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Recovery of Fertilizer Nitrogen From Soils

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INTRODUCTION

When a virgin soil is first cultivated, in areas of warm summer temperatures, organic matter rapidly declines. The inorganic nitrogen in the soil arises from this organic storehouse. Consequently, in most cases, when organic matter is depleted, nitrogen is lost as well. Attempts have been made over the years to account for the decrease in total nitrogen in cultivated soils through its removal in crops and its loss resulting from drainage and erosion. In many cases these experiments have indicated that nitrogen must be lost by still other avenues. This additional loss is frequently attributed to the escape of gaseous forms of nitrogen to the atmosphere by the process referred to as denitrification.

Denitrification is one of the many known nitrogen transformations which occur in soil. These nitrogen conversions are effected by soil micro-organisms and, therefore, may be modified by soil management practices which influence the microbial environment. The recent trend in soil management to applying large amounts of fertilizer salts—nitrogen in particular—has had a marked influence on the soil as it serves as an environment for micro-organisms.

The relation of this soil environment to losses of nitrogen, consequently, is becoming a very active area of study. Missouri farmers are now spending over 25 million dollars a year for nitrogen. This is a major production expense, heightening interest in the efficient use of nitrogen applications by different crops.

HISTORY OF MISSOURI STUDIES ON NITROGEN ECONOMY

The title of an early research project of the Department of Soils at Missouri, The Rate of Accumulation of Nitrogen and Carbon in Soils Under Different Systems of Green Manuring and Cropping, points out the prevailing philosophy at that time. It was thought that organic matter and nirogen contents of the soil could be increased by certain management practices. Nevertheless, in the first report of this project in 1921, Miller & Dudley (5) refer to results suggesting nitrogen losses rather than nitrogen gains. Detailed tests made eight years after the study was initiated showed (6) that if the surface 12 inches of soil were considered, these central Missouri plots had all lost nitrogen. When the report was made in 1929 (4) the project carried the title "Nitrogen Depletion---," and the prevailing philosophy had been modified to state that nitrogen turnover was of greater importance than the maintenance of a high nitrogen level. This point was stressed again by Miller (3) as the practical approach to nitrogen maintenance when he reported the cumulative, 24-year results of this work. This long time study showed that continuous use of legumes or bluegrass was accompanied by an increase in total nitrogen, but these cropping systems were considered impractical so far as an entire farm was concerned.

It was then recognized that the total nitrogen content of undisturbed virgin soils remained at a constant level, but that cultivation of the soil usually lowered this quantity to approach another constant value, the amount of which was determined by the cropping system. Jenny (1) studied the factors which might control the nitrogen content of the soil and concluded that climate contributed the greatest influence.

Klemme and Coleman (2) found they could relate the productivity of a soil to its total nitrogen content. This developed into a productivity index, which later mothered the assumption that the rate of nitrogen delivery could be determined from the rate of breakdown of organic matter. Woodruff (10) added support to this assumption by using the results from the plots of Sanborn Field to evaluate the average annual delivery of nitrogen from the soil to the crop. So, for many years, the principal interest in the economy of the soil's nitrogen was focused upon the rate of mineralization of the organic reserves.

Recently, the rapid expansion of the synthetic nitrogen industry has shifted interest toward gaseous losses of the soil's nitrogen. Smith and a number of graduate student associates have conducted a series of studies aimed at detecting amounts and avenues of nitrogen loss. These studies have attempted to keep pace with the rapidly developing fertilizer industry as it has introduced new materials as carriers of nitrogen.

Soon after anhydrous ammonia was made widely available to farmers, Stanley and Smith (7) reported on studies concerned with the relationship of ammonia retention to soil moisture content, to depth of placement, and to soil texture and structure. This work established the importance of proper placement of ammonia to avoid loss.

When solution carriers of nitrogen were introduced a short time later, Trickey and Smith (8) reported on studies they conducted in which loss of ammonia was measured following different methods of applying these fertilizer solutions.

With the introduction of additional synthetic nitrogen fertilizers, the use of nitrogen continued to increase rapidly concomitant with some evidences of smaller yield responses from it. Field experiments, particularly with cotton and small grains, where different sources of nitrogen have been applied at various times have shown variation in response. Crop response has varied on different soil types. Failure to obtain good crop response from nitrogen was frequently interpreted as loss from the soil. Because there was evidence of loss from solid material as well as from the gaseous and liquid carriers, and from the nitrate form as well as from the ammonium form of nitrogen, studies were undertaken of the denitrification mechanism as a possible avenue of loss. Wagner and Smith (9) studied losses occurring as elemental nitrogen gas, as oxides of nitrogen, and as ammonia from nitrogen-treated soils. This work established that both soil type and form of nitrogen influenced the loss, and it suggested that environmental factors such as soil moisture and temperature might control the extent of the loss.

THE EXPERIMENTS

In the past few years there have been two general approaches toward learning more about loss of nitrogen from soil. The first approach has been to study the microorganisms which may contribute to loss of nitrogen and the biochemical reactions effected by them. The second has been to conduct studies concerned with measuring the amount of loss under various environmental conditions of soils. Both avenues of investigation have been fruitful. The study reported here follows the second approach, since information was desired about losses of nitrogen from the different soils of Missouri under several environmental variables which were thought to influence the process.

The study was designed to show the quantitative extent of nitrogen loss from fertilized soils first by the difference in the total nitrogen at the outset and close of a given period of incubation and second by measuring the nitrogen recovered by plants from these soils. In a previous study (9) it was reported that marked losses of nitrogen via gaseous volatilization may occur when Missouri soils are treated with common nitrogen fertilizers and incubated in the laboratory under conditions favorable to nitrification. The results of this earlier paper have been confirmed and expanded by the present study.

Losses Indicated by Total Nitrogen Analysis of the Soil

Procedure:

Three-hundred-gram units of soil were treated with 150 mg of nitrogen from 10 different fertilizer materials, two of which were used in combination with wheat straw to give a C/N ratio of 10/1 for added material. Sodium molybdate was also added in one case to supply 1 part per million of molybdenum, since this trace nutrient has been associated with the activity of denitrifying organisms. Nitrogen losses were measured by the difference in total nitrogen of the soil at the outset and the close of three months of incubation at optimum moisture and room temperature. The soil units were incubated in a large sealed chamber along with open beakers of water to maintain a saturated atmosphere and thus minimize evaporation of soil moisture. Air saturated with water was passed through the chamber to insure adequate aeration.

A Weldon silt loam and a Sharkey clay were selected for this study to represent, respectively, light textured loessial soils and heavy clay soils. The Weldon and Sharkey soils previously studied (9) showed striking losses of nitrogen accompanying certain treatments. A Sharpsburg clay loam with unusually high organic matter content was also included in the study. Some chemical and physical properties of these soils and of the Putnam silt loam which was employed in the second phase of this investigation are shown in Table 1.

Results:

The changes in total nitrogen of the different soils treated with the various nitrogen carriers are reported in Table 2. The data indicate that in many cases marked losses of nitrogen from these soils have occurred. There are many dissimilarities among the fates of nitrogen from the various materials which were added to the three soils. These variations suggest that the added fertilizer materials may have had differing influences upon the soil as a habitat of microorganisms. The resultant microbial activities may have, in turn, effected the wide differences in the amount of nitrogen recovered.

The greatest loss of nitrogen amounted to 81 percent of that applied as urea to Weldon silt loam. Treatment with aqua ammonia and with carriers containing nitrate, also, resulted in substantial losses from the Weldon soil. There were only non-significant changes in total nitrogen for several of the nitrogen carriers employed. This would suggest that little or no loss of nitrogen had occurred in these cases.

More consistant negative changes in total nitrogen occurred for the different nitrogen treatments of Sharkey clay. Only the diammonium phosphate treatment of this soil gave a non-significant change in total nitrogen. The results suggest losses of nitrogen from the treated Sharkey soil ranging up to 61 percent of that added. Here again, treatment with urea, aqua ammonia, and those carriers containing nitrate resulted in greater losses than did treatment with ammonium salts.

The Sharpsburg soil showed less significant losses of nitrogen than the Weldon or Sharkey soils. Losses ranging from 29 to 15 percent of the treatment occurred from urea, aqua ammonia, and the ammonium phosphates. In addition, the treatment of Sharpsburg clay loam with ground alfalfa hay resulted in a loss

TABLE 1--CHEMICAL AND PHYSICAL PROPERTIES OF THE SOILS UNDER STUDY

Soil Type	Total Nitrogen lbs./A	Exchangeable Nutrients* Calcium lbs./A	Magnesium lbs./A	Potassium lbs./A	Available * P_2O_5 lbs./A	pH	C.E.C. Me/100g	Percent Moisture at field capacity
Weldon Silt Loam	1,772	840	165	352	278	5.6	5.7	24
Putnam Silt Loam	2,560	2,300	360	112	33	5.4	11.1	22
Sharpsburg Clay Loam	6,190	5,500	970	560+	67	5.6	24.5	45
Sharkey Clay	2,716	7,000	900	664	320	6.0	25.6	36

* Missouri Soil Test Procedure.

TABLE 2--CHANGES IN TOTAL NITROGEN OF DIFFERENT SOILS AFTER TREATMENT WITH 550 PPM OF N IN DIFFERENT NITROGEN CARRIERS AND SUBSEQUENT INCUBATION FOR THREE MONTHS AT ROOM TEMPERATURE WITH THE SOIL AT OPTIMUM MOISTURE.

Nitrogen Carrier	Soil Type: Weldon Silt Loam	Sharkey Clay	Sharpsburg Clay Loam	Means for Nitrogen Carriers
	(Loss or gain in total nitrogen as percent of treatment)			
Sodium nitrate	-35.7	-50.3	+17.5	-22.8
12-12-12 (Nitric acid)	-46.8	-57.5	+ 2.0	-34.1
Ammonium nitrate	-33.0	-15.9	-11.7	-20.2
Ammonium nitrate and straw	-16.5	-44.6	+10.5	-16.9
Ammonium nitrate and molybdenum	-15.6	-52.1	-16.5	-28.1
Ammonium sulfate	- 2.0	-28.1	-12.4	-14.2
Monoammonium phosphate	- 8.8	-31.2	-24.5	-21.5
Diammonium phosphate	- 5.3	-10.4	-15.8	-10.5
13-13-13 (Ammo phos)	-20.6	-27.2	- 8.2	-18.7
Aqua ammonia	-47.8	-61.2	-17.3	-42.1
Urea	-81.2	-41.3	-29.3	-50.6
Urea and straw	-53.0	-50.6	-18.5	-40.7
Alfalfa hay (ground)	+ 2.4	-33.9	-21.7	-17.7
Means for Soil Types	-28.0	-38.8	-11.2	

L.S.D. .05 for comparison of means for nitrogen carriers within soil types = 13.2
L.S.D. .05 for comparison of means for soil types = 3.7
L.S.D. .05 for comparison of means for nitrogen carriers = 7.6

amounting to 22 percent of the applied nitrogen. The other nitrogen treatments were accompanied by insignificant changes in total nitrogen.

The treatment of the Weldon soil with ground alfalfa hay resulted in no loss of nitrogen while the loss accompanying its addition to the Sharkey soil was similar to that from the Sharpsburg soil. The addition of straw to the urea-treated Weldon soil resulted in a smaller loss than that for urea alone. This effect of reduced loss for added organic material with urea held true for the Sharpsburg clay loam but not for Sharkey clay.

One part per million of molybdenum was added with ammonium nitrate as a treatment variation. Only the Sharkey clay soil showed an increase in loss of nitrogen after this treatment, compared with ammonium nitrate and no molybdenum. Even though molybdenum has been linked with biological reduction of nitrogen, this aspect needs further investigation before any valid conclusion can be drawn. The total molybdenum concentrations of the untreated Sharkey and Weldon soils were determined to be about 1 part per million. The molybdenum content of the Sharpsburg soil was not determined.

The large values of "Least Significant Difference" in Table 2 are a result of variation associated with the method of recovering the added nitrogen. This method proposed to measure changes in a small amount of added nitrogen in the presence of larger amounts of native soil nitrogen. The Kjeldahl procedure for determining total nitrogen, however, does not permit differentiation as to the origin of the nitrogen. As a result, the variation in amount of both native soil nitrogen and added nitrogen for the individual units of soil must be included in a single error term in the analysis of variance.

Discussion:

Results of this study suggest that denitrification of nitrate-nitrogen may be a major avenue whereby nitrogen is lost from soils following their treatment with it. This is indicated by the fact that losses following treatment with nitrate-nitrogen were greater, in general, than those following treatment with ammonium-nitrogen.

The significant losses which occurred from urea and aqua ammonia may be thought to involve either volatilization of ammonia or loss by denitrification. Loss of ammonia would be expected in cases where the treatment had brought about a temporary neutralization of the soil's acidity. Denitrification could be involved if the soil environment permitted both oxidation and reduction of nitrogen. In the previous study of nitrogen losses (9), only very small amounts of ammonia were lost from urea mixed with Weldon and Sharkey soils. This earlier work also established that ammonia was oxidized to nitrate under the conditions of the study, and that denitrification probably was involved in the losses that occurred. Therefore, it is assumed that in the present case denitrification may also be involved in the losses which followed treatment of soils with urea and aqua ammonia.

The dissimilarity of results between the soils under study should discourage the drawing of conclusions with regard to losses from soils in general. For example, the results must not be taken as evidence that losses from nitrate forms of nitrogen will always exceed those from ammonium forms. These results do suggest, however, that this would be the case for heavy clay soils under prolonged wet conditions.

All three of the soils under study were incubated at a moisture level equal to 80 percent of their field capacities. This moisture level was found in other studies, to be favorable for rapid nitrification. Nevertheless, the results suggest that losses of nitrogen may be significant even in cases where the soil environment will support microbial oxidation. As was previously pointed out the most consistent losses occurred from the Sharkey clay. This soil with its very high clay content provides an environment when wet, due to poor aeration, which is conducive to denitrification. Limited aeration, even at optimum moisture content and with a granular structure, may be encountered. Within the soil granule itself, where tiny pores are filled with water, anaerobic denitrification could occur even though the larger pores between granules are quite aerobic.

Because of its high clay content, the Sharpsburg clay loam is physically more like the Sharkey clay than the Weldon silt loam. Its behavior with regard to the fate of the various nitrogenous materials, however, was more like that of the Weldon soil. The extremely high organic matter content of this Sharpsburg soil may have had an influence contrary to that exerted by the clay.

Plant Recoveries of Nitrogen to Indicate Its Loss From Soils

Procedure:

An ultimate test of the value of nitrogen added to soil would involve its absorption by plants. To accomplish this test, Sudan grass was grown to extract the nitrogen from soils which had been incubated for a period of time following their treatment with it. The incubation period allowed the added nitrogen to undergo any transformations which would be characteristic of different environments under study.

The soils used in this study were a Weldon silt loam, a Sharkey clay, and a Putnam silt loam.* Use of the first two permitted comparison of the chemical recoveries of nitrogen shown in the foregoing study with plant recoveries in this study. Separate tests were conducted with the nitrogen amendments applied in one case on the surface of the soil and in the other case mixed within the soil. Units of one kilogram of soil in triplicate (duplicate for Sharkey clay) were treated with 500 milligrams of nitrogen, then brought to different levels of moisture (air dry to 25%) and incubated for three months at different levels of temperature (0 to 100° F).

At the end of this period the pots were seeded with 20 sudan grass seeds. The sudan was then grown in the greenhouse at optimum soil moisture until

*See Table 1 for chemical and physical properties of soils.

extreme nitrogen deficiency occurred (about 4 months). Nutrients other than nitrogen were maintained at an adequate level throughout the growth of the sudan grass. When all growth had stopped due to lack of nitrogen, the soil was washed from the roots and the plants were dried and weighed. After being weighed, the plants were ground and their total nitrogen was determined by the Kjeldahl method modified to include nitrate.** The amount of nitrogen absorbed per pot was calculated from the dry weight of the plants and their total nitrogen contents.

Results:

Nitrogen losses indicated by incomplete recoveries of it by sudan grass from the nitrogen-treated soils were similar, in a very general way, to losses determined by calculating nitrogen balances from total nitrogen determinations of these soils. They also agree with some observed responses to nitrogen in the field.

Nitrogen Mixed with Medium Textured Soils:

For the materials which were mixed with the Weldon and Putnam soils (Table 3), the recovery of nitrogen was not consistently influenced by differences in temperature or moisture during the incubation period. However, a significant difference among the mean recoveries for the various nitrogen carriers is shown by a statistical analysis of the data. For both soils, the highest recoveries were from the ammonium nitrate, the ammonium sulfate, and the aqua ammonia treatments. These recoveries were consistently greater than those from sodium nitrate by an amount approximating 10 percent of the rate of application.

Recovery from urea was generally poor for the Putnam soil. For the Weldon soil treated with urea and incubated at the lower of the two moisture levels, recovery was low when the incubation temperature was 40° but was unusually high when it was 75° F. At the higher moisture level an intermediate amount of nitrogen was recovered from the urea-treated Weldon silt loam with no differences attributable to temperature. None of the recoveries from the urea-treated Weldon soil indicated losses as extreme as that shown by total nitrogen analysis in the foregoing experiment.

For environments where the recovery from the urea treatment of either soil was low, in most cases, the addition of straw with the urea-nitrogen increased the recovery. This observation supports results of the foregoing study which suggest that straw additions decreased the loss of nitrogen from the medium textured soils under study.

A poor recovery from the alfalfa-treated soils, regardless of the environment under which they were incubated but with the better recoveries accompanying the higher moisture levels, suggests that this organic carrier of nitrogen may not have undergone complete ammonification and, consequently, was not completely available to the plants during their period of growth.

**Nitrogen analyses were by the Mo. Agric. Experiment Station Lab.

TABLE 3--MILLIGRAMS OF NITROGEN ABSORBED BY SUDAN GRASS FROM 1000 GRAMS OF SOIL AFTER MIXING WITH THE SOIL 500 MG OF N IN DIFFERENT CARRIERS AND SUBSEQUENTLY INCUBATING UNDER DIFFERENT ENVIRONMENTS FOR THREE MONTHS PRIOR TO SEEDING.

	Temperature (°F)				
	40		75		Means for Nitrogen Carriers
	Soil Moisture		Percent		
Nitrogen Carrier	7.5	25	7.5	25	
			Weldon Silt Loam		
None	28	34	57	51	42
Sodium nitrate	320	320	315	318	318
Ammonium nitrate	384	353	362	367	366
Ammonium sulfate	364	345	366	357	358
Aqua ammonia	366	366	347	385	366
Urea	264	312	416	335	348
Urea and straw	356	277	258	355	323
Alfalfa	189	199	187	247	206
Means for moistures	292	282	288	302	
Means for temperatures	287		295		
L.S.D. .05 for comparison of means for nitrogen carriers within temperatures within moistures = 79					
L.S.D. .05 for comparison of means for nitrogen carriers = 40					
			Putnam Silt Loam		
None	53	62	54	77	62
Sodium nitrate	270	282	254	212	266
Ammonium nitrate	238	341	297	328	301
Ammonium sulfate	328	313	351	329	330
Aqua ammonia	308	318	298	300	306
Urea	278	179	237	238	233
Urea and straw	264	288	272	300	281
Alfalfa	244	279	213	250	246
Means for moistures	248	258	247	260	
Means for temperatures	253		254		
L.S.D. .05 for comparison of means for nitrogen carriers = 34					

Nitrogen Applied to Surface of Medium Textured Soils:

The influence of temperature on plant recovery of nitrogen from surface application of nitrogen to Weldon and Putnam soils is shown in Table 4. No significant effect appeared over the temperature range from 0 to 100 degrees F. at the 25 percent moisture level employed. Recovery of nitrogen was lowest from the urea treatment, of the four nitrogen carriers under study, but differences between recoveries from the various carriers were small.

At 40° F, four different moisture levels were studied for their effect on the recovery of surface applied nitrogen. These results (Table 5) show that the treated soils which were incubated at the air dry moisture level supplied an average of about 60 mg less nitrogen to sudan grass than the soils which were incubated at higher moisture levels.

TABLE 4--MILLIGRAMS OF NITROGEN ABSORBED BY SUDAN GRASS FROM 1000 GRAMS OF SOIL AFTER APPLYING 500 MG OF N IN DIFFERENT CARRIERS TO THE SURFACE OF THE SOIL AND SUBSEQUENTLY INCUBATING AT DIFFERENT TEMPERATURES WITH THE SOIL AT 25 PERCENT MOISTURE FOR THREE MONTHS PRIOR TO SEEDING.

Nitrogen Carriers	Temperature (^oF) 0	75	100	Means for Nitrogen Carriers
		Weldon Silt Loam		
None	37	60	70	56
Sodium nitrate	334	340	303	326
Ammonium nitrate	357	316	334	334
Ammonium sulfate	285	353	312	317
Urea	--	310	313	312
Means for temperatures	252	276	266	
L.S.D. .05 for comparison of means for nitrogen carriers = 34				
		Putnam Silt Loam		
None	47	84	84	72
Sodium nitrate	286	232	329	282
Ammonium nitrate	337	292	310	313
Ammonium sulfate	343	337	337	339
Urea	274	299	268	280
Means for temperatures	257	249	266	
L.S.D. .05 for comparison of means for nitrogen carriers = 42				

TABLE 5--MILLIGRAMS OF NITROGEN ABSORBED BY SUDAN GRASS FROM 1000 GRAMS OF SOIL AFTER APPLYING 500 MG OF N IN DIFFERENT CARRIERS TO THE SURFACE OF THE SOIL AND SUBSEQUENTLY INCUBATING AT 40^oF WITH THE SOIL AT DIFFERENT MOISTURES FOR THREE MONTHS PRIOR TO SEEDING.

Nitrogen carriers	Air Dry	Percent Moisture 7.5	15	25	Means for nitrogen carriers
			Weldon Silt Loam		
None	43	40	22	58	41
Sodium nitrate	258	460	423	347	372
Ammonium nitrate	306	387	344	378	354
Ammonium sulfate	286	327	323	328	316
Urea	208	270	299	331	277
Means for moistures	220	297	282	288	
L.S.D. .05 for comparison of means for nitrogen carriers within moistures = 91					
L.S.D. .05 for comparison of means for nitrogen carriers = 46					
L.S.D. .05 for comparison of means for moistures = 41					
			Putnam Silt Loam		
None	36	51	45	71	51
Sodium nitrate	135	286	338	310	267
Ammonium nitrate	288	274	321	311	298
Ammonium sulfate	355	334	336	350	344
Urea	194	190	254	259	224
Means for moistures	202	227	259	260	
L.S.D. .05 for comparison of means for nitrogen carriers with moistures = 61					
L.S.D. .05 for comparison of means for nitrogen carriers = 31					
L.S.D. .05 for comparison of means for moistures = 27					

The recoveries from soils incubated at this air dry moisture level varied somewhat for the different carriers. Only 135 mg of nitrogen were recovered from the 500 which were applied as sodium nitrate to the surface of Putnam silt loam incubated at the air dry moisture level. One of the three replicate pots receiving this treatment resulted in very early death of the sudan grass plants. This suggests the poor recovery might have been due to some toxic effect associated with the treatment.

The plants failed to grow in several other pots of soil receiving sodium nitrate and in a few of those receiving urea. These appeared to be randomly distributed between the two soils and among the moisture levels studied. These failures were more numerous for surface treatments than for treatments mixed with the soil. They were not included when calculating the average recovery values which are reported. The urea fertilizer contained about 5 percent biuret. It is assumed that at least part of this biuret had undergone biological transformation during the three-month period of incubation prior to seeding of the sudan grass. The concentration of it in the soil at the time of seeding was not determined.

Considering the average recoveries for the several temperature and moisture variables under study, the application of ammonium nitrate, ammonium sulfate, and urea to the surface of the Weldon silt loam resulted in a lower recovery than when these materials were mixed within the soil. Sodium nitrate, in contrast, showed a higher average recovery for the surface treatments. For Putnam silt loam the average recoveries from sodium nitrate were about the same for both methods of application.

Recovery From Sharkey Clay:

Table 6 shows the effect of the various environmental factors on the recovery of nitrogen by sudan grass from Sharkey clay. Because of its higher organic matter content, this soil produced more plant growth than the Weldon and Putnam soils. The percentage recovery of nitrogen, however, after discounting the yield for untreated pots, would be considerably lower for the Sharkey soil than for the other two soils. The largest average net recovery of nitrogen from the Sharkey soil was from the ammonium sulfate treated soil. About 50 percent of the added nitrogen was recovered in this case. For Weldon and Putnam soils, however, the highest net recoveries exceeded 60 percent.

Temperature differences did not significantly influence recovery of nitrogen from the Sharkey soil with possibly one exception. This was for sodium nitrate mixed with soil which was brought to 7.5 percent moisture, in which case recovery was much higher when the soil was incubated at 75° F than when incubated at 40° F. At the 25 percent moisture level, however, the recoveries were unusually low at both temperature levels and were similar to that for the 40° F temperature at the 7.5 percent moisture level. Both of the values at the 40° F incubation temperature were actually lower than the amount of nitrogen

TABLE 6--MILLIGRAMS OF NITROGEN ABSORBED BY SUDAN GRASS FROM 1000 GRAMS OF SHARKEY CLAY AFTER APPLYING 500 MG OF N IN DIFFERENT CARRIERS TO THE SURFACE OF, OR BY MIXING IT WITH, THE SOIL AND INCUBATING IT UNDER DIFFERENT ENVIRONMENTS FOR THREE MONTHS PRIOR TO SEEDING.

	Surface Application				Mixed with Soil				
	Temperature (F^o)								
	40		75		40		75		Means for Nitrogen Carriers
	Soil Moisture Percentage								
Nitrogen Carrier	7.5	25	7.5	25	7.5	25	7.5	25	
None	370	330	402	294	289	266	361	171	305
Sodium nitrate	406	398	351	312	174	211	446	252	319
Ammonium nitrate	491	484	512	533	456	412	628	526	505
Ammonium sulfate	501	513	494	540	528	509	637	552	534
Urea	418	554	356	432	459	536	468	488	464
Urea and straw	400	661	370	444	384	554	462	412	461
Alfalfa	467	346	360	300	370	367	284	458	369
Means for moistures	436	469	406	408	380	402	469	408	
Means for temperatures	452		407		391		438		
Means for application methods	430				414				

L.S.D. .05 for comparison of means for nitrogen carriers within application methods within temperatures within moistures = 225

L.S.D. .05 for comparison of means for nitrogen carriers = 80 absorbed from untreated Sharkey soil. Again, it should be pointed out that some of the sodium nitrate treated pots failed to produce any plant growth. These observations suggest that toxic effects as well as loss of nitrogen may explain the low recoveries.

The moisture variable appears to have had a significant influence on recovery of nitrogen from Sharkey clay. The results suggest some loss of nitrogen via denitrification attributable to the higher moisture level for the two materials containing nitrate, and to a lesser extent for ammonium sulfate which would undergo biological oxidation to nitrate. Moisture level appears to have influenced the uptake of nitrogen even in the untreated pots with higher yields being obtained as the moisture decreased. This is likely due to loss of virgin nitrogen by denitrification.

The higher of the two moisture levels resulted in the larger recovery of urea applied to the surface of the soil. For urea mixed within the soil, recoveries followed the same pattern but to a less marked degree.

There is no evidence that straw significantly altered the recovery when applied in combination with urea. The alfalfa treatment resulted in only slight increase in yield over the non-treated pots.

Discussion:

Admittedly the quantitative extent of the absorption of nitrogen by Sudan grass from nitrogen-treated soils does not show clearly the fate of the added nitrogen. The addition of nitrogenous materials to soils could result in the occurrence of several possible nitrogen transformations which would cause differences in absorption of nitrogen by Sudan grass: (a) the added nitrogen could undergo transformations which result in gaseous nitrogen being lost from the soil; (b) available nitrogenous materials which are added to soil could become tied up in an unavailable organic form, perhaps in the bodies of microorganisms, especially if straw is added; and (c) the added nitrogen also could result in an acceleration of the breakdown of the soils reserve nitrogen in soil organic matter. This increase in breakdown of organic nitrogen could be displayed as an increase in available nitrogen or this nitrogen which was mineralized might subsequently be lost through its further transformation to a gas.

Though the absorption of nitrogen by the Sudan grass is an indirect method of determining the fate of added nitrogen, it is direct in showing the extent of the availability of each nitrogen carrier to plants and the influences of the various environmental variables under study on this availability. These direct indices of the availability of the nitrogen to Sudan grass appear to be related to the losses which were measured by total nitrogen analyses of the soil. For the two soils which were included in both studies, the general pattern of the results was similar. Therefore, the values obtained by determining the uptake of nitrogen by Sudan grass appear adequate in adjudging the influence of environmental variables on the fate of nitrogenous materials in soils. Rather than serving as a means of showing quantitative extent of losses, this method serves to show the relative influences of the different environmental factors. The method furthermore, has special merit in that soil sampling problems, especially those connected with recovery from surface applied materials, are not encountered.

The fact that the urea treatment in the second study resulted in both good and poor recoveries from the Weldon soil and generally poor recoveries from the Putnam soil does not throw light on the cause of the unusually high loss from its application to Weldon silt loam in the first study.

Moisture Effects:

Moisture exerts an influence on nitrogen transformation, particularly through its inverse relation with the soil air. An increase in soil moisture would be expected to make the soil environment more anaerobic. The influence of moisture level on recovery of nitrogen in this study was quite surprising. At the highest moisture level (25 percent), the Weldon silt loam was wetter than field capacity, the Putnam silt loam was at field capacity, and the Sharkey clay was drier than field capacity. However, the poorest recoveries (indicating largest losses) were for the Sharkey soil. This seems to contradict the assumption that loss by denitrification is principally related to soil moisture tension. For this study, an interaction between clay content and soil moisture is a major consideration since only the results for the Sharkey soil show correlation between moisture content and poor recovery of nitrogen. Poor recoveries of nitrogen from Sharkey clay even occurred at the 7.5 percent moisture level. However, as has been pointed out previously, there is some evidence that these may be due to toxic effects rather than losses.

Surface Applications:

It is to be expected that the transformations of nitrogen accompanying its surface application would not be identical with those occurring as a result of incorporating the fertilizer material with the soil. Losses via volatilization of ammonia, for example, are more likely to occur from urea applied to the surface of the soil than from urea mixed with the soil.

The fact that the surface treatments resulted in lower recoveries than treatments mixed with the soil, particularly for urea but also for ammonium nitrate and ammonium sulfate, suggests that loss of ammonia may be involved in the surface applications. Recovery from surface-applied materials was lowest from urea, which would be the expected pattern if volatilization of ammonia was involved.

Moisture had an influence on the recovery from surface treatments only at the air dry level. Recoveries were consistently less at this low moisture level. The air dry moisture level was not employed as a variable in the case where materials were mixed with the soil. Surface application of sodium nitrate in some pots, particularly where this treatment was incubated in air dry soil, yielded soil conditions which failed to grow plants. It is not known whether this toxic effect was a result of a transformation product of the material which was added to the soil or whether the high concentration of fertilizer salt was injurious in itself.

Plant Recoveries of Nitrogen from Soils of Different Fertility Levels

Procedure:

The final phase of this study was an attempt to measure the influence of widely differing levels of fertility within a single soil type on the recovery of nitrogen. Putnam silt loam soil from 12 different plots on Sanborn Field which have been under the influence of different soil treatments and cropping practices for 69 years was studied along with the Sharkey clay and the Weldon silt loam. The soil treatments, cropping histories, and soil test data for the soils from these plots of Sanborn Field are given in Table 7. The properties of the Sharkey and Weldon soils are reported in Table 1. The Weldon soil used in this part of the investigation was from a different lot than that used previously but differed only in its available P_2O_5 content, which was only 28 pounds per acre in this latter case.

The nitrogen absorbed by Sudan grass was again used as an index of its remaining in an available form in these soils following their treatment with nitrogen and their subsequent incubation under various environmental conditions for a period of time. In this study the incubation period was four months and the treatments were 500 mg. units of nitrogen from different sources added to triplicate 900-gram units of soil. No supplemental nutrients were added to the pots of soil while the plants were growing in the greenhouse as in the previous study. As a consequence, severe deficiency symptoms which may have been due in part to a lack of nutrients other than nitrogen appeared in these plants after a period of about two months. The plants of the foregoing study did not show severe nitrogen deficiency symptoms until about four months after seeding. The fact that the incubation period prior to seeding was one month longer for the present study than for the preceding one would also help to explain the earlier appearance of severe deficiency symptoms where loss of nitrogen was involved.

The different nitrogen materials and wheat straw in combination with nitrogen were studied again. In addition, calcium hydroxide at rates of 1200 to 4800 pounds of calcium per acre was added in combination with urea and with ammonium nitrate to three of the soils.

The moisture and temperature variables studied in the preceding experiment also were repeated. In addition, units of air dry Weldon silt loam, after receiving a surface treatment of nitrogen, were placed out of doors for seven evenings to allow dew to condense on the soil surfaces. Following this, the separate units of soil were incubated at 40° and at 75° F. Other identical units of soil with surface treatment of nitrogen were incubated at the two temperature levels in the air dry state for periods of one, two, four, eight, and 16 weeks after which

TABLE 7--SOIL TESTS ON SAMPLES FROM SANBORN FIELD PLOTS (PUTNAM SILT LOAM)

Plot No.	Cropping History	Soil Treatment	Organic Matter Percent	Available P_2O_5 lbs/A	Exchangeable cations Ca lbs/A	Exchangeable cations Mg lbs/A	Exchangeable cations K lbs/A	Exchangeable cations H Me./100g.	pH
2	Continuous wheat 68 years	full treatment	2.2	287	3840	670	254	4.0	5.5
6	Continuous corn since 1950	full treatment	2.2	261	2630	621	318	4.8	5.0
13	6 year rotation C, O, W, Cl, T, T	no treatment	1.9	21	2860	250	113	7.3	4.6
17	Continuous corn 69 years	no treatment	1.4	62	2400	400	240	7.9	4.5
18	Continuous corn 69 years	6 ton manure	2.2	202	3350	565	414	6.2	4.8
21	Continuous alfalfa since 1950	full treatment	2.0	350	5200	200	240	2.3	6.7
22	Continuous timothy 69 years	6 ton manure	3.1	179	2820	183	297	7.8	4.7
23	Continuous timothy 69 years	no treatment	2.6	15	2466	120	146	8.0	4.8
34	4 year Rotation C, O, W, R Cl	6 ton manure	2.7	150	2860	245	210	7.0	4.8
35	4 year Rotation C, O, W, R Cl	no treatment	2.0	38	3240	258	240	7.3	4.8
39	4 year Rotation C, O, W, R Cl	full treatment	2.4	325	6330	205	220	1.5	6.5
42	2 year Rotation C, W & Sw Cl	full treatment	2.5	210	5240	183	220	0.7	6.9

they were brought to 20 percent moisture and returned to their temperature environments for the remainder of the incubation period.

The soil from Sanborn Field plot 35 was the only Putnam soil employed for studying the influence of temperature, moisture, and other amendments on nitrogen recovery. Both the Weldon silt loam and the Sharkey clay were included in these studies.

The dry weight of plant material was obtained for each pot as was done in the preceding study. Then a composit sample of the three replicate pots for each variable under study was taken for nitrogen analysis. The total nitrogen absorbed from the soil was calculated from the dry weight of plant material and the nitrogen content of the plants. Use of the composite sample for nitrogen analysis prevented a statistical analysis of the recovery data; however, the variation is assumed to be of the order of magnitude of that for the foregoing study since the experimental designs were similar.

Results:

The amount of nitrogen absorbed by Sudan grass from the untreated units of soil of the different plots in Sanborn Field varied in general with their contents of organic matter (Table 8). In soils with added nitrogen, the recoveries were unusually low for the soils which were deficient in nutrients other than nitrogen. The lowest recoveries were from the soils of plots 13, 17, 23, and 35, all of which were very low in available phosphorus. In these soils, the alfalfa treatment consistently resulted in the best recovery. This suggests that the decomposition products of the alfalfa helped to alleviate some of the mineral deficiencies of the soil. Soils from Sanborn Field plots 2, 6, 18, and 21, which had good levels of phosphorus and potassium (P_2O_5 290 lbs/A and K 250 lb/A), gave higher recoveries of nitrogen than plots where one or both of these nutrients were deficient.

Recoveries of nitrogen from the Weldon and Sharkey soils averaged intermediate in comparison with those from the soils of Sanborn Field. This is of special interest when we note that the Weldon soil was of low fertility, particularly with regard to phosphorus, and that the Sharkey clay contained adequate nutrients, compared with the soils of Sanborn Field.

Sodium nitrate as a carrier of nitrogen resulted in the lowest precentage recovery, considering the average results for its application to all the soils under study (Table 9). The next to lowest recoveries were for urea and alfalfa as sources of nitrogen. Ammonium sulfate and aqua ammonia were recovered by the Sudan grass in the largest amounts.

The differences among the recoveries of nitrogen for the various temperature and moisture environments appeared to be randomly distributed (Table 10). This suggests that the moisture level of the soils and the temperature to which they were exposed during incubation did not significantly influence the recovery

TABLE 8--MILLIGRAMS OF NITROGEN ABSORBED BY SUDAN GRASS FROM 900 GRAMS OF SOIL AFTER APPLYING 500 MG OF N IN DIFFERENT CARRIERS TO THE SURFACE OF, OR BY MIXING IT WITH THE SOIL AND SUBSEQUENTLY INCUBATING IT AT 75°F WITH THE SOIL AT TWO DIFFERENT MOISTURE LEVELS FOR FOUR MONTHS PRIOR TO SEEDING.

		Nitrogen Treatment											
	Percent		Aqua Am.	Urea		Am. Nitrate		Am. Sulfate		Sod. Nitrate		Alfalfa	
Soil	Moisture	None	Mixed	Surface	Mixed	Surface	Mixed	Surface	Mixed	Surface	Mixed	Surface	Mixed
Sanborn													
Plot 2	7.5%	61	368	308	331	233	362	302	431	266	278	433	298
	25%	60	---	257	299	234	255	334	---	140	---	278	---
" 6	7.5%	35	232	177	230	281	224	247	215	170	200	189	201
	25%	30	---	226	265	193	191	118	---	168	---	212	---
" 13	7.5%	34	120	71	140	81	100	90	50	100	100	262	241
	25%	36	---	47	97	60	96	76	---	46	---	171	---
" 17	7.5%	13	42	70	56	65	22	120	147	15	15	185	17
	25%	10	---	26	31	25	39	160	---	10	---	126	---
" 18	7.5%	83	300	265	282	278	311	311	284	266	253	248	251
	25%	93	---	283	243	315	253	337	---	240	---	208	---
" 21	7.5%	70	272	166	307	288	247	230	269	226	212	187	256
	25%	52	---	262	298	256	276	207	---	210	---	228	---
" 22	7.5%	105	246	274	276	288	244	223	241	201	152	235	232
	25%	118	---	210	260	250	260	240	---	241	---	239	---
" 23	7.5%	33	112	89	48	117	51	125	117	117	33	166	168
	25%	47	---	57	18	40	26	117	---	67	---	151	---
" 34	7.5%	113	262	268	348	259	264	199	246	213	191	254	276
	25%	58	---	196	211	190	214	211	---	157	---	179	---
" 35	7.5%	22	110	138	44	133	23	102	90	27	54	26	149
	25%	26	---	108	26	112	45	114	---	33	---	156	---
" 39	7.5%	30	115	153	183	211	195	180	254	120	119	148	157
	25%	29	---	144	150	123	199	190	---	57	---	176	---
" 42	7.5%	47	183	224	198	258	202	243	238	135	111	185	260
	25%	18	---	208	178	116	139	176	---	91	---	64	---
Weldon Silt	7.5%	21	237	191	204	207	215	146	240	116	197	117	137
Loam	25%	32	---	245	225	234	228	207	---	132	---	108	---
	7.5%	85	322	204	207	254	256	278	246	190	141	196	139
Sharkey Clay	25%	53	---	168	248	230	183	230	---	154	---	119	---
													---

TABLE 9--RECOVERY OF NITROGEN IN PERCENT BY SUDAN GRASS FROM 900-GRAM UNITS OF SOIL TREATED WITH 500 MG OF NITROGEN. AVERAGES OF POTS INCUBATED FOUR MONTHS AT 75°F AND 7.5% AND 25% MOISTURE.

N. Fertilizer added	Sanborn Field Plots												Weldon Silt Loam	Sharkey Clay	Avg. All Soils
	2	6	13	17	18	21	22	23	34	35	39	42			
Sodium Nitrate	33	22	9	0	33	30	18	7	18	3	14	13	25	18	17
Ammonium nitrate	43	40	9	5	43	40	30	6	29	13	29	29	39	35	28
Ammonium sulfate	59	32	7	19	45	34	25	16	25	16	36	35	34	35	30
Aqua ammonia*	61	40	17	6	43	42	27	15	33	17	17	28	42	50	31
Urea	48	35	10	8	38	36	29	5	35	15	26	33	38	24	27
Alfalfa	54	33	31	19	30	32	25	25	28	17	26	25	19	15	27
Average**	47	37	13	10	38	34	25	12	27	13	26	27	31	25	

* Single treatment--applied in soil with 7.5% moisture only.

** Does not include aqua ammonia.

TABLE 10--MILLIGRAMS OF NITROGEN ABSORBED BY SUDAN GRASS FROM 900 GRAMS OF SOIL AFTER APPLYING 500 MG OF N TO THE SURFACE OF, OR BY MIXING IT WITH THE SOIL AND SUBSEQUENTLY INCUBATING AT DIFFERENT TEMPERATURE LEVELS WITH THE SOIL AT DIFFERENT MOISTURE LEVELS FOR FOUR MONTHS.

Nitrogen Carrier	Application Method	Soil Moisture Percentage	Temperature ^{O}F 0	40	75	100	Mean Recovery for Treatments as % of N Applied
			Weldon Silt Loam				
none	none	7.5	---	---	31	---	
none	none	25	---	---	32	---	
urea	surface	7.5	173	201	191	220	
urea	surface	15	149	155	242	234	
urea	surface	25	163	249	245	139	
							39
urea	mixed	7.5	---	---	204	---	
urea	mixed	15	200	236	217	199	
urea	mixed	25	327	232	225	166	
							45
am. nitrate	surface	7.5	229	181	207	246	
am. nitrate	surface	15	141	211	200	226	
am. nitrate	surface	25	172	330	234	204	
							43
am. nitrate	mixed	7.5	---	---	215	---	
am. nitrate	mixed	15	154	218	319	159	
am. nitrate	mixed	25	238	312	228	128	
							44
Mean recovery for temperatures as percent of N applied			38	51	49	37	
			Putnam Silt Loam				
none	none	7.5	---	---	32	---	
none	none	25	---	---	26	---	
urea	surface	7.5	11	262	139	232	
urea	surface	15	98	136	82	168	
urea	surface	25	94	170	110	123	
							27
urea	mixed	7.5	---	---	44	---	
urea	mixed	15	42	83	131	148	
urea	mixed	25	13	128	26	120	
							16

TABLE 10 CONTINUED

Nitrogen Carrier	Application Method	Soil Moisture Percentage	Temperature °F 0	40	75	100	Mean Recovery for Treatments as % of N Applied
am. nitrate	surface	7.5	123	130	133	162	
am. nitrate	surface	15	108	186	127	127	
am. nitrate	surface	25	66	179	112	137	26
am. nitrate	mixed	7.5	---	---	23	---	
am. nitrate	mixed	15	53	74	146	129	
am. nitrate	mixed	25	50	170	44	82	19
Mean recovery for temperatures as percent of N applied			15	29	22	25	
			Sharkey Clay				
none	none	7.5	---	---	85	---	
none	none	25	---	---	53	---	
urea	surface	7.5	182	237	204	192	
urea	surface	15	150	260	253	165	
urea	surface	25	174	432	168	453	48
urea	mixed	7.5	---	---	207	---	
urea	mixed	15	317	277	306	345	
urea	mixed	25	342	473	285	409	69
am. nitrate	surface	7.5	256	274	254	260	
am. nitrate	surface	15	251	289	278	216	
am. nitrate	surface	25	467	413	230	408	60
am. nitrate	surface	7.5	---	---	256	---	
am. nitrate	surface	15	311	267	228	318	
am. nitrate	surface	25	346	395	210	450	64
Mean recovery for temperatures as percent of N applied			65	65	61	65	

of nitrogen. The only consistent temperature effect was a relatively low recovery from the treated Putnam soils which were incubated at zero degrees F.

In the foregoing study, soil moisture clearly influenced the recovery of nitrogen from Sharkey clay. In this study, however, soil moisture does not show a consistent effect. It is assumed that the lack of nutrients other than nitrogen was the factor overshadowing any influence by the environmental variables under study.

Results in Table 10 do indicate, however, that the method of applying the nitrogenous materials to the soil influenced its recovery. Urea was more efficiently recovered from both the Weldon and the Sharkey soils when mixed with the soil than when added to the surface of the soil. For the Putnam soil which yielded low recoveries of nitrogen in general, the surface application was slightly better for both urea and ammonium nitrate.

The nitrogen absorbed by Sudan grass from soils treated with nitrogen alone and in combination with straw and calcium hydroxide is shown in Table 11. Addition of organic matter as straw to the Weldon and Putnam soils gave inconclusive results. Recoveries were somewhat improved by straw additions to Sharkey clay. Since nutrients were, in general, limiting in the soils used in this study, any effect of straw may show itself as altered availability of the nitrogen, or of nutrients other than nitrogen.

The larger amounts of nitrogen absorbed by Sudan grass as a result of adding lime to Sharkey clay suggests that the calcium level of the soil may have been a major factor limiting the recovery of nitrogen by Sudan grass for this soil. For the Weldon and the Putnam soils, however, the results do not show that lack of calcium-inhibited nitrogen recovery.

Table 12 reports the results of incubating for different periods of time, prior to moistening, air dry Weldon soil which had received a surface application of nitrogen. The period of time between adding the fertilizer to the soil and moistening it was varied from one week to four months. The results show that this factor did not significantly influence the recoveries of nitrogen from the surface applications of urea and ammonium nitrate. Also, the recoveries appeared to be unchanged by allowing the fertilizer materials to be dissolved on the surface by condensation of moisture as dew.

TABLE 11--MILLIGRAMS OF NITROGEN ABSORBED BY SUDAN GRASS FROM 900 GRAMS OF SOIL AFTER MIXING 500 MG OF N ALONE AND IN COMBINATION WITH GROUND WHEAT STRAW AND WITH CALCIUM HYDROXIDE, WITH THE SOIL AND SUBSEQUENTLY INCUBATING AT 75°F WITH THE SOIL AT 15 PERCENT MOISTURE FOR FOUR MONTHS.

Nitrogen Carrier	Nitrogen only (500 mgs)	Materials added with Nitrogen: Wheat Straw (4 g)	Calcium Hydroxide 1 g	2 g	4 g	Mean
		Weldon Silt Loam				
None	31					
Urea	217	181	161	216	237	205
Ammonium Nitrate	319	180	200	196	233	210
		Putnam Silt Loam				
None	33					
Urea	131	255	150	119	78	119
Ammonium Nitrate	146	131	119	115	100	111
		Sharkey Clay				
None	86					
Urea	306	362	412	340	300	351
Ammonium Nitrate	228	337	397	345	300	314

TABLE 12--MILLIGRAMS OF NITROGEN ABSORBED BY SUDAN GRASS FROM 900 GRAMS OF AIR DRY WELDON SILT LOAM AFTER APPLYING 500 MG OF N TO ITS SURFACE AND SUBSEQUENTLY INCUBATING FOR FOUR MONTHS AT TWO DIFFERENT TEMPERATURES LEVELS. THE SOIL UNITS WERE BROUGHT TO 20 PERCENT MOISTURE AFTER STANDING DIFFERENT PERIODS OF TIME DURING THEIR INCUBATION.

Soil Moisture Treatment	40°F None	40°F Urea	40°F Am Nitrate	75°F None	75°F Urea	75°F Am Nitrate
20% Moisture after 1 week	30	366	315	40	302	266
20% Moisture after 2 weeks	33	302	355	37	281	309
20% Moisture after 4 weeks	28	333	358	37	270	327
20% Moisture after 8 weeks	31	380	391	47	311	352
Air dry until seeding (4 mo.)	33	---	277	47	335	251
Moisture as dew*	39	285	327	34	244	407

*Cans were placed outside for seven days where condensation of moisture dissolved the surface applied fertilizer materials. After this, the cans were stored for four months at 40° or 75°F.

Discussion:

Plants harvested from those soils which yielded low recoveries of nitrogen were found to be rich in this element. The total uptake of nitrogen was low even though the concentration of it in these plants was high, because the yields of plant material were extremely low. This, of course, supports the supposition that in many cases the recovery of nitrogen was limited by a lack of other nutrients. Such an effect was to be expected, particularly from the poorer soils, since the nitrogen treatments were excessive (555 ppm) and no other supplemental nutrients were added.

Because the lowest recoveries of nitrogen were from Sanborn Field soils with the lowest levels of phosphorus, it may be assumed that lack of this nutrient was principally responsible. For several Sanborn plots with better levels of phosphorus, the limiting nutrient appears to be potassium. Sanborn plots with the best nutrient levels gave recoveries of nitrogen which were similar to those for the Putnam soil with supplemental nutrients added. Evidently the nutrient reserves in these soils were sufficient to supply the requirements of Sudan grass until nitrogen became limiting.

The soil tests show that the Weldon soil used in this study was very similar from a fertility standpoint to the soils from the Sanborn Field plots which were lowest in fertility. However, the Weldon soil showed much better recovery of nitrogen, even though the available phosphorus content of this soil was at a level which resulted in limited recovery of nitrogen for the Putnam soils from Sanborn Field. This raises the question as to whether or not the limiting factor was phosphorus in the Sanborn Field soils.

The soil tests indicate that the nutrient level of the Sharkey soil was similar to that of the more fertile soils of Sanborn Field with regard to phosphorus level, organic matter content, and percent saturation of the nutrient bases. However, the recoveries of nitrogen from this Sharkey clay appear to be limited by other nutrients. This is evidenced by the fact that the recoveries are significantly lower than those of the study where supplemental nutrients were added. The slightly better recovery of nitrogen with calcium added to this soil is not considered sufficient to explain the total apparent nutrient deficit.

Even though the recoveries of nitrogen in this study were limited in general by deficits of other nutrients, they were, nevertheless, influenced to a certain extent by the different treatments. This influence followed the same general pattern as that for the study in which nutrients other than nitrogen were not allowed to become limiting. Of the nitrogen treatments employed, the lowest and next to lowest recoveries were, again, from the sodium nitrate and urea treatments, respectively. Likewise, in both studies surface treatments generally were not recovered as well as materials which were mixed with the soil.

If nutrients other than nitrogen were limiting, then presumably these soils still contained some of the added nitrogen at the time the plant growth had ceased. The fact that the recoveries did vary with the nitrogen source, therefore, would indicate that there were some dissimilarities in availability to Sudan grass of the different nitrogenous materials other than those involving loss of nitrogen. The method of application likewise seems to influence availability through some factor other than loss.

The influence of moisture on recovery of nitrogen from Sharkey clay is seen only in the case where nutrients other than nitrogen are not limiting. Therefore, the poorer recoveries associated with the higher moisture levels for the Sharkey clay with supplemental nutrients added are presumed to be only a result of nitrogen losses.

CONCLUSIONS

Significant loss of nitrogen from the soil may occur following its application to agricultural soils. The amount of this loss is dependent upon both the type of soil and the nitrogen carrier employed. For a soil of clay texture in contrast with those of medium textures, these losses appeared to be consistently greater in magnitude and to be less dependent upon the kind of nitrogen carrier. The results suggest denitrification as a principal mechanism of the loss.

Several soil environmental factors were shown to influence recovery by Sudan grass of nitrogen added to soil. Poor recoveries were for the most part interpreted as losses of nitrogen. Soil moisture within the range from air dry to field capacity had little effect on the amount of nitrogen lost from soils of silt loam texture. However, for the clay soil, increasing the moisture level within this range resulted in increased nitrogen losses.

Variation in temperature at which the soil was incubated from 0 to 100° F showed no general influence on the loss of nitrogen.

In general, the results show that the addition of highly carbonaceous organic matter may decrease losses of nitrogen for the aerobic soil environments under study.

The results indicate that greater efficiency of nitrogen recovery is obtained where the nitrogen salts are mixed in the soil than where they are applied to the surface of the soil.

A deficit in nutrients other than nitrogen limited the recovery of nitrogen by Sudan grass. The nitrogen in the soil was never completely exhausted in these cases, but the recoveries of it did vary with the nitrogen source. This would indicate that there were some dissimilarities in availability to Sudan grass of the different nitrogenous materials other than those involving loss of nitrogen. Whether or not the nitrogenous material was applied to the surface of the soil seemed to be linked to nitrogen availability. Soil moisture, however, did not influence availability of nitrogen when other nutrients were limiting.

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