MOVEMENT OF NITRATE NITROGEN IN SOIL

by

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INTRODUCTION

It is a well established fact in soil science that nitrogen in the nitrate form is not strongly absorbed by the soil. It is a reasonable assumption therefore, since nearly all nitrate salts are quite soluble, that movements of ground water would transfer nitrogen in this form from one location in the soil to another. Data indicating definitely the effect of percolating ground water following rains and capillary water movements toward the surface during times of active evaporation on movement of nitrate nitrogen are less abundant. The investigations here reported were designed to show the extent and the nature of nitrate-nitrogen movements in soils under various natural and artificial conditions. An attempt also was made to determine whether or not any loss of nitrogen occurred during such movements.

REVIEW OF LITERATURE

Studies of the composition of drainage water have shown marked losses of nitrogen as nitrate from most soils subjected to sufficient rainfall to keep drainage channels discharging water regularly or at frequent intervals. From studies of this nature extending over a period of 37 years at the Rothamsted Experiment Station in England it was concluded (32) that "the loss of nitrogen from the soil appears wholly as nitrates in the drainage water." In years of high rainfall large amounts of nitrate nitrogen were lost while in years of low rainfall losses were very small.

Analyses of drainage water from lysimeter tanks at the New York Cornell Agricultural Experiment Station (4), (22) showed large losses of nitrate nitrogen from soil kept free of vegetation while losses from cropped soil were comparatively small. Similar work at the Florida and Tennessee Experiment Stations gave results of the same nature.

Stewart and Greaves (40) reported that spring and winter rains at the Utah Experiment Station carried nitric nitrogen down in the soil to depths of 7 to 8 feet where it was accumulated in what they called "nitrate belts." They applied successive heavy irrigations (15), (40) amounting to 37.5 inches of water in one case and 25 inches in another case and concluded that the water carried much of the nitrate nitrogen of the soil entirely beyond the reach of plants.

Beaumont and Crooks (3), Blair and Prince (5) and Whiting and Richmond (44) have emphasized the fact that heavy rainfalls readily carry nitrates below the depth of the plowed layer.

Rheinwald (31) in a thorough discussion of nitric nitrogen in the soil, observed that in a rainy period the nitrates could be washed down quickly and almost completely from the plowed layer of 12 centimeters depth, and in a dry period the same layer could be enriched in nitrates.

While nitrates may be leached when water percolates through a soil they may also be moved upward through the soil with the capillary water in times of active evaporation at the surface. Whiting and Richmond (44) believed nitrates may accumulate at or near the surface by rising from lower layers. Johansson (18) observed that "the evaporation from the surface will cause an upward flow of water with a consequent rise of the nitrates in the soil."

White (43) presented data showing that, while nitrate were often held at lower levels during periods of adequate moisture supply, the highest concentration appeared in the surface 3 inches of soil after a period of drouth.

Stewart and Greaves (40) noted upward movement of nitrates during dry periods with accumulation in the surface foot of soil.

There are three known means by which nitrogen may be lost from the soil, namely, (a) by removal in crops, (b) by leaching, and (c) by a biological process of denitrification in which N is liberated in the free, gaseous form.

It is difficult to arrive at a strict nitrogen balance in studies of nitrogen in soils because there frequently appear losses which can not be accounted for satisfactorily. The literature cited in the following paragraphs contains numerous references to such losses.

Thomas (42), Lipman and Blair (21), and Collison and Walker (10) have studied removal of nitrogen by crops and drainage from soil in cylinders and tanks but were unable to account for total losses in this way. Loss as free nitrogen and possibly to some extent as ammonia in gaseous form were hypothecated. Lyon and Bizzel (23) failed by 300 pounds of nitrogen of securing a balance when nitrogen lost by drainage and crop removal diminished by that added in manure and rainfall was compared to the loss shown by analysis of the soil. The work was done with lysimeters and covered a period of 20 years.

Gainey and associates (14) at the Kansas Station have shown large losses of nitrogen in the early years of cultivation of soils of low rainfall areas where leaching is exceedingly restricted.

In western Canada prairie soils, where annual precipitation averages 13.35 inches (31), nitrogen dissipated by cultivation has been claimed to amount to more than twice that removed by plants. At the Washington Experiment

Station (36) losses of at least 18 pounds of nitrogen per acre annually were reported in addition to that accounted for by crop removal. Large losses were detected at the Minnesota Experiment Station in a soil cropped continuously to wheat for eight years.

Burd and Martin (9), working with 13 soils in galvanized iron tanks observed that "losses of nitrates occurring during the growing season are frequently greater than can be accounted for by the amount of nitrogen removed in the crop even when leaching is precluded as has been the case in all of these experiments."

Lyon and his associates (24) reported disappearance of nitrate nitrogen from the soil of sod plots which could not be accounted for by its removal in the crops of hay or its incorporation in roots and stubble, nor presumably by its removal in drainage water. Pennman and Rountree (29), working with Australian soils which were not cropped, encountered losses which could not be attributed to leaching. Prescott and Piper (30) also working in Australia detected nitrate losses which they were unable to account for and which were produced apparently rapidly. White (43) showed that a rain of 1.14 inches reduced the nitrate content of the surface 24 inches of an acid soil at the Pennsylvania Station from an average of 19.15 parts per million parts of dry soil to 11.54 parts per million in a period of three days. Rheinwald (31) showed similar reduction of nitrates after a rain which penetrated the soil eventually to a depth of 10 inches.

Experiments reported from the Utah Station (15, 39, 40) showed losses of nitrate nitrogen from fallow soil during periods in which there had been no precipitation. In the last three years of an 11-year experiment the nitrates were one-third less in fallow soil than during the first eight years, though no loss of total nitrogen nor nitrifying power of the soil could be detected.

Jensen (17) reported sudden decreases in nitrate content of soils during short periods in summer. At Nagpur, India (1) on black cotton soil distinct losses of nitrates were detected in early summer when no crop was growing and there was no drainage discharge.

Sachs (35) and later Bartholomew (2) at the Arkansas Experiment Station reported reductions of nitrate nitrogen in fallow soil which were said to be unaccounted for by leaching losses. Several investigators (21, 24, 42) have shown that unaccountable losses of nitrogen occur when large quantities of nitrate fertilizers are applied to soils. Also such losses have been noted (9, 14, 15) from fallow soils with large nitrate accumulations, and Meggitt (25) working with soils under a hot, humid climate in India concluded that such losses in addition to the much larger drainage losses make fallow soils under such conditions undesirably wasteful.

Losses of total nitrogen are especially large during the first few years of cultivation of soil previously under a sod of grasses. Such losses eventually cease and the nitrogen content reaches an apparent equilibrium characteristic of the cropping system and cultural practices employed. Bizzel and Lyon (4) and Lipman and Blair (21) have presented data indicating such equilibrium conditions.

In soils subjected to excess water, as, for example, paddy soils, nitrates are reduced under the anaerobic conditions brought about by the excess water. Daikuhara and Imaseki (11) added organic matter to a soil and after flooding found all nitrates reduced within 48 hours. Kelley (20) and Metzger and Janssen (26) also report rapid reduction of nitrates in flooded soils, especially when organic matter is abundant. Denitrification was believed to follow reduction of the nitrates. Panganiban (28) concluded from studies of paddy soils that nitrates are nearly totally absent from submerged soil. Subrahmanyan (41) in extensive studies of submerged soils found rapid disappearance of nitrates, that the nitrification process was almost completely inhibited and ammonification was retarded.

Heating soil may result in loss of nitrates. Kelley and McGeorge (19) showed that considerable decomposition occurs at 150 degrees C while at 200 degrees C and 250 degrees C practically total decomposition took place. Russel (33) summarized work from many of the dry areas of the world with the following statements: "Under hot dry conditions the accumulative processes are less effective and the destructive processes become intensified. Nitrates disappear sometimes completely from dry tropical soils during bare fallow."

Some losses of nitrates from soils subject to erosion are attributable to that source. Duley and Miller (12), however, concluded that nitrogen lost by erosion is largely lost in insoluble form and that, generally, relatively small losses of nitrate nitrogen occur.

Two explanations have been offered for the disappearance of nitrate nitrogen not attributable to drainage losses or removal in crops. Numerous writers (2, 15, 17, 23, 24, 30, 40) have offered one or both of these explanations. Denitrification, a biological process in which nitrogen is released in free, gaseous form, is one proposal. Denitrification has been definitely demonstrated many times but it seems quite doubtful whether such a process could account for the rather sharp declines in nitrate nitrogen observed in well aerated soils not subject to leaching nor cropped. The second explanation involves the assimilation of some of the nitrate nitrogen into the protoplasm of the microbiological population of the soil. It is exceedingly difficult to definitely demonstrate this process experimentally and therefore as an explanation for the otherwise unaccountable loss of nitrate nitrogen frequently encountered it must be considered as presumptive. Pennman and Rountree (29) doubt that this explanation is tenable.

Since reduction of nitrates has been shown to occur rapidly under certain conditions in flooded soils it is possible that following heavy rains temporary excess of water in many places in the soil may result in such losses. The yellow appearance of corn plants on wet land in early summer is suggestive of a loss of available nitrogen which may not be entirely attributable to leaching.

MATERIALS AND METHODS

Four field plots, each 200 square meters in size, located on the Agronomy Farm of the Kansas State College were established as a location for the field investigations. Two were seeded with oats and the others maintained as fallow, free of all weed growth. The effect of rainfall upon the nitrate content of the soil at various depths was studied on both cropped and fallow land by determining the nitrate nitrogen of samples taken before and after rains. Also artificial irrigation was applied to triplicate small plots on each of the two larger fallow areas and the effect on the amount and distribution of nitrate determined. A total of 15 samples were composited from each of the larger plots at each sampling and nine samples were composited from each of the smaller areas.

Soil from these plots and also soil from the Agronomy Farm at the University of Nebraska was used in laboratory studies.

In all cases nitrates were extracted from the soil the same day the samples were taken. Moisture determinations were made by drying soil samples in the oven at 105 degrees C and moisture expressed on the basis of the oven dry soil. Nitrates were determined by the phenoldisulphonic acid method as modified by Harper (16). Determinations were made with duplicate soil samples. Nitrates were expressed in all cases as parts per million parts of the oven dry soil.

Mechanical analyses of the soils involved in the study were made by Engle and Yoder's modification (13) of the pipette method of Robinson and also by the hydrometer method developed by Bouyoucos, (6, 7). Moisture equivalent was determined by the centrifugal method (8) and maximum water holding capacity and hygroscopic coefficient by the methods of Hilgard. The pH values of the field soils were determined electrometrically.

Soil profile descriptions are presented with the nomenclature of Kossovitsch and Zakharov as described in the report of the American Soil Survey Association for 1931, and the nomenclature for structure proposed by Zakharov (45).

PRELIMINARY INVESTIGATIONS

Since a fairly close relationship is known to exist between the type of soil and the nature of the vegetation comprising the natural cover, the vegetation of a small, undisturbed portion of the area devoted to field investigations was carefully examined. The following species were found to be represented: Amaranthus hybridus (smooth pigweed), Mollugo verticillata, Eragrostis megasticha (stink grass), Digittaria sanquinate (crab grass), Echinocloa Crus-Galli, Setaria viridis (green foxtail), Eragrostis pilosa (small tufted grass). The occurrence of Amaranthus as dominant vegetative cover is an indication of a high content of available nitrogen in the soil.

Profile Descriptions

Two profiles were exposed in the area devoted to field investigations. They were exposed in two fallow plots, one on the north side, the other on the south side of the plot to which irrigation was applied.

Profile No. 1. North side of irrigated plot.

A_0 horizon, 6 inches. The cultivated layer, light gray in color, pulverulent, high content of sand, classified as very fine sandy clay loam.

A_1 horizon, 8 inches. A faint trace of lamination in upper part, fine granular structure in lower part. Dark colored, darker than any horizon above or below. Classified as clay.

A_2 horizon, 14 inches. Dark gray. Granular structure of cuboidal type, faces and edges sharply defined. Porous, the intersticies being about .04 - .12 inch in diameter. Structural elements comparatively feebly cemented. Worm channels fairly abundant.

B_1 horizon, 13.5 inches. Light reddish brown in color. Very compact. Cuboidal structure in top portion, prismoidal in lower portion. Edges of structure particles less clearly defined in the soil mass than above horizon. Soil breaks into clods approximately 1.2 - 2.0 inches in diameter with pores of very small diameter.

B_2 horizon, 14.5 inches. Varies from reddish yellow at top to light yellow at bottom. Less compact than B_1, easily disintegrated. Columnar structure, small columns. Minute fragments of organic matter between columns.

C horizon, 10 inches. Light yellow. Many lime concretions. Less lime at deeper depths.

The mechanical analysis of samples from profile No. 1, the moisture equivalent and pH values are presented in Table I.

The profile shows rather high sand content near the surface, with comparatively little silt and considerable clay. The sand content drops decidedly and remains nearly constant in the B and C horizons. The moisture equivalent values increase as the clay and silt content increases. The soil is moderately acid at the surface and becomes less acid lower in the profile.

Plate I is a photograph of profile No. 1 and shows clearly the various horizons of the profile.

Profile No. 2. South side of irrigated plot.

The structure and color of this profile was very similar to that of profile No. 1. The A horizon, however, was more shallow, totaling only 21 inches, 7 inches less than the A horizon of profile No. 1. This probably was

Table I. Mechanical analysis, moisture equivalent and pH values of profile No. 1.

Horizon	Depth Inches	Fine Gravel 2-1 mm	Coarse Sand 1.0 - .5 mm	Medium Sand .5 - .25 mm	Fine Sand .25 - .10mm	Very Fine Sand .10 - .05 mm	Total Sands	Silt .05-.005mm	Clay <.005 mm	Moist. Equiv.	pH
		%	%	%	%	%	%	%	%	%	
A_0	0-6	0.03	0.25	2.51	16.95	44.62	64.36	14.31	21.33	17.4	5.34
A_1	0-14	0.05	0.13	1.118	5.47	38.17	45.02	19.98	35.00	25.2	5.51
A_2	14-28	0.02	0.47	0.99	6.55	33.65	41.68	23.88	34.44	25.7	5.56
B_1	28-41	0.06	0.27	----	1.16	13.46	16.62	41.05	42.33	32.5	5.88
B_2	41-52	0.010	0.26	0.38	1.77	14.62	17.13	33.54	49.33	30.2	5.94
C	52-62	0.14	0.44	0.40	0.89	13.86	17.06	34.61	48.33	29.8	6.54

Plate I. Photograph of profile No. 1.

brought about by somewhat greater erosion at the surface of profile No. 2 since it was located farther up the gradual slope to the south than profile No. 1.

The B horizon had the same depth as in profile No. 1, i.e., 24 inches, but the color in the top of the B horizon was more intensely red than in No. 1 profile.

The C horizons of the two profiles were very similar.

A mechanical analysis was not made with the samples from profile No. 2 but a photograph of the profile is shown as Plate II.

In addition to the data from the profiles it seemed desirable to obtain more specific data for the soil of the plots subjected to irrigation. Accordingly samples were taken from these plots to a depth of 18 inches in layers of 6 inches. The mechanical analyses of the samples from these plots are shown in Table II. The data show a rather high content of total sands, with a relatively low silt content and a considerable amount of clay. Plot 2 appears to be a slightly heavier soil than plot 1. In Table III is shown comparative values for these same samples obtained by the use of the modified Robinson pipette method and the hydrometer method. The latter method showed much less sands and considerably more silt than the former. The hydrometer method is believed to be less accurate than the pipette

Profile No. 2

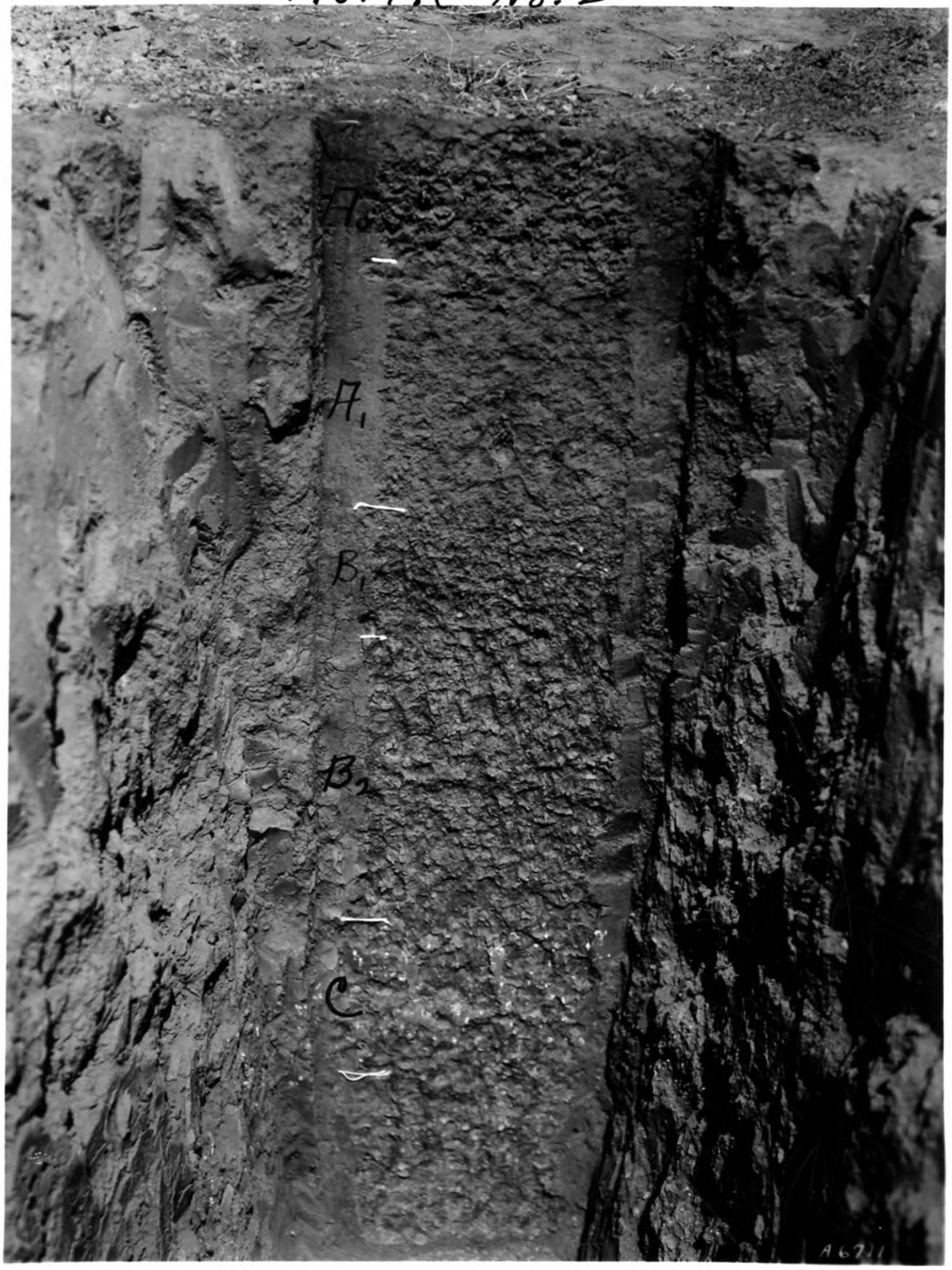

Plate II. Photograph of profile No. 2.

Table II. The mechanical analysis of soil from plots 1 and 2.

Plot No.	Depth Inches	Fine Gravel	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Total Sands	Silt	Clay
		%	%	%	%	%	%	%	%
1	0- 6	0.004	0.44	2.77	17.02	44.24	64.48	13.06	22.46
	6-12	0.06	0.30	1.77	14.18	44.14	60.45	13.75	25.80
	12-18	-----	0.25	1.10	9.80	42.23	53.38	17.82	28.80
	Average	0.032	0.33	1.88	13.66	43.53	59.43	14.87	25.68
2	0- 6	0.05	0.76	2.28	13.68	40.13	56.90	19.07	24.03
	6-12	0.04	0.37	2.63	7.36	39.48	49.88	23.27	27.00
	12-18	0.08	0.35	1.36	8.13	36.98	46.88	22.46	30.66
	Average	0.05	0.49	2.09	9.72	38.85	51.18	21.58	27.23

Table III. Comparison between the modified Robinson pipette method and the hydrometer method of mechanical analysis.

Method Employed	Depth Inches	Sand %	Sand Difference	Silt %	Silt Difference	Clay %	Clay Difference
	Plot 1						
Hydrometer	0- 6	40.46	24.02	40.60	27.54	18.94	3.52
Pipette		64.48		13.06		22.46	
Hydrometer	6-12	32.08	28.37	46.98	33.23	20.94	4.86
Pipette		60.45		13.75		25.80	
Hydrometer	12-18	26.72	26.66	51.00	33.18	22.28	6.52
Pipette		53.38		17.82		28.80	
	Plot 2						
Hydrometer	0- 6	33.64	23.26	43.61	24.54	22.75	1.28
Pipette		56.90		19.07		24.03	
Hydrometer	6-12	28.72	21.06	47.33	24.11	23.95	3.05
Pipette		49.78		23.22		27.00	
Hydrometer	12-18	26.29	20.59	47.43	24.97	26.28	4.38
Pipette		46.88		22.46		30.66	

method.

Table IV shows some of the important physical constants and the pH values for the soil from these two plots. The hygroscopic coefficient, moisture equivalent and the maximum water holding capacity all reflect the higher content of fine textured particles in the lower depths. In general it may be said that the texture of the soil of these plots is such that the soil is capable of absorbing rather large amounts of water before leaching will begin. On the other hand the content of very fine particles is not sufficiently

Table IV. Some physical constants and the pH values of the soil from plots 1 and 2.

	Depth Inches	Hygroscopic Coefficient	Moisture Equivalent	Maximum Water Holding Capacity	pH
	0- 6	6.16	17.5	54.16	5.36
Plot 1	6-12	6.58	20.1	58.73	5.45
	12-18	8.61	22.2	62.86	5.62
	Average	7.12	19.9	58.58	----
	0- 6	6.91	19.8	53.90	5.51
Plot 1	6-12	8.24	22.1	59.96	5.57
	12-18	8.85	23.4	63.60	5.62
	Average	8.00	21.8	59.15	----

high, unless highly deflocculated, to render the soil impervious at any depth.

Experimental Results from Irrigated Plots

Plots 1 and 2 were subjected to irrigation equivalent to 3 inches of water early in the summer of 1933. Samples were taken at 3-inch intervals to a depth of 24 inches before the water was applied and nitrate and moisture determinations were made with the samples from plot 2 while moisture only was determined with the samples from plot 1. Two inches of water were used in the initial application and immediately after the water was applied samples were again taken as before and moisture and nitrates were determined. This process was repeated 16 hours after irrigation. Three days after the first application 1 inch more water was applied and the plots were again sampled after the water was applied. No rain fell during this period. The results for each of three composite samples from plot 2 are shown in Table V. The average values for the three samples are shown in Table VI. In each table the depth at which the greatest concentration of nitric nitrogen was encountered at each of the various sampling periods is indicated by a line underscoring the value for

Table V. Moisture and nitrates in the soil of plot 2, before and at intervals after irrigation.

Repli-cations	Depth Inches	Before Irrigation Moisture %	Before Irrigation Nitrate p.p.m.	Immediately After Irrigation Moisture %	Immediately After Irrigation Nitrate p.p.m.	16 Hours After Irrigation Moisture %	16 Hours After Irrigation Nitrate p.p.m.	3 days later Moisture %	3 days later Nitrate p.p.m.
	0- 3	2.2	97.4	26.3	18.4	20.1	12.4	24.6	14.3
	3- 6	7.0	63.6	18.8	100.0	20.2	86.8	22.6	88.2
I	6- 9	8.3	71.8	16.0	45.0	19.2	112.8	24.3	176.0
	9-12	17.4	68.0	18.0	62.0	17.6	52.2	24.0	64.0
	12-18	17.8	66.6	17.5	60.0	15.4	46.4	23.9	90.8
	0- 3	6.9	151.0	27.7	Trace	20.9	12.4	25.9	14.5
	3- 6	12.8	114.0	21.2	66.9	21.0	62.0	22.7	66.5
	6- 9	14.4	83.5	17.7	51.0	19.9	111.6	20.3	109.8
II	9-12	17.7	84.0	18.9	67.7	19.8	58.9	19.7	71.4
	12-18	17.8	57.6	16.9	59.3	18.7	45.7	20.0	48.8
	0- 3	2.8	114.8	25.4	17.6	21.0	17.4	23.5	19.4
	3- 6	7.9	82.8	21.5	66.8	20.0	39.0	22.2	70.0
III	6- 9	11.5	81.0	15.4	51.9	20.3	95.3	22.9	79.9
	9-12	16.1	57.8	17.1	58.6	17.5	54.0	20.0	54.9
	12-18	17.0	66.0	17.5	55.0	17.0	36.0	19.9	42.7

Table VI. Average moisture and nitrates of three replications from each of the various depths of plot 2.

Depth Inches	Before Irrigation Moisture %	Before Irrigation Nitrate p.p.m.	Immediately After Irrigation Moisture %	Immediately After Irrigation Nitrate p.p.m.	16 Hours After Irrigation Moisture %	16 Hours After Irrigation Nitrate p.p.m.	3 Days After Irrigation Moisture %	3 Days After Irrigation Nitrate p.p.m.
0- 3	3.9	121.6	26.4	11.9	20.6	14.1	24.6	15.9
3- 6	9.2	86.5	20.5	77.9	20.4	62.6	22.5	74.9
6- 9	11.4	78.7	16.3	49.3	19.8	106.5	22.5	121.8
9-12	17.0	69.9	18.0	62.7	18.3	55.0	21.2	63.4
12-18	17.5	63.4	17.3	58.1	17.0	42.7	21.2	60.5
18-24	19.2	47.2	----	----	----	----	----	----

that depth.

The moisture data indicate that the soil was quite dry near the surface before irrigation but approached much nearer its saturation point in the 9-12 inch layer and at greater depths. Immediately after irrigation with 2 inches of water the moisture content was increased only to a depth of 12 inches and there was no consistent increase beyond this depth after 16 hours. Meanwhile the 0-3 inch layer dried somewhat while the two succeeding depths, in general, slightly increased in moisture content. When samples were taken immediately following the addition of 1 inch more water three days after the initial water application the entire profile showed an increase of moisture.

Before irrigation the nitrates were most concentrated in the surface 3 inches of soil. Immediately after irrigation the nitric nitrogen was present in highest concentration in the second layer, 3-6 inches. Sixteen hours after irrigation the greatest concentration of nitrates was found in the third layer, 6-9 inches, and this was also true after 1 inch more water had been added three days after the initial application of water. There was a general tendency toward lower concentration of nitrates in the lower depths immediately after irrigation and 16 hours after irrigation as compared to the values before irrigation. Some restoration of nitrates in these lower depths is shown in the samples taken after the second application of water, three days after the initial application.

Plot 1 received 2 inches of water in the initial application and no more water was added. Also in addition to the samples removed at the time of application, 16 hours and three days later, additional samples were removed after 8 days. No rain fell during this time. The results for plot 1 are shown in Table VII. The average values for the three replications for each depth are presented in Table VIII. In general the same tendencies are apparent as were shown in the data for plot 2. Immediately after irrigation, however, the water penetrated somewhat deeper in plot 1, carrying the nitrates to greater depths than in plot 2. This tendency is very probably attributable to the greater sand and lower silt content of the soil of plot 1 as compared to plot 2.

In replication 1 the nitrates were most concentrated in the third layer of soil at each of the four samplings. In the second replication the samples removed 16 hours, three days and eight days after irrigation showed the highest nitrate content at the third depth but the samples taken immediately after irrigation showed the greatest concentration at the second depth.

Table VII. Moisture and nitrates in plot 1 as affected by irrigation.

Repli-cations	Depth Inches	Before Irrigation Moisture %	Immediately After Irrig. Moist. %	Immediately After Irrig. Nitr. p.p.m.	16 Hours After Irrigation Moist. %	16 Hours After Irrigation Nitrate p.p.m.	3 Days Later Moist. %	3 Days Later Nitr. p.p.m.	8 Days Later Moist. %	8 Days Later Nitr. p.p.m.
I	0- 3	5.9	28.1	Trace	23.0	Trace	15.9	15.9	11.3	49.2
	3- 6		24.4	44.3	16.4	60.0	16.8	28.8	16.1	64.5
	6- 9	11.5	17.2	79.3	17.3	108.6	17.7	154.2	17.4	85.0
	9-12		15.8	60.0	16.5	91.8	19.1	82.3	19.4	61.8
	12-18	19.1	20.5	64.8	18.5	68.3	19.0	75.8	20.4	46.6
	18-24	----	----	----	22.7	80.2	20.7	66.9	----	----
II	0- 3	6.7	26.3	Trace	21.2	Trace	14.8	21.4	11.2	41.4
	3- 6		21.8	136.0	19.3	54.1	17.1	96.0	14.9	69.8
	6- 9	16.0	20.0	72.2	16.6	99.6	18.1	106.2	15.6	98.7
	9-12		17.5	71.1	21.9	77.2	21.0	75.2	18.9	55.7
	12-18	17.9	18.2	70.7	20.8	68.8	21.0	65.8	21.9	49.0
	18-24	----	----	----	22.7	62.0	21.4	50.4	----	----
III	0- 3	8.4	24.3	Trace	21.2	Trace	16.0	23.6	11.1	40.3
	3- 6		23.0	55.4	21.3	56.0	17.0	21.6	14.8	61.3
	6- 9	14.0	21.1	62.2	18.1	82.4	17.7	51.0	16.2	69.0
	9-12		16.4	37.8	20.5	60.7	19.7	55.8	21.2	75.7
	12-18	17.8	18.3	44.8	22.0	49.6	19.4	50.3	22.0	62.9

Table VIII. Average of moisture and nitrates of three replications as affected by irrigation in plot 2.

Depth Inches	Before Irrigation Moisture%	Immediately After Irrig. Moist. %	Immediately After Irrig. Nitr. p.p.m.	16 Hours After Irrigation Moist. %	16 Hours After Irrigation Nitrate p.p.m.	3 Days After Irrigation Moist. %	3 Days After Irrigation Nitr. p.p.m.	8 Days After Irrigation Moist. %	8 Days After Irrigation Nitr. p.p.m.
0- 3	7.0	26.2	Trace	22.1	Trace	15.5	20.3	11.2	43.6
3- 6		23.0	78.5	19.0	56.7	16.9	48.8	15.2	65.2
6- 9	13.8	19.4	71.2	17.3	96.6	17.8	103.8	16.4	84.2
9-12		16.5	56.3	19.3	76.5	19.9	71.0	19.8	64.4
12-18	18.2	19.0	60.1	20.4	62.2	19.8	63.9	21.4	52.8

The third replication showed highest concentration of nitrates at the third depth in the samples taken immediately after irrigation and 16 hours later. In the samples taken three days and eight days after irrigation, however, the greatest concentration of nitrates occurred in the fourth layer, i.e., 9-12 inches.

In all cases the nitrates were removed almost completely from the surface layer by the irrigation and only partially reappeared after three days. After eight days the concentration had been decidedly restored in this 0-3 inch layer. Unfortunately determinations of nitrates before irrigation were not made for this plot. In general the movement of nitrates downward appears to have extended at least to a depth of 18 inches and perhaps to greater depths.

When the data of the three replications are averaged the highest concentration occurs in the 6-9 inch layer in every case except those samples taken immediately after irrigation. Also a movement upward, which was inaugurated after the forces responsible for downward percolation had reached an equilibrium with those tending to move the water upward in the soil, appears to have carried nitrates back toward the surface between the samplings made on the third and the eighth days after irrigation. Nitrification may have aided in restoring this nitrate content in the surface soil since the temperature was near 90° F each day and the moisture content of the soil was near optimum for at least a part of this period of time. However, accumulation of nitrates from nitrification in a period of five days at optimum soil temperature and moisture has been shown to be small in experiments reported by Russel, Jones and Bahrt (34).

Experimental Results from Non-Irrigated Plots

Two of the four non-irrigated plots were seeded to oats on April 9, 1933. Samples were removed from both planted and fallow plots on April 12. Two very light rains had fallen earlier in the month but the soil was fairly dry at the time of sampling. The second group of samples was taken April 24, the third group May 12 and the fourth group June 12. Two additional groups of samples were removed from one cropped plot and one fallowed plot on June 22 and July 8. In these samplings the duplicate cropped plot and the duplicate fallowed plot were not sampled.

The moisture and nitrate content of the soil were determined at each sampling and the data are recorded in Table IX. Soil and air temperatures and rainfall data for the period during which these samples were taken are presented in Table X.

Table IX. Moisture and nitrates in cropped (oats) and fallowed plots.

Date of Sampling	Depth Inches	1st Trial				2nd Trial				Average			
		Oat		Fallow		Oat		Fallow		Oat		Fallow	
		Moisture %	Nitrate p.p.m.	Moisture %	Nitrate p.p.m.	Moisture %	Nitrate p.p.m.	Moisture %	Nitrate p.p.m.	Moisture %	Nitrate p.p.m.	Moisture %	Nitrate p.p.m.
April 12	0- 6	18.2	74.2	15.2	75.5	16.6	105.8	23.2	32.3	17.4	90.0	19.2	53.9
	6-12	16.4	103.8	15.6	111.1	14.2	97.6	----	66.5	15.3	100.7	----	88.8
	12-18	16.9	84.6	16.2	69.4	13.2	79.6	20.3	36.4	15.1	82.1	18.3	52.9
	18-24	18.9	67.9	18.5	80.5	19.7	62.7	20.8	74.3	19.3	65.3	19.6	77.4
April 24	0- 6	26.1	17.5	23.4	14.1	21.6	15.8	22.5	22.8	23.8	16.6	22.9	18.4
	6-12	29.1	70.1	23.9	39.2	23.4	87.6	24.0	80.0	26.2	78.8	23.9	59.6
	12-18	30.4	78.8	27.3	108.2	27.4	87.8	25.7	84.5	28.9	83.3	26.5	96.3
	18-24	19.5	63.5	22.6	78.3	23.4	58.0	21.1	71.8	21.4	60.7	21.8	75.0
May 12	0- 6	19.9	16.2	20.0	30.5	16.8	9.6	17.2	34.9	18.3	12.9	18.6	32.7
	6-12	21.8	45.7	20.7	75.0	20.1	35.9	21.0	44.0	20.9	40.8	20.8	59.5
	12-18	22.1	84.2	21.6	107.9	25.0	90.3	29.0	75.8	23.5	87.7	25.3	91.8
	18-24	24.6	69.7	26.2	58.2	23.7	63.5	30.7	63.6	24.1	66.6	28.4	61.8
June 4	0- 6	8.0	16.7	14.8	70.2	7.2	19.0	13.5	53.9	7.6	17.9	14.1	62.7
	6-12	9.7	21.4	18.1	66.6	9.7	32.4	18.1	54.9	9.7	26.9	18.1	60.7
	12-18	10.4	26.8	20.8	73.1	9.9	33.0	18.4	54.9	10.1	29.9	19.6	64.0
	18-24	13.2	31.3	22.5	61.7	4.3	28.0	21.3	44.1	12.2	29.9	21.9	52.9
June 22	0- 6	6.3	24.9	11.7	98.0	----	----	----	----	----	----	----	----
	6-12	6.2	23.8	15.0	99.7	----	----	----	----	----	----	----	----
	12-18	6.6	30.5	18.9	91.5	----	----	----	----	----	----	----	----
	18-24	7.3	28.3	22.2	78.7	----	----	----	----	----	----	----	----
July 9	0- 3	23.7	8.9	22.6	30.2	----	----	----	----	----	----	----	----
	3- 6	23.0	35.0	21.8	226.8	----	----	----	----	----	----	----	----
	6- 9	21.5	68.8	21.6	118.7	----	----	----	----	----	----	----	----
	9-12	17.1	36.0	21.9	79.3	----	----	----	----	----	----	----	----
	12-18	14.9	32.7	23.3	63.5	----	----	----	----	----	----	----	----
	18-24	8.5	38.2	22.0	81.4	----	----	----	----	----	----	----	----

Table X. Temperature of soil and air and precipitation from April to July, 1933.

Month	Temperature of Soil: 3 Inches Depth F° Average	Temperature of Soil: 9 Inches Depth F° Average	Mean Monthly Temperature of Air F° Average	Inches of Rain on Date Indicated								Total Rain, Inches
April				Day	3	9	13	19	20	21	30	
	66.0*	65.5*	55.0	Rain	0.2	0.1	0.4	0.30	0.71	0.77	0.1	2.86
May				Day	5	11	12	18	21	23	28	
	68.0	67.0	65.4	Rain	0.73	0.06	0.01	0.03	0.05	0.05	0.15	1.57
June				Day	--	--	13	26	27	28	30	
	90.4	83.2	83.6	Rain	--	--	Tr.	0.42	0.03	0.15	0.09	0.69
July				Day	--	8	12	14	18	23	--	
	90.7	87.5	82.0	Rain	--	3.35	Tr.	0.62	0.61	0.10	--	4.68

* April 20 to May 1.

On April 12 the soil was fairly dry and the nitrates were present in highest concentration in either the 0-6 or 6-12 inch layer. The newly seeded oats had not even germinated and had therefore produced no measurable effect on either moisture or nitrates. One of the fallow plots contained considerably more water and less nitrate nitrogen than the other.

A rainy period covering three days and producing 1.78 inches of rainfall preceded the April 24 sampling. Although the oats had emerged and were growing rapidly by this time the moisture contents of cropped and fallow plots were quite similar. There was some indication, however, that the oats had slightly reduced the nitrate content of the cropped soil as compared to the fallowed soil. The rains just preceding the taking of the samples had caused downward movement of soil water and the highest concentration of nitrates was found, in all cases, in the 12-18 inch layer. The nitrate and moisture contents of the two fallow plots were more nearly uniform than at the previous sampling.

When the third group of samples was removed on May 12 the moisture again was nearly as abundant in the cropped soil as in the fallow soil. The nitrates, however, had been definitely reduced in quantity by the growing oats crop throughout the 24 inches depth to which the soil was sampled. There was a fairly uniform distribution of nitrates among the four layers sampled, both in fallowed and cropped soil.

The fourth group of samples was taken June 4. Only light rains had fallen in the latter half of the month of May and no rain had fallen in June. The oats crop had decidedly reduced the moisture in the cropped plots and this reduction was apparent even in the 18-24 inch layer. The oats plants had reached maximum growth and were fully headed. The nitric nitrogen was quite uniformly distributed throughout the various layers of the fallow soil. In the cropped soil the concentration of nitrates tended to increase with successively lower layers of the soil, being most concentrated in the lowest, or 18-24 inch, layer.

On June 22 and July 9 only one cropped plot and one fallow plot were sampled. The oats were harvested just before the June 22 samples were taken. Only a small amount of rain had fallen during the month. On June 22 both the cropped plot and the fallowed plot showed a fairly uniform concentration of nitrates at the various levels. The cropped plot showed a higher nitrate content, especially near the surface, than at the previous sampling. The fallow plot still contained much more nitric nitrogen than the cropped plot. On July 8 and 9 a rain of 3.35 inches fell and the soil was sampled within a few hours after the rain. Moisture had penetrated to 12-18 inches depth and nitrates were carried downward in the soil, becoming most concentrated at 6-9 inches in the cropped soil and in the 3-6 and 6-9 inch layers of the fallowed soil. Movement of nitrates had apparently occurred, however, to at least a depth of 24 inches.

The downward movement of nitrates, illustrated in the experiments described, following rains may be of some practical significance. Yellow color of growing crops in the spring following a rainy period may result from the leaching of nitric nitrogen below the depth of root penetration of the young plants. The surface soil in which the roots are located in early stages of growth is greatly depleted of its supply of available nitrogen under such conditions and remains so until capillarity has returned some of the nitrogen carried downward or the process of nitrification has replenished the supply in these leached layers.

Results of Experiments Conducted in the Laboratory

Experiments were conducted in the laboratory to determine whether or not losses of nitrates occur when water is added to a soil sample in amounts sufficient to cause some movement but insufficient to cause loss by leaching. The soil was thoroughly mixed and uniformly compacted in brass cylinders. Therefore the movement of a given quantity of nitric nitrogen from one layer to another should cause an increase of such nitrogen, expressed as parts per million of the dry soil, in the lower layer equal to the decrease in the above layer.

Two soils were used in the experiment. The first was taken from the field plots, previously described, located on the Agronomy Farm of the Kansas State College. The second, classified as Carrington clay loam, was taken from the Agronomy Farm of the University of Nebraska. The mechanical composition of the two soils is indicated by the following data:

	Lincoln, Nebraska Soil, Per Cent	Manhattan, Kansas Soil, Per Cent
Hygroscopic coefficient	9.2	7.0
Moisture equivalent	25.6	18.6
Maximum water holding capacity	66.0	54.0
Sand	35.1	60.7
Silt	43.5	16.1
Clay	21.4	23.2

Water sufficient to provide two surface inches was applied to the cylinders. No water was allowed to drain from the soil and the amount of water added was just slightly less than sufficient to saturate the soil column throughout its length. One test was conducted with the Manhattan soil while seven tests were made with as many different samples of the Lincoln soil. After the water had completely permeated the soil the soil column was sampled by layers and nitrates and moisture determined. The data are presented in Table XI.

It may readily be observed that the additions of water in all cases caused marked movement of nitrates downward in the soil column. The lowest layer of soil in the column was the point of highest concentration after the percolation of the water in each cylinder. There were no consistent indications that any loss of nitrates occurred when columns of soil were irrigated with two inches of water in these experiments. The values listed in the table to the right of the notation "total", show that in three cases the nitrates after irrigation, as determined, were less than before the water was added while in five cases more nitrates were extracted after irrigation than before. In all cases except experiments V and VI the losses or gains are probably within the range of error inherent in the determination of nitrates. The magnitude of the gains in experiments V and VI the writer can not satisfactorily explain.

Table XI. Changes of moisture and nitrates in various layers of soil as influenced by irrigation in laboratory experiments.

Experiment	Soil Used	Amount of Water Inches	Depth of Sampling Inches	Moisture: Before Irrig. %	Moisture: After Irrig. %	Moisture: Difference %	Nitrates: Before Irrig. p.p.m.	Nitrates: After Irrig. p.p.m.	Nitrates: Difference p.p.m.
I	Manhattan Soil	2	0- 3	4.4	36.4	32.0	53.8	9.6	-44.2
			3- 6	9.6	31.0	21.4	53.8	18.1	-35.7
			6- 9	11.1	29.5	18.4	97.6	85.5	-12.1
			9-12	15.5	20.2	4.7	97.6	171.6	+74.0
								Total	-19.0
II	Lincoln Soil	2	0- 3	9.1	37.9	28.8	15.9	2.2	-13.7
			3- 6	9.1	33.7	24.6	15.9	16.4	+ 0.5
			6- 9	15.0	17.4	2.4	15.9	26.8	+10.9
			9-12	15.0	14.9	----	15.9	----	----
								Total	- 2.3
III	Lincoln Soil	2.5	0- 3	9.3	40.0	30.7	22.6	3.0	-19.6
			3- 6	9.3	37.6	28.3	22.6	22.0	- 0.6
			6- 9	15.9	22.2	6.3	22.6	37.4	+14.8
								Total	- 5.4
IV	Lincoln Soil	2	0- 4	8.8	40.1	31.3	74.9	7.0	-60.9
			4- 6	8.8	35.4	26.6	74.9	91.2	-16.3
			6- 8	8.8	17.6	8.8	74.9	159.8	+84.9
								Total	+ 7.7
V	Lincoln Soil	2	0- 4	8.8	37.6	28.8	74.9	0.17	-74.7
			4- 6	8.8	34.6	25.8	74.9	60.6	-14.3
			6- 8	8.8	22.0	13.2	74.9	199.4	124.5
								Total	+34.5
VI	Lincoln Soil	2	0- 4	5.1	41.7	36.6	76.0	5.2	-70.8
			4- 6	5.1	37.8	32.6	76.0	105.8	29.8
			6- 8	5.1	18.0	12.9	76.0	162.3	86.3
								Total	+40.3

(continued)

Table XI continued

Experiment	Soil Used	Amount of Water Inches	Depth of Sampling Inches	Moisture Before Irrig. %	Moisture After Irrig. %	Moisture Difference %	Nitrates Before Irrig. p.p.m.	Nitrates After Irrig. p.p.m.	Nitrates Difference p.p.m.
		2	0- 4	8.5	----	----	61.9	----	-61.9
	Lincoln		4- 6	8.5	32.0	23.5	61.9	62.7	+ 0.8
VII	Soil		6- 8	8.5	19.5	11.0	61.9	142.7	+80.8
								Total	+19.7
		2	0- 4	8.5	----	----	61.9	----	-61.9
	Lincoln		4- 6	8.5	31.1	22.6	61.9	72.4	10.5
VIII	Soil		6- 8	8.5	15.3	6.8	61.9	129.1	67.2
								Total	+15.8

It is a simple matter to demonstrate in the laboratory that when alcohol is added to a column of moist soil the first percolate obtained is water free from any alcohol. The alcohol displaces the soil solution as it percolates down through the soil. In like manner water percolating through a soil column drives the soil solution ahead and the first percolate obtained is representative of the soil solution in equilibrium with the solid phase of the soil before irrigation. It is interesting to note this apparent displacement in the results of the experiments given in Table XI. It will be observed that a relatively small increase in the moisture content of the lowest layer of soil usually was accompanied by a large increase in nitrate content in the same layer.

Another experiment was performed in order to determine the relative concentration of various portions of the leachate from a 100 gram sample of soil leached with a two-inch column of water. Successive 15 cc portions of the leachate were collected and nitrates determined. The results are recorded in Table XII.

Nitrates were present in measurable amounts in each of the first 15 cc portions. Succeeding portions showed no indications of the presence of nitrates although the phenodisulphonic acid method is a comparatively sensitive test.

Table XII. Nitrates extracted from 100 gr. soil by a water column of two inches depth.

Experiment	Water Before %	Nitrates Before p.p.m.	Replications	Extraction First 15 cc	Second 15 cc	Third 15 cc	Total Nitrates Extracted
I	5.12	76.04	I	68.82	3.47	2.36	74.65
			II	68.86	2.04	1.57	72.47
			III	65.35	2.99	2.36	70.70
			Average	67.67	2.80	2.09	72.60
			Per cent of total	88.9	3.7	2.8	95.4
II	8.35	73.00	I	61.27	9.58	0.89	71.74
			II	50.78	18.04	2.60	71.42
			III	70.37	0.81	0.23	71.41
			Average	60.77	9.47	1.24	71.50
			Per cent of total	83.2	12.8	1.6	97.6

More than 80 per cent of the nitrates present in the sample were removed in the first 15 cc of percolate. The amount in the second 15 cc portion was much smaller and declined still further in the third portion. Altogether 95.4 per cent of the original nitrate content was extracted in the first experiment and 97.6 per cent in the second experiment. The remaining part of the original nitrate content is unaccounted for except that the leaching process may not have been as effective in extracting nitrate nitrogen from the soil as the shaking process by which the original nitrate content was extracted from similar samples. The data indicate once more quite clearly the readily soluble and easily extractable nature of the nitrate nitrogen of the soil.

SUMMARY

Studies of the movement of nitric nitrogen in soils were made in field plots established on the Agronomy Farm of the Kansas State College. Studies were also conducted in the laboratories of the Kansas State College and the University of Nebraska.

Soil profiles were exposed and described in order to provide evidence of value in the interpretation of water and nitrate movements in the field plots. Moisture equivalent, hygroscopic coefficient and mechanical analyses also were made of samples from the various layers into which the profiles were divided.

In field plots in which the surface soil was a very fine sandy loam and the subsoil ranged from a very fine sandy clay loam to a silty clay loam the addition of 2 inches of irrigation water caused the nitric nitrogen to move downward and the zone of maximum concentration proved to be the 6-9 inch layer. Before irrigation nitrates were most concentrated in the surface 3 inches of the soil. Moisture determinations showed increases of moisture content down as far as 12 to 18 inches 16 hours after irrigation.

On drying of the soil the nitrates moved back toward the surface and again became most concentrated in either the 0-3 inch layer or the 3-6 inch layer after several days. This experiment was replicated three times on each of two experimental plots and quite consistent results resulted from all trials.

Nitrates were removed almost completely from the surface soil in samples taken immediately after 2 inches of irrigation water were applied. Nitrate movement occurred to depths of 18-24 inches.

In another experiment two plots were seeded with oats and two fallowed. No irrigation was practiced but the plots were sampled at intervals, before and after rains. The effect of the growing oats crop on the nitrate content of the soil was marked but the zone of maximum concentration of nitrates was always at about the same depth in the cropped soil as in the nearby fallowed soil. Rains caused marked movement of nitric nitrogen and the range of movement was about the same in both cropped and fallowed soil.

In the samples of soil removed from the field plots after irrigation or rainfall the nitrate content of the lower layers of the soil, below the zone of maximum accumulation, frequently was lower than before the water was added. This would indicate some loss of nitric nitrogen had occurred. The writer believes these losses occurred too rapidly in most cases to be attributed to biological denitrification. No adequate explanation can be offered from the evidence obtained in the experimental work reported here.

Laboratory experiments were designed in an effort to show the extent of such losses. Of eight experiments, three showed losses and five showed gains. The conditions were not similar in some important respects to those in the field plots and the results must be considered inconclusive. Movements of nitrates downward with percolating water were similar to those observed in the field plots.

Leaching of 100 gram samples of soil with 2 inch columns of water in the laboratory showed that over 80 per cent of the total nitrate content of the soil was recovered in the first 15 cc of percolate. After the third 15 cc portion no nitrates could be detected. Complete removal of the nitrates of the soil could not be obtained in this way, about 2.5 per cent to 4.5 per cent of the original nitrate content not being accounted for in the leachings.

The results of all experiments clearly point to the high solubility and ready mobility of the nitric nitrogen of the soil.

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