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Nitrate Production as Affected by Grain-Crop Residues on the Surface of the Soil

T. M. McCalla and J. C. Russel [1]

THE influence of crop residues on soil nitrates where plant materials are worked into the soil has been extensively investigated. In comparison, the effects on soil nitrates of residues on the surface are relatively unknown, except where heavy mulches have been used. A need for information arises because of a new system of cultivation known as subsurface tillage (5)[2] in which soil is pulverized without inversion, and residues are left above ground. The use of this method has been confined largely to regions of limited rainfall. The object of maintaining residues on the surface has been primarily for soil moisture conservation and erosion control. In this system it is generally those residues that are produced on the land that are retained on the surface. Therefore, only light mulches of one to four tons per acre are likely to be used. They may be composed of any type of farm by-products such as straw, stalks, manure, weeds, or legume material.

Residues left on the surface, through their tendency to keep soil cool, may diminish the rates at which nitrates are produced. However, there are occasions when soils get too hot for maximum nitrification, and then a lowering of the temperature would be beneficial. Through their tendency to keep the surface soil moist, residues on the surface at times may maintain a higher rate of nitrate production than will bare soil, but if the soil should remain wet for a long period the rate may be reduced. Nitrifying organisms require aeration, and one of the notable effects of residues on the surface is that they tend to keep the surface soil loose and open. Thus they may increase nitrate production during periods when exposed soil is compacted and sealed by dashing rains. If materials of low C/N (carbon-nitrogen) ratio are plowed under they may decay too rapidly for the most effective use of the nitrate produced, whereas materials of high C/N ratio may depress nitrate production or cause a disappearance of nitrates already present. If residues are left on the surface, both of these disadvantages possibly may be avoided through slower decomposition or through a less intimate contact of highly carbonaceous material with soil nitrates and nitrifying organisms. Obviously, no definite conclusions can be drawn about nitrate production under subsurface tillage practices without the evidence of actual field experiments.

The purpose of this bulletin is to present the data on nitrate contents and nitrate production in tests where straw or stalk residues were left on the surface through subsurface tillage, as compared with check treatments where these

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[2] Figures in parenthesis refer to "Literature Cited," page 21.

residues were plowed under or were absent. Nine of these tests were at Lincoln, Nebraska, and one was at the Hastings, Nebraska, Hydrological Project. Two tests were conducted in 1939, four in 1941, and four in 1942.

Review of Literature

THERE have been few studies of nitrates reported that relate directly to the use of residues as discussed in this bulletin. Scott (10) conducted an experiment at Manhattan, Kansas, in 1915–16 in which straw was applied at rates of two and four tons per acre to uncropped land, and to wheat as a winter top-dressing. The applications were made in November and nitrates were determined at intervals during the following spring and summer. Scott was concerned primarily in an explanation of the adverse effects of straw applied to growing wheat, and he displayed his data to emphasize nitrate contents in the surface soil rather than total nitrate production. He noted that the nitrates in the uncropped land were low throughout the spring and summer as a result of a 4-ton treatment, but were not appreciably decreased by a 2-ton treatment. He offered no explanation for nitrate fluctuations but gave precipitation data which indicate strong possibilities of downward leaching beyond the 3-foot depth of nitrate sampling. The top-dressings on winter wheat produced symptoms of nitrate deficiency the following spring, and reduced the yields under conditions where nitrates were low to medium at seeding time, but did not reduce yields where nitrates at seeding time were high.

Jones (6) conducted tests at Lincoln, Nebraska, during 1923–24 in which straw was applied to growing wheat in early April of one season at the rate of four tons per acre, and in January of another season at the rate of two tons per acre. Nitrates and soil moisture were determined at frequent intervals up to and including the date of harvest, and the crop was analyzed for nitrogen in order to account as completely as possible for all nitrate production. The 4-ton application produced decided symptoms of nitrate deficiency and reduced the soil nitrate contents, the total nitrate production, and yield. The 2-ton application had no detrimental effects. The weather conditions during these tests were not such as to produce any loss of nitrates through leaching beyond the 2-foot depth of nitrate sampling. The results of this investigation are not generally accessible, and the following is presented as a brief summary:

Season of test	Top-dressing of straw per acre	Yield per acre	Nitrogen removed per acre in crop*	Nitrate-nitrogen in soil to a depth of 2 feet		Computed nitrate-nitrogen production‡
				Initial†	Final	
	tons	*bu.*	*lbs.*	*lbs. per A.*	*lbs. per A.*	*lbs. per A.*
1923	4	9.8	26.6	30.6	12.7	8.7
	0	18.6	40.9	30.6	13.0	23.3
1924	2	23.4	35.5	22.9	6.4	19.0
	0	23.4	36.1	27.8	7.3	15.6

* Grain and straw, but not roots.

† Determined the first week in April before wheat had made any appreciable growth.

‡ Nitrogen removed in crop plus final nitrate-nitrogen in the soil minus the initial nitrate-nitrogen.

Albrecht et al (1, 2) at Missouri reported that nitrate accumulation on uncropped land to a depth of seven inches was decidedly depressed by 8-ton mulches of straw. This depression was attributed mainly to a persistently high moisture content and lack of aeration, and in a lesser degree to a reduced soil temperature.

Beaumont and associates (3, 4, 8) at Massachusetts found increased nitrate production in mulched orchards where six to eight tons of straw and hay were applied annually and allowed to decay in place. The increased nitrates came largely from the decayed material in contact with the soil.

Numerous other investigators have studied nitrate conditions under mulches for horticultural crops in which nitrate conditions have been reported, but the large quantities of material employed, the lack of tillage, and the possibility that nitrates were leached beyond the shallow depths of sampling, render them incomparable with the tests reported in this bulletin.

Experimental Methods

Description of Soil. The studies reported in this paper were conducted mainly at Lincoln, Nebraska, on Marshall silty clay loam that has been under cultivation for about 60 years.[1] Its texture and fertility are fairly typical of eastern Nebraska conditions. It has ample available potassium but responds occasionally to phosphorus fertilizer. It has a pH of about 5.4 to 5.7 but no consistent need for lime. Its nitrogen and organic matter contents are about 0.17 per cent and 3.4 per cent respectively in the 0–6-inch section. These percentages are about one-third less than those of the original virgin soil. In the management of this soil the problems of primary concern are moisture conservation and erosion control, together with nitrogen maintenance and nitrification. The mean annual precipitation is approximately 27 inches. About 22 inches of this comes during the period April to September. Limited studies were made at the Hastings Hydrological Station on soil classified as Hastings silt loam.

Plots Used. The plots used in this investigation were established mainly for the study of crop residues on the surface in relation to erosion, moisture storage, and crop yields. As a rule, they were triplicated and randomized and were subjected to the usual operations of tillage and cropping, including subsurface tillage. Except for a few data accumulated in 1939, the nitrification studies in connection with these plots were not begun until June, 1941.

Nitrate Determinations. The sampling for nitrates was done with tubes at depth intervals of 0–0.5, 0.5–1.0, 2, 3, 4, 5, and 6 feet. Each plot was sampled at four systematic locations and the four cores composited. At each of the four locations three cores were taken for the 0–0.5-foot section and 12 cores were composited. Nitrates were determined by the phenoldisulphonic acid technique of the Nebraska Station (9), using duplicate 100-gram portions of soil as it came from the field, except for screening and mixing.[2] Nitrate contents were

[1] Publications previous to 1935 identify this undulating upland soil at Lincoln as Carrington series.

[2] Where analyses could not be made the same day that samples were taken, biological activity was suspended as regards nitrates by refrigerator storage, except for samples in 1939 which were air dried before analysis.

computed as parts per million of nitrate-nitrogen and were converted to pounds per acre by use of factors based on actual volume weights.[1]

Results

Nitrates Under Straw Mulches Applied to Corn

A FIELD of surface-planted corn on residue-free plowed land had been mulched between the rows with straw shortly after planting, at rates of 0, 2, 4, and 8 tons per acre. Nitrates were determined under these treatments on three occasions. The data are shown in Table 1.

Table 1. Effect of straw mulch applied at various rates upon the nitrate-nitrogen content* in pounds per acre of corn plots at successive intervals, 1941–1942.

Straw per acre†	Depth of sampling (feet)			
	0–0.5	0–1	0–3	0–6
tons	*lbs.*	*lbs.*	*lbs.*	*lbs.*
		July 3, 1941		
0	28.6	38.4	68.3	...
2	21.6	40.3	69.0	...
4	21.1	38.7	66.5	...
8	31.7	48.4	76.2	...
		December 9, 1941		
0	29.0	57.8	124.7	152.1
2	21.8	49.6	102.7	131.2
4	21.0	44.7	104.5	151.0
8	14.7	37.7	81.9	111.9
		April 2, 1942		
0	5.9	14.8	69.0	135.1
2	6.9	14.2	46.2	118.8
4	5.4	11.5	38.7	98.1
8	5.3	10.5	33.8	78.1

* Averages of three plots.
† Straw was applied between rows at time of planting, June 5. The plots having 0-, 2-, and 4-ton applications were cultivated twice with large sweeps. Those with eight tons were not cultivated but remained practically free of weeds.

The quantities of nitrates in the upper three feet of soil at the July 3 sampling were fairly similar in all plots and were sufficient to produce a fair crop without any further nitrification. At the time of this sampling the mulches had been in place for four weeks and there had been only one rain of any consequence. The rain, 1.07 inches on June 7, may have produced some leaching of nitrates into but not beyond the second six inches. The nitrate conditions when the mulches were applied were not known, but presumably they were fairly uniform.

The nitrates of the December 9 sampling under the various treatments were highest in total to a depth of six feet where no straw had been applied

[1] The mean weights of cultivated Marshall silty clay loam at Lincoln, Nebraska, for 0–0.5, 0.5–1.0, 2, 3, 4, 5, and 6 feet depth intervals in millions of pounds per acre are 1.60, 1.78, 3.98, 4.20, 3.92, 3.89, and 3.73, respectively.

and were the least under the 8-ton mulch. Nitrates had continued to develop beyond crop requirements all through the summer. Beginning in October, there were rains that had leached these nitrates downward. At the time of the December sampling there was evidence in the distribution of both moisture and nitrate-nitrogen in the profile that leaching in the three unmulched plots had extended into but not beyond the third foot. In the plots with two and four tons of straw there was evidence of leaching into the third and fourth foot sections but not beyond the fifth foot. Under the 8-ton treatment there was movement of moisture beyond the sixth-foot level in one plot. Heavier crops were produced on the mulched plots, hence there were also nitrate absorption differences to be taken into consideration.

Computations based on crop yields show a probable absorption of 63, 70, 68, and 89 pounds of nitrogen per acre for production of grain, stover, and roots under the 0-, 2-, 4-, and 8-ton treatments, respectively. Adding these quantities to the December data, it appears that there were only five pounds less nitrate-nitrogen produced under the 2- and 4-ton mulches as a mean of the two treatments, than under the checks, which amount was not significant. On the 8-ton mulch plots there are 15 pounds of nitrate-nitrogen to be accounted for either by leaching, or by nitrate depression at some time during the season.[1] Apparently it is not unreasonable to conclude that nitrates developed practically as abundantly during the period July to December under the straw mulches applied to corn as under unmulched conditions.

A short time previous to the December sampling, all cornstalks had been cut and removed. At sampling time decomposition studies were made (7) which indicated that approximately one-third, one-half, and two-thirds of the original 2-, 4-, and 8-ton straw applications still persisted. A few days later snow came, and from then until the middle of March the plots were buried a large part of the time under a few inches to a foot of snow. Late March was cool but not excessively wet. It was after such conditions as these that the April data of Table 1 were obtained.

Viewing these data solely from the standpoint of quantity of nitrates at various depths, it would seem that the several mulches were detrimental to nitrate conditions somewhat in proportion to the amount of straw applied. During the December to April interval, nitrates had moved downward along with the descent of water and for that reason had decreased in quantity at every depth above the third foot (Fig. 1). These had accumulated largely in the lower three feet, but some nitrates undoubtedly escaped beyond the 6-foot depth of sampling. If there had been less precipitation during the fall and winter, which would have been a more nearly normal condition at Lincoln, all of these nitrates might have been found at higher levels in the profile.

In addition to the nitrate studies, soil temperatures at 1- and 4-inch depths were observed at occasional intervals from June to April. Frequently, at midday during the summer, depressions of as much as 10° to 20° C. were noted under the 8-ton mulch as compared with the temperatures of the unmulched

[1] This 15-pound quantity is only seven per cent of the total N involved (including N in crop) and is not statistically significant. The highest and lowest nitrate contents of all plots and the widest variation among individual plots occurred under this 8-ton treatment.

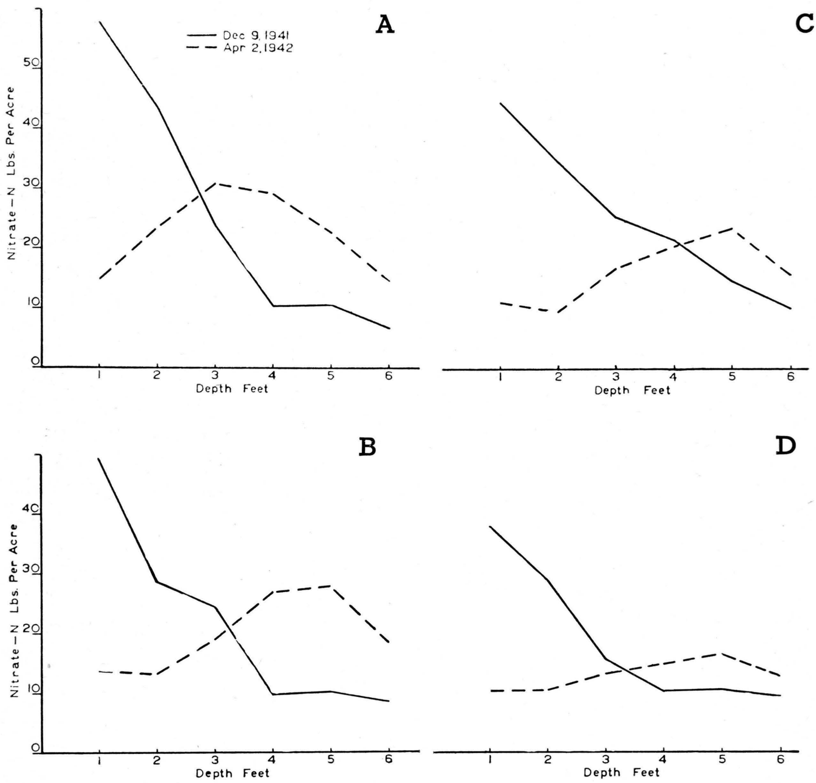

Figure 1. The profile distribution of nitrate-nitrogen on straw-mulched corn land in December and April: A, No straw; B, 2-T straw; C, 4-T straw; D, 8-T straw.

soil. This, of course, would be a depressive factor in nitrate production except that the temperature of the unmulched soil was in excess of the optimum about as often as the temperature of the mulched soil was below the optimum. Also, the disadvantages to nitrification due to low temperatures under the 8-ton mulch were generally offset by more favorable moisture conditions.

There was one period during the early summer when corn on the 8-ton plots had all the appearance of nitrogen deficiency (Fig. 2). This condition began with a general retardation of growth, particularly a slimness of stalk, shortly after straw was applied. Gradually the leaves became spindly and chlorotic. Tissue tests on July 10 showed ample nitrates. On July 3 the soil contained 31.7 and 16.7 pounds per acre of nitrate-nitrogen in the 0–0.5 and 0.5–1.0 foot sections, respectively. Obviously, the chlorotic condition was not due to nitrate deficiency. In mid-August, about the time that the crop on unmulched plots showed symptoms of drought, the chlorotic condition disappeared and growth thereafter became generally luxuriant and vigorous. The final yield was 13 per cent more grain and 34 per cent more stover than was obtained on the untreated checks. The corn on the 2-ton straw plots grew

Figure 2. A temporary chlorotic condition of corn growing on a plot mulched with eight tons of straw per acre. Soil analyses and plant tissue tests showed that it was not a nitrate deficiency. The corn gradually improved from the date of this view (July 3, 1941) and finally outyielded the cultivated unmulched corn adjacent.

normally at all stages. That on the 4-ton plots was slightly retarded in growth early in the season but never became notably yellow. These effects of mulches on corn in 1941 were of the same character as in three previous years of this experiment, except that the yellowness of foliage on the 8-ton mulched plots was more extreme than in previous years.

Nitrates Under Straw Residues Subtilled for Sorghum

A group of stubble plots of uniform tillage and crop treatment throughout two previous years had been top-dressed with fresh straw on May 16 at the rate of 1.5 tons per acre as a supplement to a few hundred pounds of stubble that had existed through the winter. Three plots were subtilled immediately and three were plowed, in preparation for sorghum. An initial set of nitrate samples was taken on June 2, just before the crop was planted, and another

Table 2. Nitrate-nitrogen content in pounds per acre of sorghum plots with straw residues on the surface and plowed under. The data are means of triplicated randomized plots.

Treatment	Depth of sampling (feet)			
	0–0.5	0–1	0–3	0–6
	lbs.	*lbs.*	*lbs.*	*lbs.*
June 2, 1942				
Straw on surface, subtilled	14.7	24.3	45.5	69.8
Straw plowed under	10.4	15.6	29.1	45.6
July 9, 1942				
Straw on surface, subtilled	39.2	59.5	90.4	127.8
Straw plowed under	30.6	52.5	79.7	106.3

taken on July 9, before the sorghum was six inches tall. The nitrate contents of the soil at the two sampling dates are shown in Table 2.

During the interval June 2 to July 9, nitrates developed extensively and to an almost identical extent under both treatments. For the two treatments, straw on the surface and plowed under, the increases to a depth of one foot were 35.2 and 36.9 pounds of nitrate-nitrogen per acre, respectively. To a depth of six feet the increases were 58.0 and 60.7 pounds of nitrate-nitrogen per acre, respectively.

Nitrates Under Subsurface Tillage Fallow

A summer fallow experiment that has been in progress at Lincoln since 1939 and more recently duplicated at the Hastings Hydrological Project[1] includes four plots with one, two, two, and four tons of straw per acre left on the surface, two plots with two tons of straw per acre initially incorporated with the soil by disking or plowing, and two plots initially disked or plowed without residue treatment. The fallow period extends from April to September. Tillage to keep the land free of weeds throughout the summer is done with a subsurface tiller on the first four plots and with a disk on the second four plots. During two years of this experiment, nitrates have been determined just prior to the seeding of winter wheat.

Table 3. Nitrate-nitrogen in pounds per acre at winter wheat seeding time on summer fallow plots.

Treatment	Depth of sampling (feet)			
	0–0.5	0–1	0–3	0–6
	lbs.	*lbs.*	*lbs.*	*lbs*
*September 27, 1939—Lincoln**				
Residues on the surface, subtilled	68.0	92.9	225.5	325.1
Residues incorporated, plowed or disked	121.9	144.3	302.8	346.6
No residues, plowed or disked	117.1	147.5	309.3	359.7
September 11, 1941—Lincoln				
Residues on the surface, subtilled	48.6	67.8	156.5	242.9
Residues incorporated, plowed or disked	65.6	88.2	164.4	287.5
No residues, plowed or disked	68.3	87.2	200.8	283.7
September 17, 1941—Hastings Hydrological Project				
Residues on the surface, subtilled	47.6	65.5	126.1	171.4
Residues incorporated, plowed or disked	76.2	94.7	169.4	243.0
No residues, plowed or disked	52.1	71.2	143.1	194.4

* The writers are indebted to H. W. Smith, instructor in soils, for making the nitrate analyses in 1939.

In the two years of test (1939 and 1941) at Lincoln and one year at the Hastings Hydrological Project, nitrate contents were lower at all depths at wheat seeding time (Table 3) under the method of subsurface tillage with residues on the surface than under either of the other methods. There was no

[1] The Hastings experimental plots were on an eroded eight per cent slope that contained about two-thirds the organic matter and nitrogen of the Lincoln site.

leaching beyond the sixth foot in any of the plots, and initial conditions presumably were uniform,[1] hence the totals to a depth of six feet can be regarded as the ranking of the three treatments with respect to nitrate production. Although nitrates apparently were produced at a somewhat slower rate under subsurface tillage than under the other two treatments, the quantities at seeding time were fully adequate for the crops of wheat which followed, without further accumulation after the date of seeding. The larger quantities under the other two methods of tillage were simply in excess of crop needs. They were not detrimental in any way, but they did not increase yield. The highest yields were on the subsurface tillage treatments.

Figure 3. Continuous corn plots in early April 1942, showing stalks freshly subtilled (right) and plowed under (left) as preliminary operations for corn, oats, and summer fallow.

Nitrates in Three Winter Wheat Seedbeds

In a subsurface tillage experiment with continuous row crop, the stalks of three consecutive crops of corn had been left on the surface in one group of uniformly managed plots and had been plowed under in another group (Fig. 3). In the spring of 1942, two plots of each treatment were diverted to summer fallow and four of each to oats. After harvest two each of the two sets of oats plots were subtilled and two were plowed. In the fall of 1942, the summer fallow and oats plots, and two plots of each treatment that had been continued in corn, were seeded to winter wheat. Samples for nitrates were taken from the summer fallow plots in the spring and at two intervals during the summer, then at wheat seeding time all plots were sampled. The summer fallow plots were located in such manner relative to the others that their initial

[1] Oats with an after-crop of weeds, and wheat with an after-crop of sudan grass preceded the 1939 and 1941 tests at Lincoln, and sorghum preceded the 1941 test at Hastings. Under these conditions, the nitrate contents to a depth of at least four feet undoubtedly were low when fallowing was begun in April.

sampling sufficed for all. The nitrate data are presented in Tables 4, 5, and 6.

Summer Fallow. At the initial sampling on April 16 (Table 4), the nitrates were lower in quantity at every depth where stalks had been subtilled than where they had been plowed under. From the second foot downward under subsurface tillage the amounts increased progressively with depth to a maximum in the sixth foot. Under plowing, zones of high nitrate content occurred in the third and the fifth feet. These nitrate distributions in the profile suggest over-winter leaching under both treatments, but of more extensive degree under subsurface tillage than under plowing. Moisture samples showed that both treatments were wet to field-carrying capacity to the full 6-foot depth of sampling, with a tendency toward dryness at the top of the seventh foot where stalks had been plowed under, indicating that the infiltration had been less than under subsurface tillage.

At the time of the second sampling (May 28) nitrates had increased in the top foot, but had decreased at depths below in a manner suggestive of leaching

Table 4. Nitrate-nitrogen in pounds per acre in summer fallow following three crops of corn with stalks left on the surface or plowed under, and gains or losses in nitrate-nitrogen during intervals between four dates of sampling. The data are means of duplicate plots.

Disposition of stalks *	Depth of sampling (feet)									
	0–0.5	0.5–1	2	3	4	5	6	0–1	0–3	0–6
	lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*
				April 16, 1942—Initial sampling						
Subtilled	8.6	6.9	14.7	21.0	26.3	28.8	30.2	15.5	51.2	136.5
Plowed under	11.2	11.0	29.9	44.1	31.8	49.0	32.8	22.2	96.2	209.8
				May 28, 1942						
Subtilled	16.2	6.2	12.7	13.9	14.1	20.6	31.7	22.4	49.0	115.4
Plowed under	23.2	19.9	25.5	26.0	24.3	35.4	40.7	43.1	94.6	195.0
				July 1, 1942						
Subtilled	32.3	20.3	37.8	25.6	31.0	32.3	31.0	52.6	116.0	210.3
Plowed under	30.7	26.7	34.2	24.4	31.4	42.0	54.8	57.4	116.0	244.2
				September 30, 1942—Wheat seeding time						
Subtilled	7.8	21.5	26.7	12.6	9.0	8.9	10.8	29.3	68.6	97.3
Plowed under	13.1	22.1	37.0	14.3	14.5	19.1	16.4	35.2	86.5	136.5
				Gains or losses during intervals between samplings						
April 16—May 28, 1942			Stalks subtilled					6.9	−2.2	−21.1
Rainfall, 4.97 inches			Stalks plowed under					20.9	−1.6	−14.8
May 28—July 1, 1942			Stalks subtilled					30.2	67.0	94.9
Rainfall, 4.05 inches			Stalks plowed under					14.3	21.4	49.2
July 1—Sept. 30, 1942			Stalks subtilled					−23.3	−47.4	−113.0
Rainfall, 8.70 inches			Stalks plowed under					−22.2	−30.0	−107.7
April 16—Sept. 30, 1942			Stalks subtilled					13.8	17.4	−39.2
Rainfall, 17.72 inches			Stalks plowed under					13.0	9.7	−73.3

* The stalk growth of 1941 was 2,655 pounds per acre on subtilled land and 1,995 pounds per acre on plowed land. Stalks in 1939 and 1940 had averaged about 2,000 pounds per acre. On the subsurface tillage plots remnants of these still persisted.

beyond the depth of sampling. The net result was a loss of nitrates under both treatments but more loss (or less gain) under subsurface tillage.

The nitrate contents at the third sampling (July 1) indicated a very active nitrate production during the May 28 to July 1 interval under both treatments and an accompanying downward leaching into or beyond the sixth foot. Apparently, during this period, nitrates either had been produced much more rapidly under subsurface tillage than under plowing, or had not been so extensively leached. There had been only one rain to induce leaching (2.25 inches, June 20), and the larger intake at that time was under subsurface tillage. It is hardly reasonable, therefore, that the plowed land could have lost much more nitrate than the subtilled land, even though it did have larger amounts subject to loss. Had intakes been equal and sufficient in quantity to have leached all of the nitrates of the upper three feet into the lower three feet, and all nitrates of the lower three feet as of May 28 on beyond the depth of sampling, the computed nitrate productions still would have been somewhat in favor of subsurface tillage.

From July 1 onward, nitrates undoubtedly were produced, but at the same time there were numerous rains that induced an extreme degree of leaching. The final results were losses rather than gains, of about the same magnitude under both treatments. The quantities under plowing to a depth of two feet on September 30 suggest a higher rate of nitrate production under that treatment than under subsurface tillage, but they equally suggest a lower amount of downward leaching. Moisture studies on September 30 showed moisture conditions slightly in excess of field-carrying capacity under both treatments.

Comparing conditions when the fallow was started with conditions at termination, it will be noted that subsurface tillage and plowing showed equal gain to a depth of one foot. To a depth of two feet subsurface tillage showed more gain than plowing. To a depth of three feet subsurface tillage showed gains, and plowing showed loss. To depths below three feet both treatments showed loss, but subsurface tillage showed less loss than plowing.

Corn Land. The nitrate contents in corn land on September 30 (Table 5) to a depth of six feet were not greatly different from those at the initial sampling on April 16. To a depth of one foot the two treatments showed about equal gains. To a depth of six feet subsurface tillage showed a small loss, and plowing an insignificant gain. Between April 16 and corn planting on May 30, the corn land had been handled in practically the same manner as summer fallow. Subsequently, the growing corn abstracted sufficient soil moisture [1] that there was no possibility of any nitrate loss through leaching under either subsurface tillage or plowing. Accordingly, the data of May 28 in Table 4 serve as a better base for computing nitrate changes than the data of April 16. Computations from the May 28 base indicate gains to a depth of six feet under both treatments, the amounts being 9.8 and 18.1 pounds of nitrate-nitrogen for stalks on the surface and plowed under, respectively. In

[1] Moisture samples on October 1 showed field-carrying capacity wetness conditions to a depth of two feet, and distinct dryness in the third and fourth feet, under both treatments. The fifth and sixth feet under plowing had the same wetness as on April 16. Under subsurface tillage the moisture contents at these latter depths had declined slightly.

Table 5. Nitrate-nitrogen in pounds per acre in corn land following three previous corn crops with stalks on surface or plowed under. The data are means of duplicate plots.

Disposition of stalks		Depth of sampling (feet) 0–0.5	0–1	0–3	0–6
		lbs.	*lbs.*	*lbs.*	*lbs.*
	April 16, 1942—Initial sampling				
1939–'41	Cornstalks on surface	8.6	15.5	51.2	136.5
1939–'41	Cornstalks plowed under	11.2	22.2	96.2	209.8
	September 30, 1942—Wheat seeding time				
1939–'41	Cornstalks on surface	24.3	43.0	64.2	125.2
1939–'41	Cornstalks plowed under	20.3	51.1	92.3	213.1
	Gains or losses				
April 16—Sept. 30	Stalks subtilled	15.7	27.5	13.0	–11.3
Rainfall 17.72 inches	Stalks plowed under	9.1	28.9	–3.9	3.3
May 28*—Sept. 30	Stalks subtilled	8.1	20.6	15.2	9.8
Rainfall 12.75 inches	Stalks plowed under	–2.9	8.0	–2.3	18.1

* Data taken from Table 4.

addition, other nitrates were developed during the season that were absorbed by the crop. Estimates of nitrogen absorption based on yields are 78 and 88 pounds of nitrogen per acre. During the corn-growing period, therefore, there was an apparent nitrate production of about 88 pounds of nitrate-nitrogen per acre where stalks had been left on the surface as compared with 106 pounds where stalks were plowed under.

Oats Land. The nitrate condition on September 30 in winter wheat seedbeds following oats (Table 6) was definitely higher under plowing than under subsurface tillage where land had been subtilled for three previous crops. On the other hand, the nitrate contents to a depth of three feet were higher under subsurface tillage than under plowing where land previously had always been plowed. The increases due to treatment were not large and are not indicative of any decided depression of nitrate production due to long-continued usage of residues on the surface without soil inversion. Neither do they indicate any marked stimulation of nitrification processes where the soil is turned over and old residues buried. Unfortunately no nitrate samples were taken at oats harvest time or previous to fall tillage, hence the conclusions above cannot be expressed in terms of comparative nitrate production as was done in the case of corn land.

Moisture studies on these plots before seedbed tillage for wheat was started showed a fairly uniform removal of moisture among the four plots of each prior treatment. Studies on October 1 indicated considerable moisture storage to depths of three or four feet in all plots but no infiltration beyond the sixth foot. Therefore, the differences observed in Table 6 involve no questions of nitrate leaching.

Nitrates in Subsurface Tillage Rotation Plots

In a rotation involving corn, oats, and winter wheat, one set of plots has been subtilled and cropped consistently since 1938–39 in such manner as to

Table 6. Nitrate-nitrogen in pounds per acre on September 30, 1942, by two seedbed methods following oats (1942) and three previous crops of corn with stalks left on the surface or plowed under. The data are means of duplicate plots.

Seedbed preparation for winter wheat *	Depth of sampling (feet)			
	0–0.5	0–1	0–3	0–6
	lbs.	*lbs.*	*lbs.*	*lbs.*
Oats land following continuous corn—1939–'41 cornstalks on surface				
Oat straw and previous stalks on surface, subtilled	9.9	23.3	50.6	78.0
Oat straw and previous stalks, plowed under	17.0	40.3	66.7	85.5
Increase due to plowing	7.1	17.0	16.1	7.5
Oats land following continuous corn—1939–'41 cornstalks plowed under				
Oat straw on surface, subtilled	18.9	36.9	74.0	116.4
Oat straw, plowed under	13.0	32.9	59.0	135.2
Increase due to subsurface tillage	5.9	4.0	15.0	–18.8

* Oats were harvested with a binder and residues were returned uniformly over all plots to give a straw cover of 2,265 pounds per acre, inclusive of stubble. A light after-crop of weeds was mowed and left in place. Seedbed tillage was started on August 11.

leave all residues on the surface to the maximum degree possible. For comparison with this, four other sets of plots have been handled by four common farm procedures.

Wheat Plots. Nitrate conditions at wheat seeding time during three years of test are shown in Table 7. On the average, the soil nitrates have been about equally low where residues were left on the surface and where disked in, and about equally high where residues were plowed under and where removed before plowing was done. Nitrate contents under basin listing have been intermediate.

In 1939 the effects of all treatments were similar. The plots previously had been cropped to oats for two seasons and straw at the rate of two tons per acre uniformly applied ahead of the tillage treatments. The summer was dry and there was no moisture infiltration beyond 18 inches. All nitrates below that depth presumably were a hold-over from previous cropping. Accumulations due to treatment probably are best represented by the quantities found in the first foot of soil. The amount of nitrate to this depth under subsurface tillage and the mean amounts under the other four treatments were practically identical.

In 1941, the higher nitrate contents at seeding time were under the two plowing treatments and the lower contents were under residues-subtilled and residues-disked-in. The difference between subsurface tillage and the average for the two plowing treatments is about 74 pounds of nitrate-nitrogen per acre to a depth of six feet. It should not be concluded, however, that this difference is indicative of reduced nitrate production under subsurface tillage treatment. As a matter of fact, the increases in crop yields in prior years due to residues on the surface will account for 34 pounds of this difference through increased nitrogen absorption. In addition, there was one occasion during the three years since the experiments were started when there was a possibility of some nitrate loss through leaching under subsurface tillage, whereas there

Table 7. Nitrate-nitrogen in pounds per acre at time of planting winter wheat in a corn-oats-wheat rotation in relation to disposition of crop residues and manner of seedbed preparation, three years, 1939, 1941, and 1942.

Crop residues and seedbed preparation	Depth of sampling (feet)			
	0–0.5	0–1	0–3	0–6
	lbs.	*lbs.*	*lbs.*	*lbs.*
	*1939 (Sept. 27)**			
Residues **				
Subtilled	43.7	62.6	130.4	155.6
Disked in †	43.5	56.3	113.9	144.1
Basin listed	39.2	50.2	96.3	119.1
Plowed under	55.2	68.4	112.2	149.9
No residues				
Plowed	58.4	71.8	116.8	146.6
	1941 (Sept. 23)			
Residues **				
Subtilled	21.6	35.8	57.9	104.3
Disked in	20.6	35.7	53.0	104.3
Basin listed	30.4	49.3	121.9	154.4
Plowed under	21.3	44.3	132.2	180.7
No residues				
Plowed	20.5	42.6	134.5	175.3
	1942 (Sept. 24)			
Residues **				
Subtilled	5.4	9.3	24.4	77.3‡
Disked in	11.4	23.7	54.3	122.8
Basin listed	13.8	28.2	57.1	106.1
Plowed under	21.9	44.7	91.8	127.3
No residues				
Plowed	18.9	46.1	96.6	139.2
	Mean of three seasons			
Residues				
Subtilled	23.6	35.9	70.9	112.4
Disked in	25.2	38.6	73.7	123.7
Basin listed	27.8	42.6	91.8	126.5
Plowed under	32.8	52.5	112.1	152.6
No residues				
Plowed	32.6	53.5	116.0	153.7

* The writers are indebted to H. W. Smith, instructor in soils, for making the nitrate analyses in 1939.

** The residues involved have been those produced by previous crops except in 1939 when straw was applied uniformly to all residue plots at the rate of two tons per acre. The oats residues prior to subsurface tillage treatment were 1,450 pounds per acre in 1941 and 2,080 pounds per acre in 1942, but some remnants of previous cornstalks were also present.

† Due to the heaviness of the residue cover in 1939 only about one-half of the plant material was actually covered by disking.

‡ This low amount is probably due in part to growth of volunteer oats.

was no such loss during the entire period under the plowing treatments. Regardless of the lower nitrates at seeding time, wheat yields in 1942 were slightly in favor of subsurface tillage as compared with any other treatment.

In 1942 the nitrates under subsurface tillage were decidedly low. The highest nitrate contents were under the two plowing treatments, the same as in 1941. Shortly after the seedbed preparation was started, a prolonged period of wet weather occurred which favored the growth of volunteer oats. Where shattered seed had been plowed under, this volunteer was never serious and was promptly eradicated. Where listing or disking had been done, the volunteer was moderate and was killed at an early stage. On subsurface tillage the growth was luxuriant and persistent and was not completely stopped until just before seeding time. Judged by the denseness of stand and height of growth, this volunteer oats may have absorbed as much as 20 pounds of nitrate-nitrogen per acre.

Corn Plots. The nitrate conditions at two spring dates in 1942 in the rotation plots prepared for corn are shown in Table 8. The seedbed preparations on four of the rotation treatments had been initiated late in November of the previous fall. Before that there had been a light growth of annual weeds over all plots and these had prevented any large fall accumulation of nitrates. The first determination of nitrate conditions in the five sets of plots was made 15 days after plowing under the stubble and straw of the one spring-plowing treatment. A second determination of nitrates was made 26 days later.

The first sampling showed lower amounts of nitrate under the subtilled and spring-plowed treatments than under the two fall-plowed treatments. The highest amounts were under basin listing. These diverse nitrate contents are probably the result of soil-heat differences more than any other factor. The basin-listed plots would have warmed more rapidly than others because of their greater surface exposure, and the spring-plowed plots up to their date

Table 8. Nitrate-nitrogen in pounds per acre in corn-oats-wheat rotation plots at planting time for corn in 1942. The data are means of randomized triplicated plots.

Crop residues and seedbed preparation	Depth of sampling (feet)			
	0–0.5	0–1	0–3	0–6
	lbs.	*lbs.*	*lbs.*	*lbs.*
1942 (May 14)				
Residues *				
Subtilled in fall and spring	10.2	15.0	29.7	49.7
Plowed under in spring †	9.6	13.7	26.4	47.2
Basin listed in fall	16.0	27.9	50.2	70.2
Plowed under in fall	13.0	21.7	45.6	69.6
No residues				
Plowed in fall	11.0	18.3	37.1	54.4
1942 (June 9) ‡				
Residues				
Subtilled in fall and spring	15.8	21.5	37.1	60.1
Plowed under in spring	24.8	35.3	52.9	75.2
Basin listed in fall	30.4	50.3	80.7	104.6
Plowed under in fall	17.4	26.7	50.7	86.1
No residues				
Plowed in fall	16.3	25.2	50.0	68.0

* The residues involved have been those of three previous crops and a preliminary application of two tons of straw per acre when the rotation was first started. The wheat residues prior to subsurface tillage treatment were 2,945 pounds per acre.

† Plowed April 29, six inches deep.

‡ Corn was planted May 30, with a surface planter equipped with small furrow openers.

of plowing would have warmed least rapidly because of the completeness of their straw and stubble cover and also their solidity.

The nitrate conditions at the second sampling also reflect differences due to soil temperature. The highest apparent gain in nitrates [1] in the 26-day interval was under basin listing (34.2 pounds). The next highest (28.0 pounds) was under the spring plowing treatment, which would have become warm rapidly after the residue cover was plowed under. The lowest accumulation (10.4 pounds) during the period was under the subsurface tillage treatment where the soil beneath the residues likely continued cool.

Discussion

THE residues of grain crops left on the surface, such as wheat and oats straw and cornstalks, plus a small amount of annual weeds, have shown a tendency to reduce nitrate production early in the season as compared with residues turned under or absent, probably because they delayed the warming of the soil in the spring. They also have shown a slight tendency to reduce nitrate production during a season of summer fallow beginning in April and ending the last of September. They have not displayed any clear-cut tendency to reduce nitrate production during the warm portions of the year either in connection with the growing of row crops or in seedbed preparation for winter wheat.

It should be understood that the foregoing statements apply to nitrate production and not to nitrate contents. The latter at one depth or another have been lower in some cases where residues have been left on the surface than where they were plowed under or were absent, not because of reduced nitrate production, but because of a greater leaching or a heavier use by crops. Residues, through the prevention of runoff, the increase of intake, and the reduction of evaporation, induced a deeper storage of moisture in the soil. The nitrates, being freely soluble and non-adsorbed, were translocated downward in the profile. Consequently their contents were diminished in upper layers and increased at lower depths. This physical effect of residues on translocation apparently was a much more important factor in nitrate content under the conditions of this study than was their effect on nitrate production.

Under conditions where the moisture supply is abundant, an increase in moisture intake through residues on the surface might lead to loss of nitrates through leaching to depths below the root zone. One of the problems in the use of residues on the surface specifically for erosion control in regions of

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[1] The computed gains in nitrates to a depth of six feet probably were not as large as actually occurred. Moisture studies on May 14 had indicated two zones of downward moving water that would have produced nitrate leaching prior to that date. An upper zone of moisture in excess of field-carrying capacity due to precipitation in early May (3.36 inches) was well advanced into the second foot uniformly under all treatments. A lower zone due to infiltration over winter was moving out of the sixth foot under the subtilled, spring-plowed, and basin-listed treatments, and out of the fifth foot under the two fall-plowed treatments. The period May 14 to June 9 was warm and dry and there was only one small rain (May 17, 0.67 inch) to accelerate downward movement from out the top half-foot. However, the lower zone of moisture in excess of field-carrying capacity referred to above would have progressed beyond the sixth foot and would have carried nitrates of the May 14 sampling beyond the depth of the June 9 sampling. The maximum errors of this source would have occurred under the two plowed treatments where the descending moisture zone had not reached the bottom of the sixth foot on May 14.

abundant moisture may be that of nitrate loss, unless nitrates are utilized by keeping the land covered continually with growing crop.

In the Great Plains or in the western edge of the Corn Belt where moisture is a common limiting factor in crop production, it is highly desirable to have moisture stored in the subsoil to a depth of four to six feet at the beginning of the spring or at the end of a summer-fallow season. If in the process of such deep storage of water through residues on the surface, nitrates are translocated more deeply than where residues are plowed under or destroyed, these need not be considered lost unless the depth of storage is excessive. They will be absorbed, if needed, at the same time that the moisture is absorbed. The only additional consideration is that they develop with sufficient rapidity in the surface, and persist there in sufficient quantity to assure a proper growth of plants during their early, shallow-root-system stages.

The development of nitrates beneath residues undoubtedly will vary with different soils and in different seasons. The soil and climate in the Great Plains and in the western edge of the Corn Belt in general are favorable to a sufficiency of nitrate production under residues, regardless of the possibilities of an occasional depression or temporary loss by leaching. The 40 to 60 pounds of nitrate-nitrogen that apparently developed between oats harvest and wheat-seeding time in 1939, or the 58 pounds that developed in sorghum plots between June 2 and July 9 in 1942, as well as the surpluses under corn at Lincoln in 1941 or 1942, all illustrate the nitrification possibilities under crop residues when moisture and temperature conditions are favorable.

Summary

1. The development of nitrates in soil protected by crop residues and cultivated by subsurface tillage has been compared with nitrate production under conventional tillage where residues were either incorporated with the soil or removed. The investigation was conducted on field plots at Lincoln, Nebraska, and at the Hastings, Nebraska, Hydrological Station. Sampling for nitrates was done at depth intervals of 0–0.5, 0.5–1.0, 2, 3, 4, 5, and 6 feet.

2. Where straw mulches were applied to corn between the rows at planting time no significant differences in nitrate content were observed at the end of 30 days. At the end of the season nitrates were lower under 2-, 4-, and 8-ton mulches than under unmulched conditions, but yields were higher. When nitrogen absorption by the crop was taken into consideration, no significant differences in total nitrate production among the various treatments were indicated. Nitrate contents declined during winter, and the following April they were inversely related to the amounts of mulch applied. These reduced nitrate contents apparently were due to over-winter leaching. At one period during the experiment the corn on the 8-ton mulch plots was spindling and yellow, but nitrates in the soil and in growing corn tissue were high. This corn recovered during a period of dry weather, since it had the most soil moisture, and outyielded the other treatments.

3. In subtilled and plowed plots planted to sorghum, approximately equal amounts of nitrates were produced during a five-week early season period where 1.5 tons of straw residues had been left on the surface and where these had been plowed under.

4. In a summer-fallow test with straw residues of one, two, and four tons per acre, lower nitrate contents were observed at wheat-seeding time where subsurface tillage was employed than where land had been plowed or disked with residue incorporated or absent. Nitrates in all cases were in excess of crop needs, as shown by the yields of wheat which followed. These yields were highest on the subsurface tillage plots.

5. In another summer-fallow test involving the residues of continuous corn, more nitrates were produced during the summer where fallowing was done by subsurface tillage, following previous subsurface tillage for corn, than where plowing was done following previous plowing for corn. However, more nitrate leaching occurred under the subsurface tillage method, and at wheat seeding the plowed land had the higher nitrate content.

6. In a corn, oats, wheat rotation where seedbeds for winter wheat were prepared by subsurface tillage and four other common farm methods, nitrate contents under all methods were in close agreement at wheat-seeding time during the first year when all prior conditions were uniform. During a second year of test, nitrates were lower under subsurface tillage than under any other method, due largely to a heavier nitrate usage by previous crops. In the third year of test, nitrates were low under subsurface tillage largely on account of an excessive growth of volunteer oats that was not completely killed until just before wheat-seeding time.

7. In wheat seedbeds following oats on land where oats had followed three years of corn, nitrates developed slightly more abundantly under plowing than under subsurface tillage where land previously had been subtilled for corn and oats. The reverse occurred where land previously had been plowed for corn and oats. The differences, however, were not large, and did not indicate any radical stimulation of nitrate production through inversion of soil or residues that had been subtilled for three consecutive years.

8. In seedbeds for corn following wheat, in a corn, oats, wheat rotation, nitrates developed less rapidly early in the season where residues had been left on the surface than where land had been plowed in the fall. Nitrate production in the spring was slower under stubble conditions than under fall subsurface tillage and was greatly accelerated when stubble was plowed under. The most rapid nitrate production in the spring was on land that had been fall listed. This variation in nitrate production apparently was related to the rapidity with which soil under the various treatments became warm in the spring.

9. In continuous corn land, nitrates were lower, both at the beginning and at the end of the season, where subsurface tillage had been employed for three successive crops with all stalks left on the surface, than where plowing had been done with all stalks turned under. However, the total amounts of nitrates produced during the season under the two methods were not radically different when leaching and nitrogen absorption by crop were considered.

10. The outstanding influence of surface residues revealed by this study was not so much an effect on production as on translocation of nitrates downward. This effect was so large as regards the upper half foot of soil that it was only during very dry periods that nitrates were as abundant at this depth

interval under residues as under other treatments. In most instances the influence of residues on nitrates extended beyond the third foot and in some cases even beyond the sixth foot.

11. In regions where storage of moisture in the subsoil is a highly desirable process, a translocation of nitrates downward as a result of residues on the surface should be expected. The advantages of a greater intake and a reduced evaporation through residue protection cannot be had without an increased movement of nitrates downward, along with the increased movement of moisture downward.

12. The data of this paper, and all observations of crops and records of yields so far made, indicate substantially the same level of nitrate production under subsurface tillage practice with residues on the surface that obtains under the more common methods of tillage and residue disposal.

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