THE MOVEMENT OF SURFACE APPLIED NITRATE IONS INTO SOILS AT FIVE MOISTURE LEVELS AND PLANT ABSORPTION OF NITROGEN FROM SOILS BELOW PERMANENT WILTING POINT

By

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PREFACE

The studies reported in this thesis are a part of the soil management research conducted jointly by the Agricultural Research Service, United States Department of Agriculture, and the Oklahoma Agricultural Experiment Station.

The author is grateful to Dr. Harold V. Eck, thesis adviser, for his patient assistance throughout the course of this study, and for his advice and helpful criticisms. The writer wishes also to thank Dr. J. Q. Lynd, Dr. Robert M. Reed and Dr. A. M. Schlehuber for helpful advice and criticisms in preparing the manuscript, and to other members of the Department of Agronomy for suggestions and assistance.

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INTRODUCTION

In the Great Plains region, nitrogen fertilizers are commonly broadcast on, or placed from one to three inches below, the surface of the soil. It is a common practice to broadcast ammonium nitrate or other dry nitrogen carriers as top dressings on established stands of winter wheat in late February or early March. This is the season when wheat normally enters a stage of rapid growth. In many seasons, no appreciable precipitation occurs for two to four weeks after the fertilizer is applied. The fertilizer usually disappears from the surface of the soil within a few days regardless of whether or not precipitation is received. Also, in this semi-arid area, the portion of the soil in which fertilizers are applied is at or below the wilting percentage during much of the growing season. Moisture for plant subsistence and growth is obtained from the subsoil.

The objectives of this study were: (1) to determine whether the nitrate nitrogen in ammonium nitrate moves into the soil to the root zone when it disappears from the soil surface in the absence of effective precipitation or whether it remains immediately beneath the soil surface until sufficient rainfall is received to move it into the root zone and (2) to determine if plants can absorb nitrogen from a soil at or below the wilting percentage when there is available moisture elsewhere in the root system.

REVIEW OF LITERATURE

Movement of Surface Applied Nitrate Ions into Soils

There has been only a limited amount of research published dealing with the movement of nitrates by diffusion. Most of the nitrate movement experiments have been leaching studies.

Muntz and Gaudechon (21)[1/], in 1909, concluded that the "soil is a discontinuous medium in which even the most soluble substances diffuse only with extreme slowness and in which there will exist simultaneously and for a long period, zones of very different composition unless uniformity is brought about by cultivation or increase in moisture." In 1913, Malpeaux and Lefort (19) conducted studies using calcium and sodium nitrate in boxes of sand and loam soil. They showed that simple diffusion was comparatively slow and was practically the same laterally as vertically. Sprinkling with water accelerated downward as well as lateral diffusion, but there was a comparatively rapid return of the nitrates to the superficial layers of the soil. The diffusion was somewhat slower but more uniform in the loam soil than in the sandy soil. Lebedev (17) stated in 1933 that salts did not move in soils at a moisture below maximum hygroscopicity. He further stated that in the presence of film and gravitational water, salt moved in the direction of lesser concentration, and while somé of the movement was the same

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[1/] Figures in parentheses refer to "Literature Cited," Page 33.

direction as that of the moisture movement, it also moved in the opposite direction. Brown (5), in 1953, carried out an excellent laboratory experiment studying cation exchange at moisture variables from saturation to the wilting percentage. He stated that the ionization and transport of cations through the soil by diffusion, migration, or by contact exchange was dependent upon the thickness and continuity of the water films within the pore system of the soil. The rate and extent of cation exchange was controlled by the moisture status. Brown concluded that cations did move through the soil at all moisture contents from maximum water holding capacity to 15 atmosphere percentage, but decreased in movement as the moisture decreased.

In 1895 Puncher (22) made a study to determine the movement of soluble salts as affected by movement of water, both downward and upward. The soils used varied from quartz sand to rich humus soils. He found that soluble salts rose and sank with the soil water, but that the movement was somewhat dependent on the chemical and physical properties of the soil. The accumulation of salts at the surface increased with the rapidity of evaporation. Krantz and co-workers (16) found that while ammonium ions were rather immobile in the soil because they were absorbed by the base exchange complex, nitrate anions moved freely with the soil moisture. They also found that, during seasons of prolonged droughts, nitrates moved upward in the soil to accumulate at the surface. However, any moderate rainfall moved the nitrates back into the main root zone and made them available again to plants. King and Whitson (14, 15), carried out some laboratory studies on the upward movement of nitrates in cylinders of fallow soil. They were primarily interested in the effect of various depths of dust mulches, but they did report some tremendously high accumulations of nitrates in the surface inch. Buckman (6) made similar studies in 1910. He also reported an accumulation of nitrates in the surface soil, as a result of upward movement during the summer. Finnell (7), in 1932, reported that the interval between the last previous harvest and nitrate sampling was the most important factor determining the accumulation of nitrates. The number of excessive rains was important in adversely affecting nitrate accumulation.

Plant Absorption of Nitrogen from Soils Below Permanent Wilting Point

Only a small amount of research has been done in regard to nutrient uptake at moisture levels at or below the wilting percentage. This problem, however, is of great importance in dry land agriculture when fertilizers are applied only on or in the surface soil.

Magistad and Breazeale (18), in 1925, offered a theory that plants might be able to take up nutrients from a soil that was below the permanent wilting point if there was water elsewhere in the root zone. Their thinking was that at all percentages of soil moisture, from optimum to an air dry condition, there was a film of water surrounding each soil particle regardless of its size. In the inner layers of the soil film, nutrient materials were the most concentrated. The enormous attractive force of the soil particle for water at the wilting percentage might prevent the absorption of water by the plant, but it might not interfere with the absorption of nutrient material. They concluded that surface soil which was maintained at the wilting percentage during a great part of the growing season might furnish a feeding ground for plants, although there was no available water present. Breazeale (1) in 1929, published data to substantiate the theory that had been presented earlier. He found that a plant was able to absorb moisture from any soil horizon where water was available, for example a subsoil, and transport that moisture to another horizon, where moisture was scarce, for example the surface soil. He presented a theory that nutrient ions were probably taken up by the plant as electrical charges, and that no bodily movement of water was necessary. He believed that since there was a direct water contact between the plant and the soil, that nutrient ions could move from the soil to the plant, even after all soil water movement had ceased. His data showed that a plant was able to absorb water from a soil at optimum moisture level and reduce the percentage to the wilting point, and at the same time to increase the moisture of a dry soil to the wilting point. Breazeale and Crider (2), in 1934, presented more data showing that plants could transport water from one horizon to another. They also showed that a deep rooted plant was able to absorb water from the subsoil, transport and exude it into surface soil where it was absorbed by a shallow rooted plant. These studies were carried out in the laboratory. Another part of their experiment showed that roots of certain plants were able to penetrate soils that were below the wilting point. Breazeale and McGeorge (3), in 1949, presented a new technique for determining the wilting percentage of the soil. They jacketed three tomato plants with soil, one at 0% moisture, one at 6%, and one at 28%. All three tomato plants were placed in a pot with optimum moisture. They sampled the soil after seven weeks of growth and found that all three jackets contained soil with 11% moisture. They assumed this to be the wilting point. This also confirmed their theory that plants could transport water from one horizon to another. Hunter and Kelley (12), in 1946, grew corn for 30 days in tar-paraffin pots filled with moist soil and surrounded by air-dry soil. In all cases, the corn roots penetrated the wall of the pot and extended into the dry soil. The moisture content of the dry soil was increased, but values as high as the permanent wilting percentage were not obtained. Volk (24), in 1947, found that corn grew roots into air-dry Plainfield sand and increased the moisture content to 2.3 times the initial level. Corn also grew roots into Clyde silt loam at .7 and .9 of the wilting point, and showed a net translocation of moisture into dry soil. Contrary to the experiments mentioned above, Hendrickson and Veihmeyer (9), in 1931, stated that their results indicated that roots would not grow into soil which contained less moisture than the permanent wilting point.

Breazeale (1), in 1929, found that wheat plants were able to take up potassium from a soil at wilting point if part of their roots were in water. Hunter and Kelley (13), in 1946, using alfalfa as the crop, attempted to determine whether plants could absorb nutrients from a soil below the wilting percentage. They used a wooden column with tar partitions about every 8 to 9 inches. Radioactive phosphorus was added to the soil in the top three partitions. It was added in a solution and then they allowed the plants to absorb the water from the soil in those partitions until the wilting percentage was reached. The alfalfa tops were removed and water was added to the partitions below those where radioactive phosphorus had been added. The data obtained indicated an increase in phosphorus content during the month following, but the workers stated that the increase might have been due to the translocation to the tops of radioactive phosphorus present in the roots when the initial tops were removed 6 days after application of the radioactive phosphorus. They felt that their experimental results were not conclusive. Volk (24), in 1947, showed that millet could absorb nitrogen from a soil at the permanent wilting point if the soil was protected against evaporation. In other similar experiments, Volk showed that potassium could be absorbed from a dry soil but that the absorption of phosphorus was more doubtful. He concluded that certain elements apparently could be absorbed by plants with roots in soil depleted of available moisture but maintained approximately at the wilting point. Hobbs and Bertramson (11), in 1949, grew tomato plants in the greenhouse to study the effect of dry soil conditions on the uptake of boron by plants. The results showed that fast growing tomato plants were not able to obtain enough boron from dry surface soil to maintain normal development, even though adequate moisture was available in the subsoil.

Millar and Turk (20) stated that "it is generally believed that material must be in solution to pass through the plant-root membrane. Nutrients in the soil solution should therefore be in suitable condition for absorption. It must be pointed out, however, that the presence of a nutrient in the soil solution does not assure its use by the plant because the passage of ions and molecules through the absorbing membranes of the root is affected by various factors. Furthermore, it can not be assumed that nutrients must be in solution to be used by plants. In the zone of intimate contact which exists between a root hair and a soil particle or a colloidal aggregate, there is the possibility of the solution and absorption of nutrients."

MATERIALS AND METHODS

Movement of Surface Applied Nitrate Ions into Soils

Four experiments were designed to determine whether or not the nitrate nitrogen in ammonium nitrate moves into the soil to the root zone when it disappears from the soil surface in the absence of effective precipitation. They were as follows:

Experiment 1 - A study of the effect of soil moisture on the diffusion of nitrates.

Experiment 2 - A study of the effect of fluctuating temperature on the diffusion of nitrates in soil.

Experiment 3 - A study of the diffusion of nitrates in soil under field conditions.

Experiment 4 - A study of the upward movement of nitrates as a result of soil drying.

The four experiments are presented individually.

Experiment 1

Soil moisture contents of moisture equivalent, 3, 5, 8, and 15 atmosphere percentages were selected for this experiment. Tillman clay loam soil was used because it represented a typical wheat soil. It is one of the major wheat producing soils and is similar in physical properties to other major wheat producing soils.

Soil from the upper 6 inches of the profile was brought into the laboratory, air dried, processed, and divided into aliquots of 450 grams. The aliquots were brought individually to the desired moisture percentage.

and then placed in open aluminum cylinders which were 3 inches in diameter and 3 inches in height. One end of each cylinder was covered with a piece of cloth which was held in place by a heavy rubber band. The moisture equivalent percentage was obtained by adding a known amount of water to a known amount of soil, mixing, and allowing the system to stand until equilibrium was reached. The amount of water to be added was calculated from the moisture equivalent value determined by the centrifuge method (4). The 3, 5, 8, and 15 atmosphere percentages were obtained by use of the pressure membrane method proposed by Richards (23).

Ammonium nitrate was placed on the surface of the soil in the cylinders at the rate of 600 pounds per acre. The individual cylinders were then placed into plastic bags which were immediately sealed. They were placed in a constant temperature room at 65^0 F for a period of 14 days. The soil was removed in horizontal one-half inch sections. Nitrates were then determined by the phenol disulphonic acid method (8). There were 4 replications for each treatment except the 3 atmosphere percentage which was replicated only 3 times.

Experiment 2

Tillman clay loam soil was again used and was brought to the 5 atmosphere moisture percentage in the same manner as in Experiment 1. Ammonium nitrate was applied to the surface of the soil at the rate of 600 pounds per acre and the cylinders were placed in plastic bags and sealed. The cylinders were placed in a refrigerator regulated at 40^0 F for fifteen hours and then placed in a room at 75^0 F for nine hours. This cycle was continued for a period of 14 days. The soil was removed, and nitrate determinations were made. There were 3 replications.

Experiment 3

Kirkland silt loam, Pond Creek silt loam, and Grant silt loam soils were used for this study. Ammonium nitrate was applied on the surface of field plots at the rate of 240 pounds per acre. The plots on the Kirkland silt loam were sampled 7 days after the ammonium nitrate was added, on the Pond Creek silt loam 9 days after application, and on the Grant silt loam 10 days after application. Samples were also taken from adjacent plots which did not receive ammonium nitrate. The samples were taken by pressing a cylinder (same as described in Exp. 1) into the soil and then removing the cylinder of soil after the adhering soil particles had been removed from the sides of the cylinder. The samples were immediately brought to the laboratory and sectioned horizontally into one-half inch sections. Moisture and nitrate determinations were made on each section. There were five subsamples taken on each plot.

Experiment 4

Tillman clay loam was used for this study. Four aliquots of soil were brought to the one-atmosphere moisture percentage by adding water to the soil, and tumbling the soil-water mixture in a tumbling machine until equilibrium was reached. Ammonium nitrate, at the rate of 400 pounds per acre, was dissolved in the water before it was added to the soil. The aliquots were placed in cylinders which had one end sealed with rubber sheeting and a layer of paraffin on top of the sheeting. The soil was placed in the bottom two and one-quarter inches of the cylinder. The top three-quarters inch of the cylinder was filled with air-dry, nitrate free soil. (Nitrates were removed from the soil by leaching with distilled water). The cylinders were allowed to stand at room temperatures (approximately 75° F) until all the soil was air-dry. This was determined by frequent weighings. Nineteen days were required for the soil to dry to the air-dry percentage. The soil was then sampled in one-half inch horizontal sections and nitrate determinations made. There were four replications.

Plant Absorption of Nitrogen from Soils Below Permanent Wilting Point

A growth room experiment was conducted to determine whether plants can absorb nitrogen from a soil at or below the wilting percentage when there is available moisture elsewhere in the root system. Wheat plants were grown in specially constructed pots in which a portion of the roots was grown in soil and the remainder was grown in a culture solution. A diagram of one of the pots is shown in Figure 1.

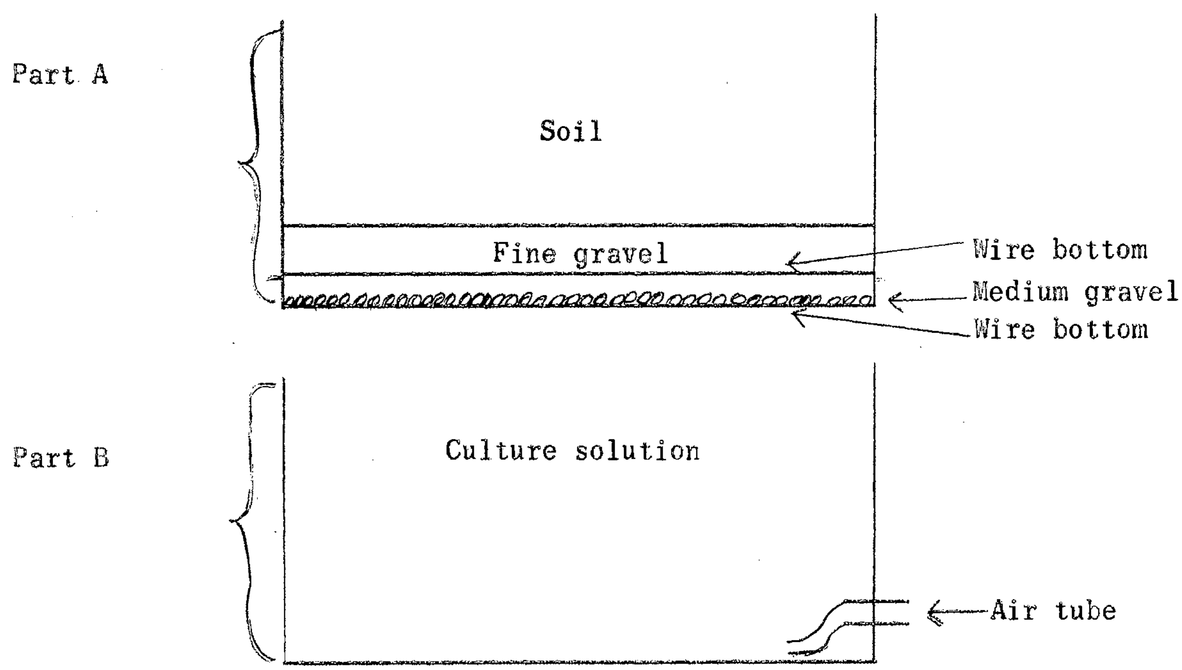

Figure 1. Diagram of one of the pots.

The pots were constructed from galvanized sheet metal. The fine gravel was placed in Part A to serve as a buffer zone to prevent capillary water movement. The second wire bottom, covered with a layer of medium gravel, was added to catch any splashes of water ejected when air bubbles rose to the surface. Air was supplied through a tube in the bottom of Part B to insure an adequate supply of oxygen. The air space between the wire bottoms served as a buffer zone to further assure that the moisture from the culture solution did not wet the soil to a moisture content above the wilting percentage.

Nine hundred grams of Tillman clay loam soil were added to each pot. Superphosphate containing 20% P_2O_5 was added at the equivalent rate of 400 pounds per acre and ammonium nitrate was added at the equivalent rate of 600 pounds per acre. The fertilizers were mixed with the soil before potting. Culture solutions, complete, and minus nitrogen, as prescribed by Hoagland and Arnon (10), were added to Part B of the pots. There were 6 pots, 3 of which had complete culture solutions and 3 had minus nitrogen solutions.

The pots were placed in a constant temperature room at 70° F. Fluorescent and tungsten bulbs were placed approximately two feet above the pots to serve as a light source. The lights were turned on for 16 hours and off for 8 hours each day.

The soil was wetted to moisture equivalent and winter wheat (Concho variety) was planted. Forty seeds were planted in each pot. The soil moisture was maintained at an optimum moisture content until the plants established good root systems in the culture solution. Watering was then discontinued and in a short time the soil was below the wilting percentage and the only source of water for plant growth was the culture solution. The tops of the plants were clipped to remove nitrogen stored in the plant leaves. The plants were allowed to grow to approximately 10 inches in height and were clipped again. They were then allowed to grow until they headed and reached maturity. During this period, the plants were placed in a room at approximately 40^{0} F for 2 days for vernalization of the winter wheat.

Weights were taken of the clippings, mature plants, heads, and of the roots that were in Part B of the pot. Nitrogen determinations were made on the above ground vegetative material and on the grain by the Kjeldahl method (8).

The experiment was repeated with a few modifications. Spring wheat (Dickinson variety) was planted so the plants would not have to be subjected to cold air for the vernalization period. The number of plants was reduced to 6 per pot. Also, in this modified study, water was added to the soil only long enough to get a few roots in to Part B of the pot. The plants were not clipped and were not allowed to reach full maturity. Nitrogen determinations were made on the roots in addition to the above ground material.

RESULTS AND DISCUSSION

Movement of Surface Applied Nitrate Ions into Soils

Experiment 1

Soil moisture is a very important factor in the movement of surface applied nitrates into the soil. The data presented in Table I show this relation. The data clearly show that as the available moisture in the soil decreased, a larger percentage of the added nitrates remained near the surface and a smaller percentage moved into the root zone.

Table I. Percent of surface applied nitrates found at various soil depths as affected by soil moisture

Soil Depth	Moisture Equivalent 18.24%	3 Atmospheres 9.06%	5 Atmospheres 8.27%	8 Atmospheres 7.76%	15 Atmospheres 6.62%
0- ½"	44.75	48.30	53.05	58.04	65.77
½- 1"	26.93	28.35	29.54	26.05	29.85
1-1½"	16.44	13.55	11.92	7.40	3.20
1½- 2"	8.71	5.60	3.38	2.41	.51
2-2½"	2.77	2.49	1.42	4.18	.34
2½- 3"	.40	1.71	.71	1.93	.34

Standard error for difference between two means = 1.71%

The percentages shown are the total nitrates that were in each particular soil depth. This means that a small portion of these percentages is a measure of the nitrates originally present in the soil and is not a result of downward movement of the surface applied nitrates. However, the soil was analyzed for nitrates before the experiment was initiated and it contained only about 2 percent as many nitrates in the core as was added on the surface. If we assume that the initial nitrates were evenly distributed throughout the core, the amount was negligible for purposes of this experiment.

The data show a very consistent relationship between nitrate movement and moisture content, to a depth of two inches. The percentages obtained for the last inch seem somewhat erratic, but some explanation can be given. The percentages for the two to two and one-half inch depths show decreases in movement of nitrates as the moisture content decreased, except for the eight atmosphere moisture percentage. The value, 4.18 percent, is an average of four replications and two of these replications were much higher in nitrates than the other two, making the average figure higher. If only the two low replications had been used, a value of 1.64 percent would have been obtained, which is reasonable when compared to values obtained at the other moisture levels. The erratic results obtained for the two and one-half to three inch depths can be attributed to sampling error. The soil was sampled by sliding the soil up the cylinder one-half inch at a time and then slicing off the soil. The two and one-half to three inch sample was the remains in each case and was usually either a little more or a little less than the desired half-inch.

The data show that a statistically significant portion of surface applied nitrates moved into the soil to a depth of two and one-half inches in a two week period when the soil was at the moisture equivalent.

Nitrates moved to a depth of two inches when the soil was at the three or five atmosphere percentage and to a depth of one and one half inches at the eight and fifteen atmosphere percentages.

Experiment 2

This experiment was conducted to determine whether variable temperatures would appreciably change the results that were obtained earlier under constant temperature. The results are shown in Table II.

Table II. Percent of surface applied nitrates found at various soil depths as affected by temperature.

	Temperature	
Soil Depth	Constant 65° F	Variable 40° F - 15 hrs., 75° F - 9 hrs.
0- ½"	53.05	59.18
½- 1"	29.54	30.48
1-1½"	11.92	8.20
1½- 2"	3.38	1.25
2-2½"	1.42	.35
2½- 3"	.71	.54

Surface applied nitrates moved to a depth of two inches under constant temperature and to a depth of only one and one-half inches under variable temperature. However, since diffusion is directly affected by temperature, the lesser movement under variable temperature may have been due to a lower mean temperature and not to the variations in temperature. The results are not conclusive but indicate that varying temperatures did not have an appreciable effect on the movement of surface applied nitrates into the soil.

Experiment 3

The results are presented in Table III. The moisture percentages of the 0-6 inch layer of the soils at the time of nitrate application were 16.49 for the Grant silt loam, 17.89 for the Kirkland silt loam, and 17.82 for the Pond Creek silt loam. The moisture percentages mentioned above approach the moisture equivalent percentages which are 16.80, 18.81, and 17.40 respectively. The 15 atmosphere moisture percentages are 6.57, 7.27, and 7.00 respectively. The moisture contents of the samples at the time of sampling are listed in Table III.

The percentages of applied nitrates found in each particular depth are presented in Table III. Nitrate determinations were made on adjacent plots without added nitrates and subtracted from the determinations of the treated plots. The data show that a significant amount of nitrates moved into the second half-inch and that there was some movement of nitrates into the third half-inch, although statistical analyses did not show this amount to be significantly different from the amounts below that depth. The soil moisture percentages at the time of sampling show that the soil moisture was evaporating at the same time the nitrates were moving downward.

Experiment 4

The results are presented in Table IV. It was assumed at the beginning of the experiment that the added nitrates were evenly distributed throughout the bottom two and one-quarter inches of soil and that the upper three-quarters inch was free of nitrates. Under this

Table III. Percent of surface applied nitrates found at various soil depths under field conditions.

Depth of sample	Grant silt loam 16.49% moisture at time of application		Kirkland silt loam 17.89% moisture at time of application		Pond Creek silt loam 17.82% moisture at time of application	
	% moisture at time of sampling	% added nitrates	% moisture at time of sampling	% added nitrates	% moisture at time of sampling	% added nitrates
0- ½"	4.45	74.35	7.95	77.23	5.57	79.93
½- 1"	5.32	20.43	8.79	15.56	7.72	15.49
1-1½"	7.65	4.35	12.28	3.75	9.14	3.17
1½- 2"	9.53	.87	13.20	1.73	9.34	.70
2-2½"	10.11	.00	12.85	.87	10.16	.70
2½- 3"	9.79	.00	13.23	.86	10.49	.00

Standard error for difference between two means = 5.17%

assumption, each of the four bottom one-half inch layers contained 22 percent of the added nitrates and the one-half to one inch layer contained 12 percent of the added nitrates.

Table IV. Percent of nitrates found at various soil depths after evaporation of soil moisture.

Soil Depth					
0 -½"	½ - 1"	1 - 1½"	1½ - 2"	2 - 2½"	2½ - 3"
8.39	58.04	8.39	7.69	10.14	7.35

The results show that there was an upward movement of a portion of the nitrates, and that most of the upward movement stopped at the transition zone between the moist soil and the air dry soil. The data indicate that during seasons of prolonged drouth, a portion of the nitrates will move upward as the moisture evaporates. However, it is indicated that on fields where there is a dust mulch on the surface, the greatest accumulation of nitrates will be found at the mulch-undisturbed soil interface.

Conclusions

The data show that surface applied nitrates will move into the soil at all moisture contents from moisture equivalent to the wilting percentage. However, the amount and depth of movement definitely were affected by the amount of moisture in the soil. One can expect some utilization of surface applied nitrates before rainfall has washed the nitrates downward, but maximum efficiency can be expected only after rainfall has been received to move the nitrates deeper into the root zone.

Plant Absorption of Nitrogen From Soils Below Permanent Wilting Point

Experiment 1

There were differences between pots in both top and root growth at the time the soil moisture was exhausted and the roots were placed in differential culture solutions. There was approximately the same number of plants in each pot. The differences can be attributed to uncontrolled variables such as differences in light or differences in aeration in the culture solutions. Aeration in all six pots was regulated with one gauge and it was difficult to maintain equal aeration in all pots. The differences in growth may be observed in Figure 2.

The pots were paired on the basis of top and root growth and the roots of one of each pair were placed in culture solutions containing nitrogen (the N series) and the roots of the other of each pair were placed in culture solutions containing no nitrogen (the no-N series). The tops were clipped off evenly on all pots. The reason for this clipping was to remove nitrogen stored in the leaves and to make the paired pots as nearly alike in top growth as practicable. The three pairs, after clipping, are shown in Figure 3. The yield and nitrogen content of this clipping were not recorded.

Forage yield, grain yield, and nitrogen uptake data are presented in Table V. The first and second clippings were made 11 and 28 days after the differential treatments were introduced. The final harvest

Figure 2. The 6 pots of Experiment 1, after pairing and just previous to clipping and introduction of differential culture solutions. Pairs were as follows, left to right: Pots 2 and 5, 6 and 3, and 4 and 1. Pots 2, 3, and 1 were used for the N-series and pots 5, 6, and 4 were used for the no-N series.

Figure 3. The 6 pots of Experiment 1, after pairing and clipping and just previous to introduction of differential culture solutions. Pairs were as follows, left to right: Pots 2 and 5, 6 and 3, and 4 and 1. Pots 2, 3, and 1 were used for the N-series and pots 5, 6, and 4 were used for the no-N series.

Table V. Forage yield and nitrogen uptake data 11 and 28 days after introduction of treatments and forage yield, grain yield and nitrogen uptake data at maturity (Experiment 1).

		First Clipping			Second Clipping			At Maturity: Forage			At Maturity: Grain		
	Pot No.	Yield	Nitrogen	Nitrogen	Yield	Nitrogen	Nitrogen	Yield	Nitrogen	Nitrogen	Yield	Protein	Nitrogen
		gms.	Percent	mgms.	gms.	Percent	mgms.	gms.	percent	mgms.	gms.	Percent	mgms.
N Series	1	.48	4.76	22.8	.77	3.86	29.7	7.77	2.45	190.4	*		
	2	.88	4.60	40.5	.97	3.87	37.5	9.00	2.24	201.6	*		
	3	1.79	4.56	81.6	2.20	3.87	85.1	19.22	1.98	380.6	.61	25.08	26.8
no-N Series	4	.79	4.46	35.2	.69	2.94	20.3	9.63	1.06	102.1	.12	16.72	3.5
	5	1.31	3.86	50.6	.92	2.59	23.8	13.48	1.18	159.1	.25	19.44	8.5
	6	1.93	4.04	80.0	1.50	2.91	43.7	13.60	1.02	138.7	.52	18.66	17.0

* Plants died.

was made 141 days after the differential treatments were introduced. At the first clipping, the nitrogen content of the clippings from the no-N series was only slightly lower than that of the N series. Differences in forage yields at this time were probably more a reflection of lack of initial uniformity than of differences due to treatment. The average yield on the N series was 1.05 gms. per pot while that on the no-N series was 1.34 grams per pot. Average nitrogen removal for the two series was 48.3 and 55.3 mgms. per pot, respectively.

At the second clipping, the no-N series was markedly lower in nitrogen content than the N series. The average yield on the N series was 1.31 gms. per pot while that on the no-N series was 1.04 grams per pot. Average nitrogen removal for the two series was 50.8 and 29.3 mgms. per pot respectively. The widened difference in nitrogen content of clippings between the two series at the second clipping as compared to the first, indicate that nitrogen uptake in the no-N series was definitely lower than that in the N series.

The plants in two of the three pots of the N series died before heading and maturing, thus yield and nitrogen removal data were obtained from only one pot in that series. That pot was paired with and most comparable to pot 6 in the no-N series at the outset of the experiment, thus the most logical comparison available is between those two pots, shown in Figure 4. The N series pot yielded a total of 19.83 gms. (grain and straw) while the no-N series pot yielded a total of 14.12 grams (grain and straw). The total nitrogen uptake (grain and straw) on the N series was 407.4 mgms. while that on the no-N series was 155.7 mgms. The grain yield on the N series pot was .61 gms. while that on the no-N series pot was .52 gms. Grain protein was high on both pots but somewhat higher on

Figure 4. A comparison of the no-N series with the N-series (Experiment 1) on harvest date. Left to right: Pot 6 - no-N series, pot 3 - N series, pot 5 - no-N series. Pots 6 and 3 were paired pots.

the N series pot than on the no-N series pot. The values were 25.08 and 18.66 percent, respectively.

The results of this experiment do not give conclusive proof as to whether or not nitrogen was taken up from dry soil. The reduced growth, lowered nitrogen content, and lowered nitrogen removal on the no-N series definitely show that if nitrogen was taken up from the dry soil, uptake was much slower from dry soil than from a culture solution. The total nitrogen removed in the no-N series pots from the time the differential treatments were introduced to maturity, 161.1 mgms. from pot 1, 242.0 mgms. from pot 2, and 279.4 mgms. from pot 3, could have been in the plant material at the time the differential treatments were introduced. Eight grams of dry plant material at 3.5 percent nitrogen would have contained 280 mgms. of nitrogen, the total removed from pot 3 of the no-N series. Though the amount of dry material present at the introduction of the differential treatments can only be estimated, 8 gms. is not unreasonable. An average nitrogen content of 3.5 percent for an entire plant is not unreasonable either when one considers that the first clippings contained 4.76 percent nitrogen.

Experiment 2

The plants were paired with respect to the amount of top and root growth and the roots were placed in culture solutions as described in Experiment 1. However, in this experiment, the roots were placed in the culture solutions as soon as roots from all of the plants were long enough to reach the solution level. The soil was then allowed to dry.

Forage yield, root yield, and nitrogen uptake data are presented in Table 6. Forage yields averaged 7.80 gms. per pot for the no-N series and 6.77 gms. per pot for the N series. The plants were harvested 60 days after the roots were placed in the culture solutions. The no-N series were approaching maturity while the N series were just beginning to reach the boot stage. It was quite evident that if the plants in the N series had been allowed to reach the same degree of maturity as those in the no-N series, their yields would have been much higher. The plants in the N series had an average of 2.3 tillers per plant while only 2 plants in the no-N series had more than one tiller. Also, the leaves of the N series plants were much broader than those of the no-N series plants. Figures 5 and 6 show these differences. The plants were harvested before reaching maturity so that nitrogen determinations could be made on the live root systems.

Table VI. Forage yield, root yield, and nitrogen uptake data from Experiment 2.

	Pot	Shoots			Roots (In culture solution only)		
	No.	Yield	Nitrogen	Nitrogen	Yield	Nitrogen	Nitrogen
		gms.	Percent	mgmg.	gms.	Percent	mgms.
N Series	1	3.08	2.78	85.6	.58	1.40	8.1
	2	5.29	3.01	159.2	1.04	2.71	28.1
	3	11.93	3.01	359.1	1.53	2.12	32.4
no-N Series	4	3.58	.90	32.3	1.15	1.12	12.9
	5	6.09	.90	54.7	2.39	.94	22.5
	6	13.74	.82	113.1	3.80	.84	31.9

Weights of roots in the culture solutions averaged 2.45 gms. per pot for the no-N series and 1.05 gms. per pot for the N series.

Figure 5. The N-series pots, Experiment 2, just previous to harvest. Left to right: pots 2, 3, and 1.

Figure 6. The no-N series pots, Experiment 2, just previous to harvest. Left to right: pots 5, 6, and 4.

Total nitrogen removal (root nitrogen plus shoot nitrogen) averaged 224.2 mgms. per pot in the N series as compared to 89.1 mgms. per pot for the no-N series. If we assume that at the time the soil moisture was exhausted, the plants contained 4 percent nitrogen; 1.13, 1.93, and 3.63 gms. per pot of dry material would have been required to contain as much nitrogen as was recovered at the time of harvest in pots 4, 5, and 6 respectively. The plants were 31 days old at the time the soil was assumed exhausted of moisture and 4 percent nitrogen at that early stage of growth does not seem unreasonable. There is no way of knowing exactly how much dry plant material was present at the time the soil moisture was depleted, but the weights mentioned above are less than one third of the dry weights at harvest and seem within reason. The data indicate that if there was any nitrogen taken up from the dry soil, it was in such small quantities that the plants could not make optimum growth.

Shoot-Root Ratios

Data are presented in Table VII. The shoot-root ratios were narrower in every case in the no-N series. In Experiment 1, the average shoot-root ratios were 11.00 to 1 for the N series and 8.05 to 1 for the no-N series. In Experiment 2, the average was 6.07 to 1 for the N series as compared to 3.09 to 1 for the no-N series. The reason that the no-N series plants produced more roots in proportion to shoots than the N series plants was not ascertained but this was apparent throughout both experiments, as can be seen in Figures 4, 5, and 6.

Table VII. Shoot-root* ratios of plants from Experiments 1 and 2.

	Pot No.	Experiment 1	Experiment 2
N Series	1	11.28:1	5.31:1
	2	11.18:1	5.09:1
	3	10.54:1	7.80:1
no-N Series	4	7.20:1	3.11:1
	5	8.31:1	2.55:1
	6	8.65:1	3.62:1

* Root weights used in the calculations of shoot-root ratios were those of the roots in culture solutions only.

Conclusions

The data do not conclusively show whether or not wheat plants can absorb nitrogen from a soil below the wilting percentage when there is water elsewhere in the root system. They do show, however, that if nitrogen was absorbed from dry soil in this experiment, it was absorbed in much smaller quantities than it was from a culture solution and that insufficient nitrogen was absorbed for optimum growth and yield. It is quite possible that no nitrogen was absorbed from the soil after it reached the wilting point and that after that time, nitrogen already in the plants furnished the supply of nitrogen for all further growth. If this is true, the wheat plants absorbed enough nitrogen in the first 31 days after planting to enable them to head and approach maturity. In plants grown under nitrogen deficient conditions after the initial growth period, maturity was hastened, and tillering, head size, and grain protein were reduced; but the ability to enter the fruiting stage and to reach maturity were not materially affected.

SUMMARY AND CONCLUSIONS

Nitrogen fertilizers, in the Great Plains region are generally applied on the surface or from one to three inches below the surface of the soil; and this zone is at or below the wilting percentage a large portion of the growing season. The objectives of this experiment were (1) to determine whether the nitrate nitrogen in ammonium nitrate moves into the root zone when it disappears from the soil surface in the absence of effective precipitation and (2) to determine whether plants can absorb nitrogen from a soil at or below the wilting percentage.

A portion of the surface applied nitrates moved into the soil at all moisture contents from moisture equivalent to the wilting percentage. However, the amount and depth of movement decreased as the soil moisture decreased.

If nitrogen was absorbed from dry soil, it was absorbed in much smaller quantities than it was from a culture solution and insufficient nitrogen was absorbed for optimum growth and yield. It is quite possible that no nitrogen was absorbed from the soil after it reached the wilting point and that after this time, nitrogen already in the plants furnished the supply of nitrogen for all further growth.

Since only limited movement of surface applied nitrates can be expected before effective rainfall is received, and since plants can take up little if any nitrogen from dry soil, maximum utilization of nitrogen fertilizer can be expected only after effective precipitation has been received.

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