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ABSTRACT

Unamended, limed, and phosphorus-enriched Caddo, Beauregard, and Wrightsville silt loams (A_1 horizon) were incubated for six months at room temperature under two moisture regimes. At field capacity, unamended soils lost 0.7% of organic matter and converted 166 ppm of organic nitrogen to inorganic forms. Ninety-five percent of the converted nitrogen was present as NH_4- or NO_3-N. Limed and phosphorus-treated soils at field capacity lost about 1.0% of organic matter and accumulated 191 to 201 ppm of inorganic nitrogen. Submerged soils lost very little organic matter and accumulated only 24 to 28 ppm of inorganic nitrogen. There was a loss of 35 to 78 ppm of nitrogen from the submerged soils, presumably through denitrification.

INTRODUCTION

Organic matter in moderately well and less perfectly drained forest soils of the West Gulf Flatwoods contains up to 2240 kg/ha of nitrogen (USSCS 1966). How rapidly this nitrogen is mineralized profoundly affects tree growth as well as response of timber stands to nitrogen fertilization. The research reported here concerns the effects of soil aeration, phosphorus fertilization, and liming on mineralization and nitrification of organic nitrogen in three important southern pine-growing soils of the region.

Research on agricultural soils of other regions had indicated that calcium salts usually promote mineralization of soil nitrogen (Singh et al. 1969, Agarwal et al. 1971, Broadbent and Nakashima 1971) and that phosphorus salts may increase or decrease net mineralization depending on the soil and the level of microbial activity (Ryan et al. 1972, Ryan and Sims 1974).

Broadbent and Reyes (1971) reported that greater amounts of nitrogen were mineralized under flooded than under upland conditions. Ponnamperuma (1972) concluded that deamination of organic residues may proceed more rapidly in aerobic than in anaerobic soils, but that anaerobic soils may accumulate more inorganic nitrogen because less is immobilized by microorganisms. More recently, Stanford and Epstein (1974) found that more mineral nitrogen usually accumulated in soils having 80 to 90% of the total pore space filled with water than in wetter or dryer soils. They thought denitrification was responsible for the reduced accumulation of mineral nitrogen in wetter soils. Patrick and Tusneem (1972) described aerobic and anaerobic layers in submerged soils and showed that denitrification was the major pathway through which submerged soils lose NH_4-N as well as NO_3-N.

METHODS AND MATERIALS

Soils. Three dominant virgin soils of the West Gulf Coastal Flatwoods studied were Beauregard silt loam (Plinthaquic Paleudult, fine-silty, siliceous, thermic), Caddo silt loam (Typic Glossaqualf, fine-silty, siliceous, thermic), and Wrightsville silt loam (Typic Glossaqualf, fine, mixed, thermic). Each soil was represented by composite samples of the A_1 horizon (0-15 cm depth) collected in midsummer from each of two locations in Rapides Parish, Louisiana.

Individual composites contained 2.4 to 4.0% organic matter (Table I). They averaged 640 to 1250 ppm of organic nitrogen and fewer than 5 ppm of inorganic nitrogen. In pH, they ranged from 4.35 to 4.60. Total exchangeable bases ranged from 2.24 to 3.57 meq/100 g of soil. Available P ranged from 2.4 to 4.1 ppm.

Study Procedures. Soil from each location was mixed thoroughly while moist and divided into eight parts. Two parts were assigned at random to each of four lime-phosphorus treatments:

1. Untreated (checks).
2. Lime ($CaCO_3$) incorporated into the soil to supply 1 meq of Ca/100 g of soil.
3. Phosphorus and KH_2PO_4 incorporated at a rate of 88 ppm of P.
4. Both $CaCO_3$ and KH_2PO_4 added at the above rates.

Potassium was eliminated as a variable in the experiment by adding sufficient KCl to treatment 1 and 2 soils to compensate for the K in the phosphorus carrier in treatments 3 and 4.

After receiving the amendments, individual lots of soils were sampled for chemical analysis and further subdivided to be incubated at field capacity or submerged under one inch of water. Each plot consisted of a one-gallon plastic pot containing 2.5 kg (oven dry weight) of soil. The soils were incubated at room temperature (25-28C) for six months and then resampled for chemical analysis.

Soil samples were analyzed by the following procedures. Organic-N + NH_4-N were determined by the Kjeldahl method as described by Jackson (1958). Exchangeable NH_4-N was determined by a modification of Kjeldahl method using MgO instead of NaOH to release NH_4-N (Horwitz 1955). Nitrate nitrogen was determined with the procedure described by Sims and Jackson (1971). Organic matter and organic carbon were determined by the wet oxidation method (Jackson 1958) with Ferroin as the indicator. Exchangeable bases were replaced with 1 *N* NH_4OAc (pH 7.0) and determined with an atomic absorption spectrophotometer. Available phosphorus was extracted with .03 *N* NH_4F in .025 *N* HCl and determined colorimetrically by the chlorostannous-reduced molybdophosphoric blue color method, in a hydrochloric acid system. Soil pH was measured with a glass electrode using 1:1 soil to water ratio.

Total mineralizaton of soil nitrogen was estimated by subtracting postincubation levels of organic nitrogen from preincubation levels in soils. Differences between pre- and postincubation levels of NH_4-N and NO_3-N also were computed to estimate mineralization of soil nitrogen to inorganic forms that should be available to plants. Loss in organic matter during incubation was determined by subtracting final from initial levels. Carbon to nitrogen ratios were determined by dividing organic carbon by the sum of Kjeldahl and nitrate nitrogen.

All the data were subjected to analysis of variance. In the analysis, soils comprised major plots in a randomized split plot design: fertilizer treatments were minor plots. Results for two moisture levels were analyzed individually because the data were derived from the same estimates of chemical properties before incubation.

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RESULTS

On the basis of the chemical data in Table I, the similar texture of surface soils, and the lack of significant differences among soil series for organic matter decomposition and changes in soil nitrogen during incubation, the results presented here for three series were averaged.

Soil Organic Matter. During incubation at field capacity, untreated (check) soils lost 0.7% of organic matter (Table II) or about one-fourth of the amount present initially. Both lime and phosphorus fertilization significantly increased the rate of decomposition. Together they increased breakdown by 58% over the check-soil rate. Submerged soils showed no change in their organic matter content during incubation. Neither lime nor phosphorus fertilization affected breakdown significantly.

Soil Nitrogen. Organic nitrogen decreased 166 ppm in check soils and 196 to 231 ppm in the fertilized soils incubated at field capacity (Table II). Application of lime or phosphorus significantly increased mineralization, but the effects of the two nutrient supplements were not additive. The lime-phosphorus treatment accelerated mineralization of soil nitrogen 65 ppm whereas lime alone increased mineralization 46 ppm and phosphorus alone increased it 30 ppm.

Significantly more NO_3-N accumulated in fertilized than in unfertilized soils incubated at field capacity. The advantage amounted to 43 ppm for the lime treatment, 33 ppm for the phosphorus treatment, and 36 ppm for the combination. A significant lime × phosphorus interaction indicated that response to lime and phosphorus was not additive. Addition of phosphorus and lime had no significant effect on the accumuletion of NH_4-N, which averaged only 7 ppm.

At field capacity, 5 to 19% more nitrogen had mineralized than actually was found in soils as NO_3- or NH_4-N, indicating possible presence of NO_2-N and some loss of nitrogen in gaseous form. The greatest loss (37 ppm) occurred in the lime plus phosphorus treatment.

Organic nitrogen altered to mineral form in submerged soils was less than half as much as that in soils incubated at field capacity. Alteration of organic nitrogen to mineral form in submerged soil ranged from 59 ppm for the check to 106 ppm for the lime plus phosphorus treatment. Both lime and phosphorus affected mineralization significantly. Levels of NO_3-N declined during incubation of submerged soils, indicating large N losses due to denitrification. These losses were enhanced by lime and phosphorus treatments.

Twenty-six to 30 ppm of NH_4-N accumulated. Phosphorus, but not lime, increased significantly the amount of nitrogen mineralized to this form. The difference was unimportant, however, as it averaged only 3 ppm.

About two-thirds of the soil nitrogen that was altered in form during incubaton of submerged soils was not present in the soil as NH_4-N. Losses were increased by the addition of either lime or phosphorus and were most severe when both were supplied. Soils given the latter treatment lost 78 ppm, in contrast to 35 ppm for check soils.

Carbon to nitrogen ratios. Carbon to total nitrogen (organic, exchangeable NH_4, and NO_3) ratios of field capacity soils narrowed 5.0 to 7.3 units during incubation. Significantly greater changes occurred in soils that were limed or fertilized with phosphorus than in check soils. There was also a significant lime × phosphorus interaction which indicated that the responses to the two nutrients were not additive (Table II).

Incubation of submerged soils slightly increased the C:total-N ratio. Changes were significantly greater with the addition of lime and phosphorus than without. Addition of both nutrients resulted in an increase of 2.1 units. The carbon to organic nitrogen ratios narrowed less in untreated soils at field capacity and widened more in submerged soils than did overall C:N ratios. However, lime and phosphorus treatments produced changes in the C:organic-N ratios similar to those in the overall C:N ratios. Thus, postincubation C:organic-N ratios of field capacity soils ranged from 21.4 for check soils to 20.1 for the phosphorus treated soils. Submerged soil ratios ranged from 23.3 for checks to 25.1 for the lime-phosphorus treated soils.

DISCUSSION AND CONCLUSIONS

Untreated soils incubated at field capacity showed a significant decrease in organic matter and C:N ratio and an increase in mineralization of organic nitrogen and its conversion to NO_3-N. Lime and phosphorus treatments further significantly increased mineralization of organic N in comparison with the check.

Submerged soils showed no change in organic matter regardless of treatments. The NH_4-N in soils showed some accumulation but no NO_3-N was found in soils. This lack of NO_3-N and the large amounts of mineralized N unaccounted for indicate that there was a great loss of N due to denitrification.

Results of this study together with those of Stanford and Epstein (1974) indicate that drainage and timely irrigation of the soils studied would be beneficial for mineralization of organic N to forms available to plants. These soils are saturated with water for prolonged periods in winter (Shoulders and McKee 1973). During summer, however, when soil temperatures favor rapid mineralization of organic nitrogen (Stanford et al. 1973), these soils intermittently develop major moisture deficits (Van Bravel 1959). Intensive control of soil moisture by drainage and irrigation may not be currently practical in the production of southern pine timber crops (Mareogaran 1973).

Lime and phosphorus were equally effective in increasing the supply of inorganic N (NH_4 and NO_3) that pine trees use. No additional advantage occurred from application of both nutrients. Because phosphorus deficiency is more likely than lime deficiency to limit pine growth in the West Gulf Region (Shoulders and McKee 1973) phosphorus fertilization appears preferable to liming to promote the release of mineral nitrogen and to reduce the amount of nitrogen fertilizer needed for maximum pine tree growth on these soils.

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Table I. Selected Chemical Properties of Study Soils before Incubation

Series and location	pH	Total exch. bases	Available P	Organic N	Mineral N Exc. NH -N	Mineral N NO -N	Organic Matter	C/N ratio
		meq/100g	-----------Parts per million			-----------	Percent	
Beauregard								
Location 1	4.52	2.77	2.8	900	0.8	3.8	3.8	24
Location 2	4.60	2.40	4.1	736	.1	3.7	2.4	19
Average	4.56	2.58	3.4	818	.5	3.8	3.1	22
Caddo								
Location 1	4.40	2.24	3.8	674	.3	1.9	3.0	26
Location 2	4.42	2.97	4.1	1246	.5	2.7	4.0	18
Average	4.41	2.60	3.9	960	.4	2.3	3.5	22
Wrightsville								
Location 1	4.35	2.81	2.4	639	.1	3.0	2.5	23
Location 2	4.58	3.57	3.1	720	.3	3.4	2.8	22
Average	4.46	3.19	2.8	680	.2	3.2	2.7	23

Table II. Changes in Organic Matter Content, Nitrogen, Fractions, and C:N Ratio During Incubation*

Treatment	Organic matter lost	Total mineralized organic N	Mineralized N as Exch. NH_4-N	Mineralized N as NO_3-N	N unaccounted for	Change in C/N ratio
	%	ppm	ppm	ppm	ppm	
Soil at field capacity						
Check	0.70 a	166 a	6 a	151 a	9	-5.0 a
Lime (L)	0.97 b	212 bc	7 a	194 b	11	-6.8 b
Phosphorus	1.02 b	196 b	7 a	184 b	5	-7.3 b
L + P	1.12 b	231 c	7 a	187 b	37	-7.3 b
Submerged soil						
Check	.06 a	59 a	26 a	-2 a	35	.5 a
Lime	.06 a	86 b	27 a	-2 a	61	1.3 b
Phosphorus	.07 a	84 b	30 b	-2 a	56	1.0 ab
L + P	.03 a	106 c	30 b	-2 a	78	2.1 c

*Values in a column within a soil moisture treatment followed by the same letter are not significantly different at 0.05 level.