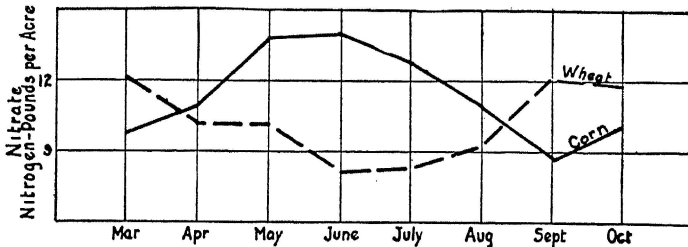


Fig. 3.—Nitrate nitrogen levels in the soil during the growing season for wheat (3 plots) and corn (2 plots) during 13 years.

wheat, the data are taken from three plots, one plowed in July, one in August, and one in September, all given no treatment for six years followed by seven years of fertilizer treatments consisting of additions of superphosphate, of ammonium sulphate and superphosphate, and of ammonium sulphate, superphosphate and potassium, respectively. During the seven years all these wheat plots were plowed on August 15. The data for the corn include two plots with regular cultivation and surface scraping but no fertilizer treatment for six years followed by regular cultivation and with ammonium sulphate broadcast at planting time in one plot during the succeeding seven years. The data for the three wheat plots and two corn plots are assembled as averages for the graphs in Figure 3.

The seasonal curve for corn is the opposite of that for wheat. The former rises until May and June, declines to September and then rises again. The latter falls until June, rises until September and then falls slightly again.

Declining Levels of Nitrates Under Wheat and Corn.—When the nitrates on these same plots are assembled as advancing five year averages of the season as given in Figure 4, the decided drop in nitrates with time is a most outstanding feature. There is also a marked diver-

gence of these two curves with time because of a decidedly lower nitrate level under wheat than under corn. Since the cultural treatments of the soil under these two crops are so widely different, these effects by wheat can scarcely be ascribed wholly to the crop, and raise a question as to the effects of the tillage operations on the accumulations of nitrates.

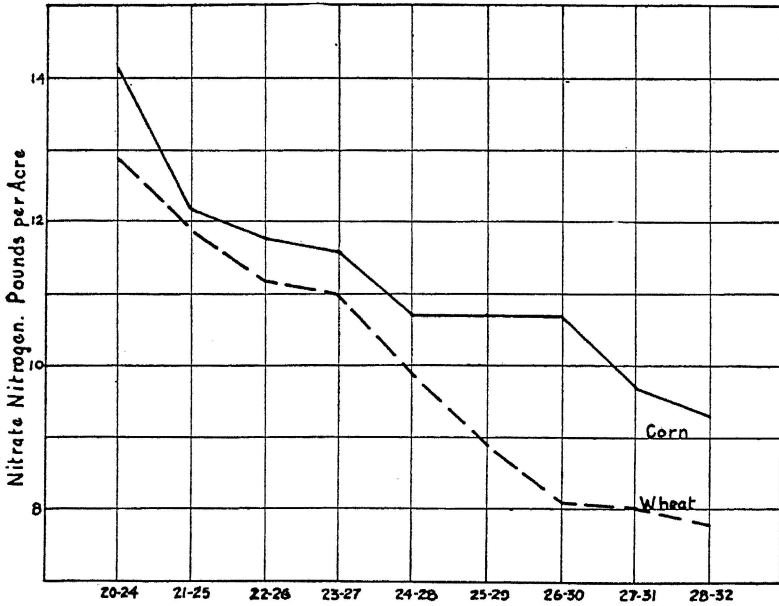


Fig. 4.—Nitrate nitrogen levels in the soil in wheat and in corn as advancing five year averages of the season.

Nitrates in the Soil as Influenced by Tillage.—*Turning with the Plow*—The tillage operations, both that of turning with the moldboard plow and that of surface cultivation, are the most influential soil treatments for nitrate increase. During the first six years, plots 1, 2 and 3 were designed to determine the influence of spring plowing and surface cultivation when all were grown to corn. As shown by the results given in Figure 5, the plowing of plot 2 increased the nitrate level

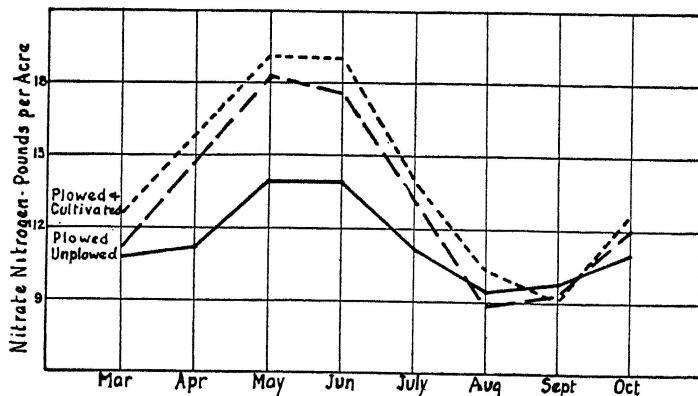


Fig. 5.—Levels of nitrate nitrogen during the growing season in the soil under corn as influenced by plowing and surface cultivation. (6 years).

markedly over plot 1, unplowed, especially during the growing season. From March to August the average difference was 2.16 pounds of nitrate nitrogen, while for the entire year this was 1.66 pounds. These differences reflected themselves in the yields of the corn crop. As a four year average this was 10.26 bushels per acre on the unplowed soil and 16.32 on that plowed and prepared but given no subsequent cultivation.

Surface Cultivation.—Surface cultivation added to spring plowing was additional means of increasing nitrate accumulation in the soil as is shown by the curves (Figure 5). Scraping with a hoe removed the weeds in the unplowed and plowed plots, while the plot given the surface cultivation, commonly given to corn, produced an increase of less than 1.0 pound of nitrate nitrogen for the surface tillage. The yields of corn on the plowed and scraped plot and on that plowed and cultivated, namely 16.32 and 23.33 bushels, respectively, as the five year average gave a difference of 7.0 bushels corresponding to this small nitrate increase or influence by surface cultivation.

In the fallow plots, Numbers 4 and 5, which differed from each other only by this surface cultivation, the effect of this treatment was

more marked. It manifested its effects particularly during the period June to October as given in Figure 6.

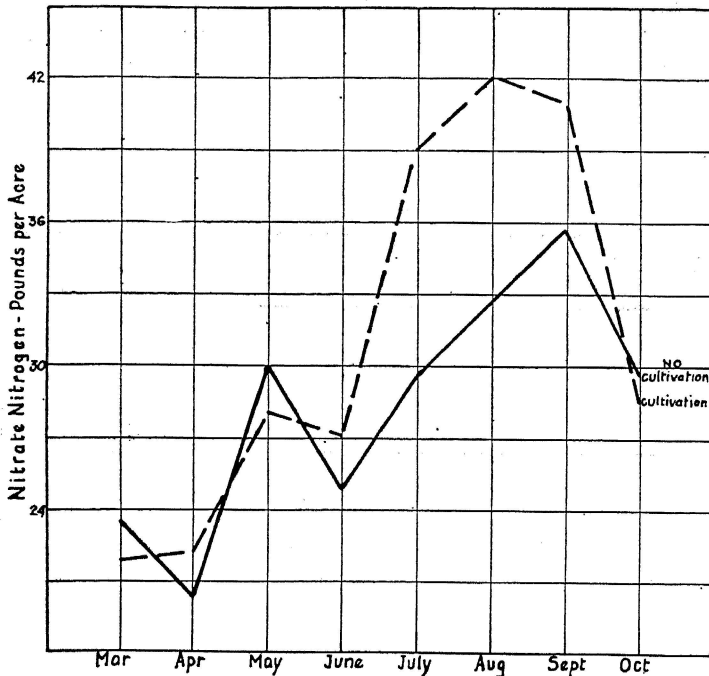


Fig. 6.—Levels of nitrate nitrogen during the growing season in the soil under fallow as influenced by surface cultivation (6 years).

That these differences were due to tillage is indicated by the nitrate levels of the last seven years when the tillage treatments were the same for these different plots. For the latter period of the study, the nitrate nitrogen curves of plots 1, 2 and 3 are shown in Figure 7, and are all in different order than during the preceding six years as given in Figure 5. Plot 1, which was fallowed during the second period, was slightly higher than plot 3. Plot 2, continuously cropped and untreated, was decidedly the lowest of all three plots, and stood but little below plot 1, except during July and August. During this latter period the plots reflected the effects of the fallowing and fertilizer treatments, when during the first six years they reflected the varied tillage treatments. It is interesting to note that the general level of the second period of seven years, fluctuated between three and fifteen pounds of

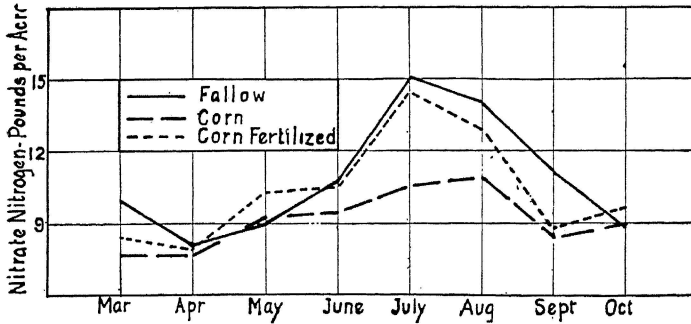


Fig. 7.—Levels of nitrate nitrogen during the growing season in soil given similar tillage treatment (7 years) following varied tillage treatments (6 years).

nitrogen per acre which was a level below that of the first six years. It points toward a decreasing nitrate nitrogen supply, as shown by graphs for plots 2 and 3 in corn included in Figure 4 as advancing five year averages. The corn crops on plots 2 and 3, which carried through both studies, and on plots 4 and 5 previously fallowed, are shown in Figures 8 and 8a, in one of the later years in the study.

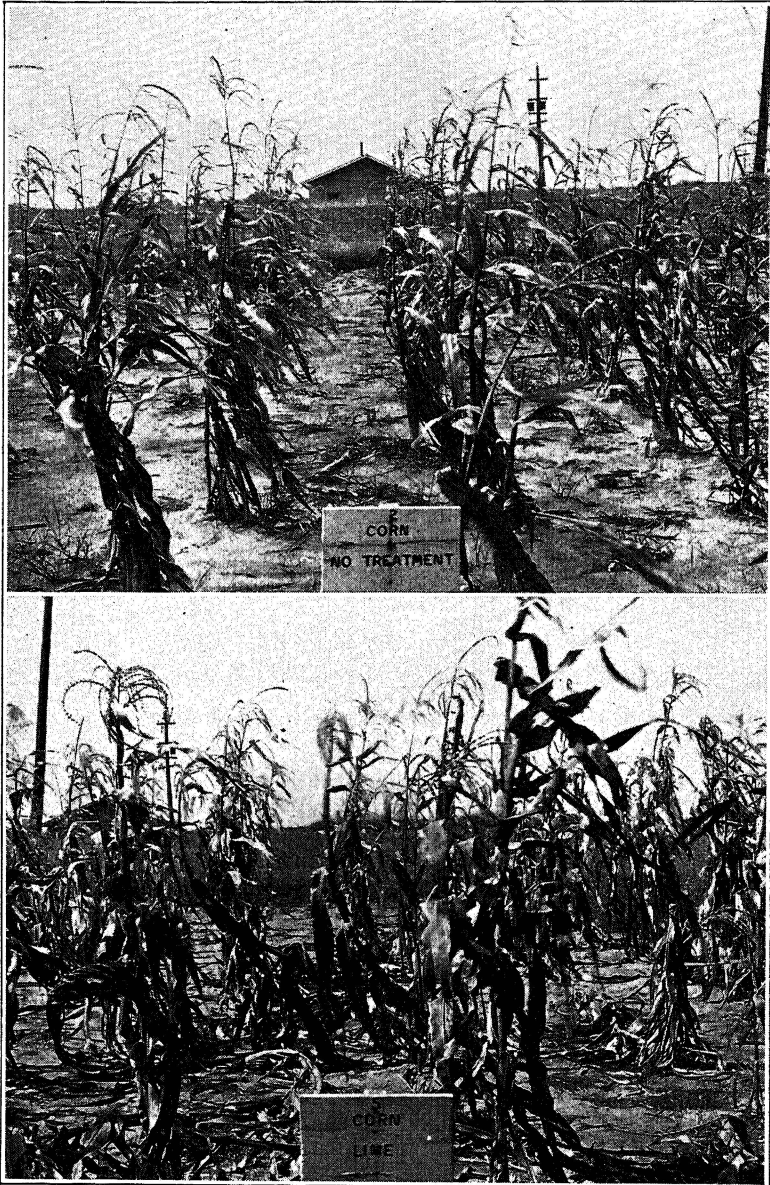


Fig. 8.—Corn crops in one of the later years of the study as they reflect the nitrate levels in the soil with different treatments. (No treatment, lime).



Fig. 8a.—Corn crops in one of the later years of the study as they reflect the nitrate levels in the soil with different treatments. (Nitrogen, lime and nitrogen).

Date of Fall Plowing.—The date at which the fall plowing is done for wheat emphasizes even more forcibly the influence of tillage on nitrate accumulation. These three plots were treated alike in all respects during the first six years, except that one was plowed on July 15, one on August 15, and one on September 15. The nitrate curves for the plots as given in Figure 9 reflect the importance of the date of

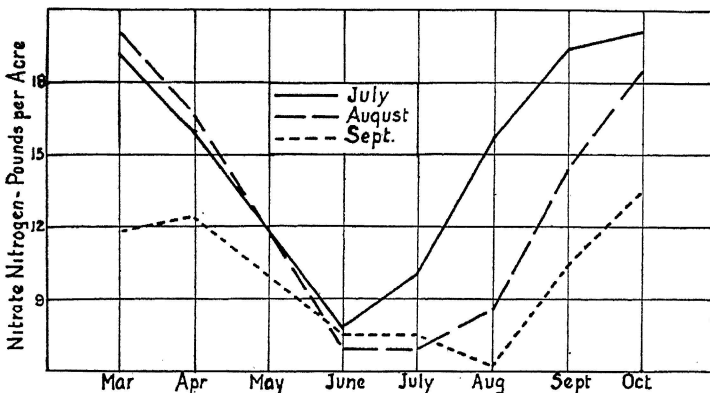


Fig. 9.—Nitrate nitrogen in the soil in wheat as influenced by the date of fall plowing (6 years).

plowing in giving added nitrate supply for the early October seeding of wheat. For this month the average figures for the nitrate nitrogen supply in the soil were 20, 18.5, and 13 pounds per acre according to July, August and September dates of plowing, respectively.

The increases in nitrates followed closely in each plot on the date of plowing as shown by the rise in the curve after the month in which the soil was turned. Counteracting this effect of plowing to increase the nitrates is the growth of the weeds on the unplowed soil to reduce them. More weeds grew on the plots as the plowing was delayed. This is shown in Figure 10. These differences in nitrates were reflected in the growth of the wheat crop illustrated in Figure 11, and in the five year average yields, which were 12.9, 12.5, and 8.1 bushels for July, August, and September plowing, respectively.

These same plots, Numbers 8, 9, and 10, when all were plowed at the same date (August 15) and given fertilizer treatments during the last seven years fail to reflect significant differences in nitrate content. The plot previously plowed in July was fertilized with nitrogen in the ammonium sulphate form, that plowed in August was given nitrogen and superphosphate, while the third one previously plowed in September was given nitrogen, phosphorus and potassium. Alongside these three plots, wheat was also grown with no treatment on the plot,

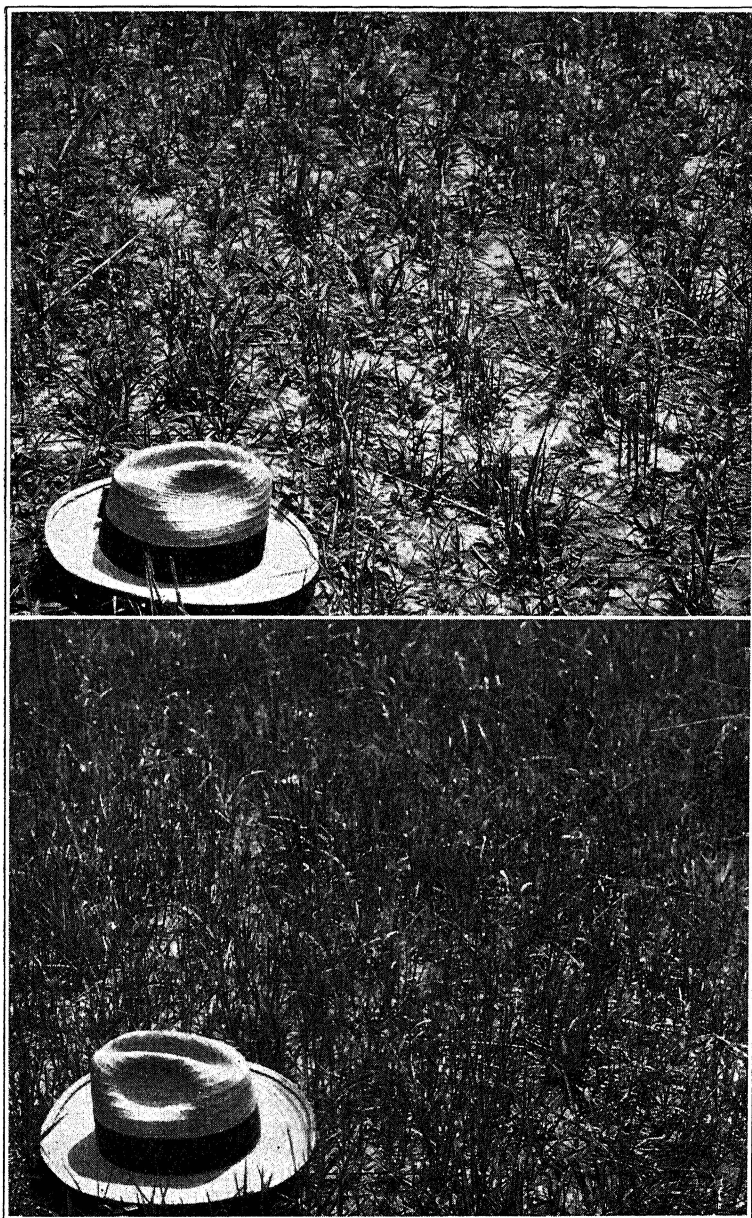


Fig. 10.—Differences in weeds in wheat stubble in July as a result of difference in time of fall plowing for the crop. (August 15, September 15, reading downward).

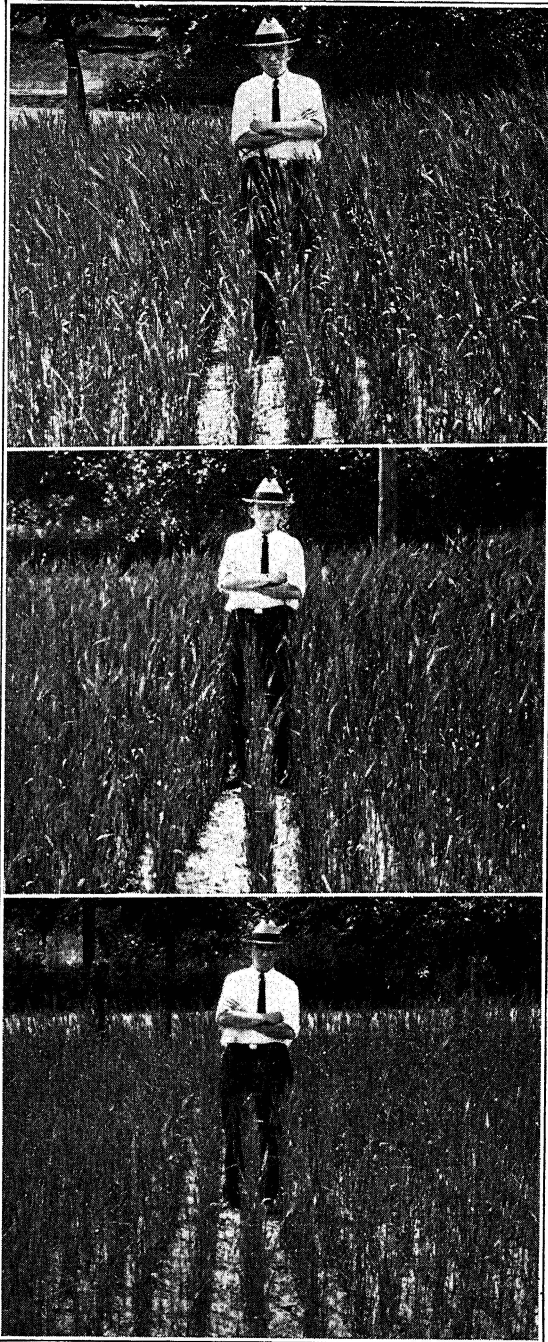


Fig. 11.—Differences in the wheat crop in response to different dates of plowing for the crop. (July 15, August 15, September 15, reading downward).

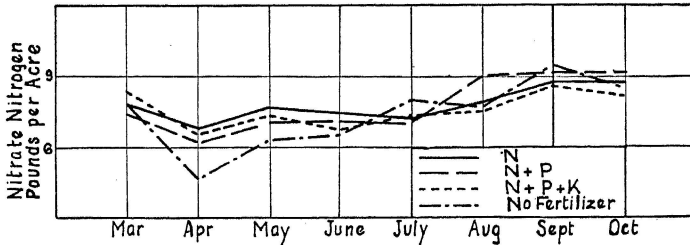


Fig. 12.—Levels of nitrate nitrogen during the growing season under wheat given similar tillage but different fertilizer treatments.

Number 11, previously kept in sod. These treatments do not reflect themselves as differences in the nitrate curves given in Figure 12. These curves are all very similar and at noticeably low levels, fluctuating between six and ten pounds of nitrogen per acre. The monthly averages for seven years, when added for the growing season March to October inclusive, were 62.6, 63.2, 61.5 and 60.6 pounds of nitrate nitrogen for plots 8, 9, 10, 11, respectively.

Fertilizer Treatments and Nitrates.—In case of both wheat and corn plots which reflected the influence of dates of plowing and types of tillage, respectively, in the first six years, the wheat plots showed little influence by fertilizer treatments during the second period and the corn plots, which previously reflected a distinct effect of tillage on nitrate accumulation reflected but slight effect of fertilizers on the nitrate supply. The influence of the fertilizers on nitrate residue seems insignificant, but it is impossible to say whether this low residual supply may not be due to a greater ability of the fertilized plots to exhaust the soil of this form of nitrogen. These corn plots maintained higher nitrate level at eight to fifteen pounds per acre in the last seven years than was the case of the wheat plots at six to ten pounds of nitrate nitrogen per acre. It is possible that the difference is due partly to the different abilities of these two crops to exhaust the nitrate nitrogen to a low level and to the additional cultivation given in the case of the corn. In spite of the nitrogenous fertilizers added, there was a decline of nitrates in the soil in the case of both crops as shown in Figure 4.

Straw Mulch and Nitrates—The detrimental influence of the straw mulch on the nitrate level is as pronounced as perhaps any single effect by a treatment. Two plots, Numbers 6 and 7, were uncropped during the first six years with a wheat straw mulch of two tons and six tons, respectively, applied in April after seedbed preparation. The low nitrate level, going with the heavier straw mulch, in particular, was

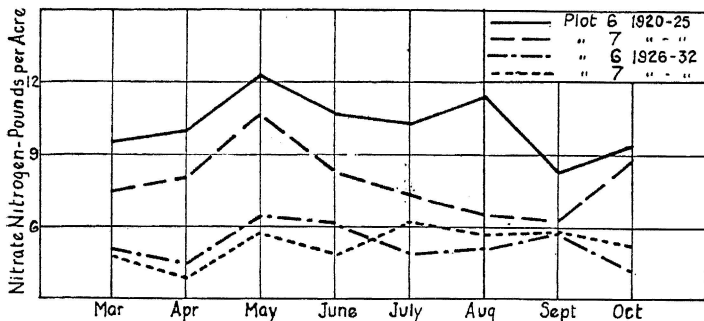


Fig. 13.—Nitrate nitrogen levels during the growing season under a straw mulch on fallow (6 years), and with green manure treatment on both fallow and corn (7 years). (1920-25. Plot 6, fallow, 2 tons straw mulch. Plot 7 fallow, 6 tons straw mulch. 1926-32. Plot 6, corn, green manure and 6 tons straw mulch. Plot 7, fallow, green manure and 6 tons straw mulch).

very noticeable during the first period as shown in Figure 13. In order to test the possibility of raising this by adding a nitrogen carrier there was turned under each spring during the last seven years, chopped sweet clover, equivalent to the rate of two tons per acre. One of the plots, Number 6, was also planted to corn.

The outstanding observation is the fact that during the second period of seven years the nitrate levels were still lower than during the first, regardless of the addition of the sweet clover. The plot under the mulch and growing the corn was slightly lower in nitrates from July to

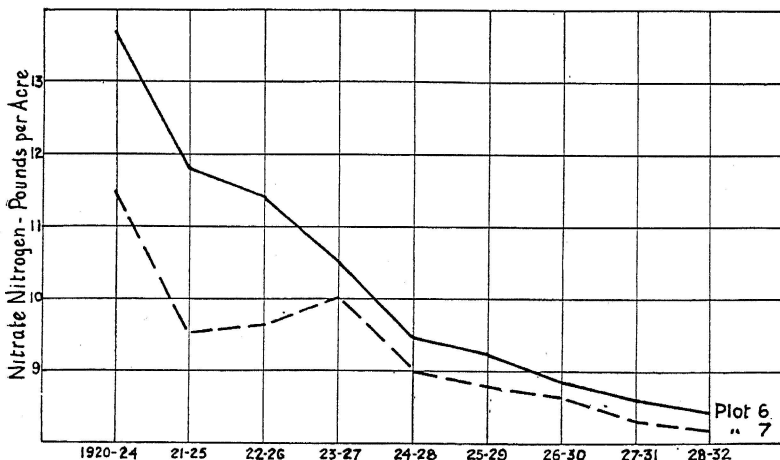


Fig. 14.—Levels of nitrate nitrogen during the growing season as advancing five year averages for fallow soil, unfertilized or given green manure and under straw mulch. (Plot 6, fallow under 2 tons straw mulch followed by corn with green manure and 6 tons straw mulch. Plot 7, fallow under 6 tons straw mulch followed by green manure and the same mulch.)

October in the average of the last seven years than the fallowed, mulched plot. But this difference seems insignificant since the two curves in the later period are very similar. In the curves of the advancing five year averages, Figure 14, these two plots are almost alike after the first three five-year periods. Their difference at the beginning was due to the lighter application of two tons of straw on plot 6 in contrast to six tons on plot 7. Further, both plots dropped in their nitrate levels whether under fallow or under corn, so that their lowest points were slightly below the low point of continuous unmulched corn, and slightly above the lowest point of continuous wheat (Figure 4). The ability of plot 6 to grow corn is illustrated in Figure 15, which may be contrasted with the crop in Figures 8 and 8a, showing the crop on unmulched soils at the same time.



Fig. 15.—The corn crop in one of the later years of the study on soil given green manure and straw mulch.

Determinations of ammonia nitrogen in these mulched soils at the same time that the nitrates were measured did not suggest excessive accumulations of this form of nitrogen. Rather, the low level of nitrates was due to the addition of organic matter of a wide carbon-nitrogen ratio (straw) and the consequent consumption of nitrate nitrogen by the soil micro-organisms. No complete report of the ammonia studies is included.

Crop Rotations and Nitrate Accumulation—Where the corn and legume rotation was the system of management, the nitrate accumulations during the last seven years were on the same general seasonal levels as where corn was cropped singly with the different fertilizer treatments. This was true whether the corn crop in the rotation was given 300 pounds of a 2-12-2 fertilizer, or whether it was omitted. The similarity of the seasonal nitrate levels in the rotation with these treatments as given in Figure 16 to those of plots in continuous corn is evident

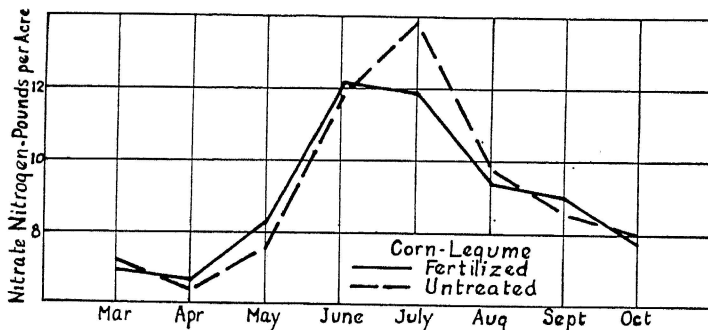


Fig. 16.—Seasonal nitrate levels in soil under a corn-legume rotation with and without fertilizer treatments.

by comparing this figure with Figure 5. There is a suggestion that the activity was somewhat different in July where no fertilizer was used, since the residual nitrogen as nitrate was higher in this month. There was a significant difference in the two curves only at this time, though the fertilized plot was higher in the early season and lower in the later season. It gives a suggestion that the fertilizer helped nitrate production early in the season, and encouraged more complete consumption of the nitrates by the crop later.

Since the crop yields in the rotation were larger than those in continuous cropping to corn, it is evident that this soil was delivering more nitrogen to the corn in this rotation. However, in both cases the corn was exhausting the nitrates to the lowest levels and since these levels of remaining nitrates are those measured, these residues of nitrogen

then may well correspond, irrespective of the larger amounts that may have been produced and removed from the soil by the higher corn yields in the case of the rotation.

In the rotation of corn, wheat and clover with the livestock and grain systems of farming, there again the two plots were very similar in their behavior. Since corn occurred only three times in each, and the wheat and clover each only twice during the seven years, it is scarcely advisable to separate these data according to the crops. Consequently, the data are plotted as averages for the seven years during the growing season as shown in Figure 17. The close similarity of these

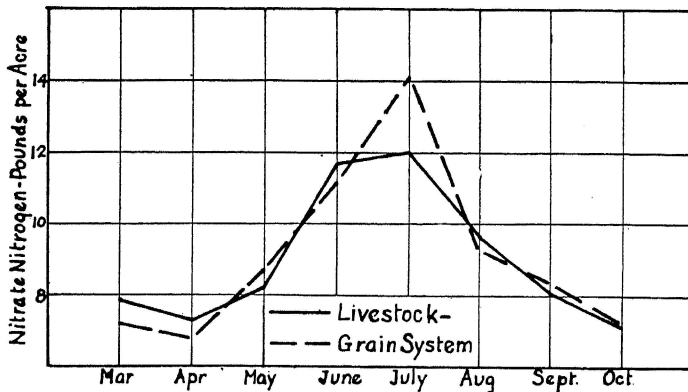
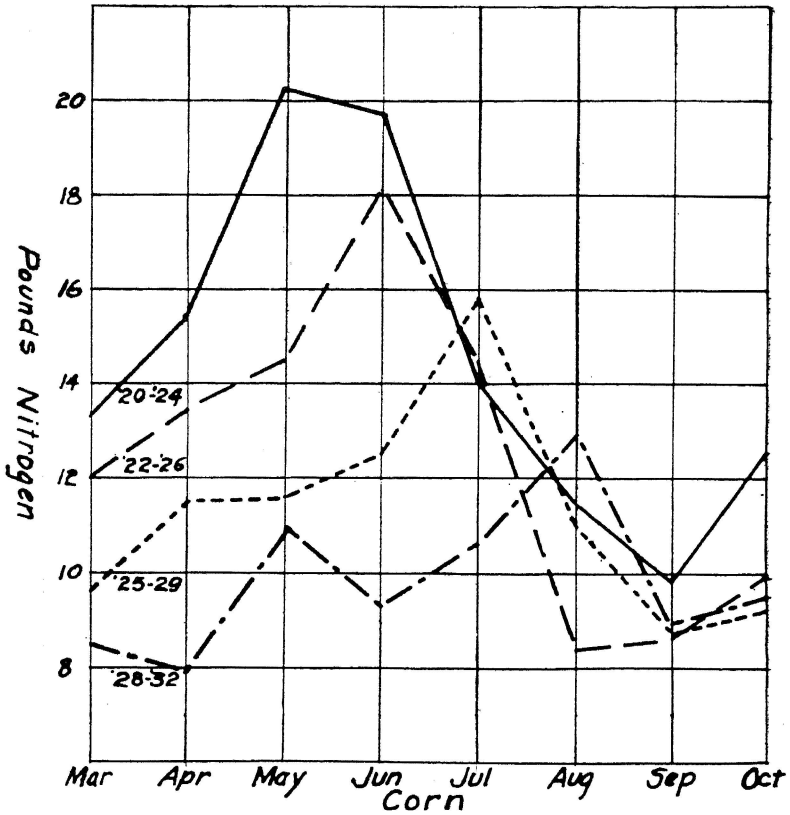


Fig. 17.—Nitrate levels in the soil under corn, wheat, clover rotation for the livestock and grain systems of soil treatment.

to those in the corn-legume rotation and to all the other corn crop curves is evident. Again, larger crops were produced but since only the residual nitrate at any one time was measured, no account is taken of the total nitrogen transformed as nitrates.

As was true for the corn-legume rotation, likewise in the three year rotation there was a higher accumulation of nitrates in July in one case than in the other. Here this occurred in the grain system of farming with its fertilizer treatment, while in the former case it was in the unfertilized soil. No significance can be attached to the fertilizer treatment as the cause of this condition, since fertilizer was applied in the grain system where the nitrates were high in July and was omitted in the other case where they were high in this month. Whether this larger amount of nitrate during this month in these two cases has any significant causal factor cannot be discovered from any evidence obtained thus far.

Soil Fertility Exhaustion Demonstrated—The advancing five year averages of nitrate levels show such a decided decline, (Figures 4 and



*Nitrate levels during the growing season
Five year averages*

Fig. 18.—Seasonal levels of nitrates under corn as averaged for different five-year periods showing the declining nitrate levels and later seasonal maxima with continued cropping.

14), that one can interpret such only as a lowered ability of this soil to deliver nitrates. This decline is more marked when the seasonal cycle of nitrates for succeeding years or some few of them in the succession of years are plotted together as for corn in Figure 18. Not only are the levels of nitrate lower with succeeding years of continued cropping, but the high point of the year is reached at a later date in the season. During the first five year period this high point under corn was reached in May, during the next five year period selected for two years later, this high point came in June, then in the next period later by three years than the second it advanced to July and in the last five year

period to August. Thus, as the cropping continued under continuous corn, this soil was able to deliver its maximum amount of soluble nitrogen only at a successively later date in the season and at successively lower levels. Curves plotted similarly for the soil in wheat and for that in fallow demonstrate lower levels corresponding to those for corn and emphasize the declining ability of this soil to deliver nitrates.

That this decline is in the fertility as well as in nitrates is further indicated in the results from the seeding of clovers on these soils after the study of nitrates ceased. These plots were treated with limestone, and this combined with phosphorus and with both phosphorus and potassium and seeded to a clover mixture. On the plots grown continuously to wheat previously, scattered stands of improved numbers of plants agreeing with the increased additions of fertilizer were obtained. But these numbers were still too insignificant to hold the clover crop. Only red clover plants were in the stands. No sweet clover plants were obtained in this area formerly in wheat.

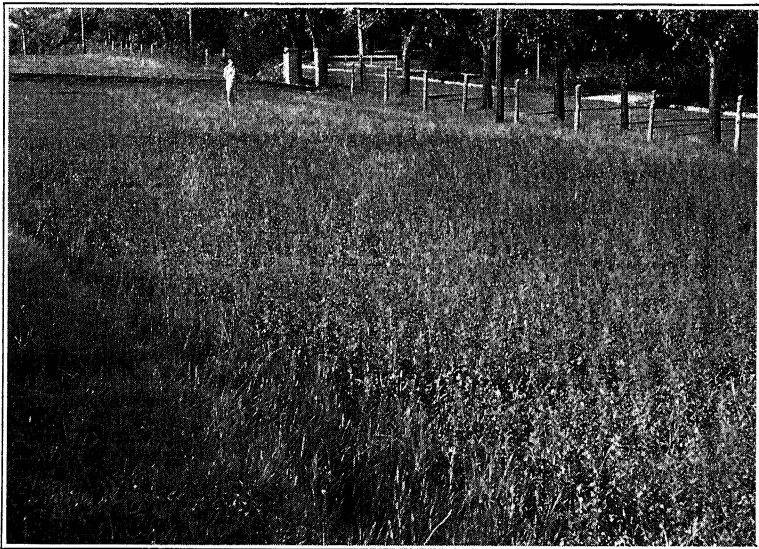


Fig. 19.—View of the plots on which the varying levels of nitrate nitrogen were revealed by differences in clover stands and other crops. In the foreground is seen the sweet clover stand after corn; in the background, sweet clover failure after wheat.

On the plots formerly fallowed, mulched, or grown to corn, the situation was quite different. There was no red clover, but a good stand of sweet clover was obtained. This improved with the limestone and fertilizer additions. The influence of lime additions was pronounced, especially those additions of limestone made during the period of



Fig. 20.—Difference in crops resulting from clover seeding. Sweet clover stand on plot (No. 7) fallowed and mulched in contrast to bracted plantain (*Plantago aristata*) on plot (No. 10) formerly in continuous wheat.

nitrate study. The plots formerly fallowed likewise reflected their higher fertility in better sweet clover because they had remained uncropped. The sweet clover crop on these plots was of such density and growth as to warrant its consideration as a fair crop in contrast to that on the former wheat plots which could in no way be so considered. Some suggestions as to these differences in fertility and clover crops may be obtained from the illustration Figure 19 representing the spring condition of the crop in the second year after the clover seeding, and two years after the close of the nitrate study. Figure 20 gives further detailed differences at the same time for one of the plots (Number 7) which was fallowed and given a straw mulch during the thirteen years; and one (Number 10) which had been in wheat continuously with August plowing and no fertilizer treatment for six years followed by similar plowing date and the additions of nitrogen and phosphorus as fertilizers. These clover crop differences reflect clearly the differences in fertility which were also reflected in the different levels of nitrate accumulation.

SUMMARY

In this study, measure was taken regularly of the accumulation of nitrates in the soil under different crops, different methods of tillage or cultivation, different fertilizer treatments and under the straw mulch. Such determinations do not measure the amount of nitrates produced or removed, but rather the nitrate level at which the production of nitrates is temporarily balanced against their consumption by the plants as the crop above the soil or by the nitrate consuming micro-organisms within it. They measure, however, the lowest level to which the supply in the soil can be, or is, exhausted by the crops or by leaching, and the heights to which the accumulation may mount against, or in absence of, these reducing forces.

That the crop is a significant factor in removing the nitrates is shown by the lower nitrate accumulation in the cropped soil in contrast to that in the fallowed soil. Without the crop the seasonal nitrate nitrogen levels fluctuated from approximately 21 pounds at the lower level to 42 pounds as the upper figure. For the crops, their exhaustion of the nitrates was very similar whether grass, corn, or wheat. The similarity was greatest between wheat and grass whose average lower levels were the same at 6 pounds and upper levels also alike at 12 pounds.

For corn the two corresponding figures were each two pounds higher at 8 and 14 pounds, respectively. These facts demonstrate clearly that nitrates accumulate in the fallow soil and are removed by the crops to a degree closely similar for the same soil regardless of the crop.

The accumulation of nitrates follows seasonal conditions closely. With the advent of spring the nitrates in the soil increase and show that this process like any other biochemical soil process is subject to the moisture level and the prevailing seasonal temperature. It is set to agree closely in its activity with that of the growing crop.

Soil tillage is a beneficial soil treatment because of its effect in bringing about an increased supply of available nitrogen or nitrate for the crop growing on the soils. Turning the soil with the moldboard plow is the foremost tillage performance to increase nitrate production. Surface cultivation likewise stimulates nitrate production. Plowing is effective whether the soil is tilled in the spring, April, or in the later summer months of July, August and September. These differences in nitrates would lead one to believe they suggest that plowing and tillage are not fully appreciated for their effects on this process of transforming soil nitrogen into the nitrate or soluble nitrogen form.

Fertilizers did not bring about any great change in the level to which nitrates were exhausted. Their effects were generally unnoticed in terms of the measurement of the nitrate nitrogen supply on the soil though there were suggestions that they encouraged early season nitrate accumulations and aided in the late season nitrate removals. These were but suggestions by small differences in no way commensurate with the differences in the crop yields from fertilizer use. This study did not measure the possible increase in total nitrate production from fertilizer use, but only the accumulated level, hence such items as the influence of fertilizer on total nitrate production could not be determined. Perhaps heavier additions of fertilizer are necessary to raise the level above that found in these trials.

The most detrimental effect to nitrate accumulation in a fallow soil in these studies was manifested by the straw mulch. Under the application of six tons of straw per acre, the fallow soil failed to accumulate nitrates above the levels common in soils growing crops. This effect was not overcome when nitrogenous green manures were turned under in the form of sweet clover. The growth of corn in the straw mulched soil was, however, the equivalent of that on unmulched soils where higher accumulations of nitrate occurred.

Whether continuous cropping or crop rotation was practiced, the level of nitrate nitrogen under the same crop was but little disturbed as a general average. The nitrates under corn continuously were closely similar to those under corn alternated with a legume crop; to those under corn in a three year rotation handled as a livestock system of farming, and to those under the grain system of soil management. This suggests that these different systems like fertilizing are not reflected in raising or lowering the levels at which there is the equilibrium between production and exhaustion of the nitrate in a soil at any one time. In all these cases of different cropping systems the soil was holding the nitrate level to about the same number of pounds per acre. This suggests that the crops were reducing it to the limit which was a constant for this soil and the particular crops, whether in a rotation or continuous sequence.

Perhaps the most noticeable feature of the nitrate levels observed in this soil was the decline of the levels with time. Under the wheat or under the corn, and likewise under the fallow soils, both mulched and unmulched, the nitrate levels observed were lower as the years of the study advanced. This points forcibly to the decline in ability of this soil to deliver nitrates early in the season and at high levels as cropping continued. These levels had fallen so low that it was difficult to establish

sod legumes such as red clover and sweet clover on these soils even with an application of finely ground limestone and commercial fertilizer. These declines represented reductions in levels as much as 50 per cent and should direct our attention to the significant speed at which the soil's power to produce nitrates is being depleted when such reductions occur within a period as brief as 13 years.