NITROGEN FERTILIZER EQUIVALENCY OF ANAEROBICALLY DIGESTED MUNICIPAL SLUDGE

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Abstract

Crop yield response to municipal sludge is largely affected by the amount of nitrogen (N) made available during the growing season. The effect of sludge rate and N fertilizer rate on either grain sorghum [*Sorghum bicolor* (L.)] or corn [*Zea mays* (L.)] yield response was studied on three farms in Lancaster county, Nebraska. A combination of five rates of dewatered (80% H_2O) anaerobically digested sludge and five rates of N fertilizer (NH_4NO_3) were applied before planting and incorporated by discing within three days of sludge application. Sludge increased corn grain yield from 109 bushels acre^{-1} (0 sludge) to 150 bushels acre^{-1} (28 tons sludge acre^{-1}) on the irrigated site. The 21 ton acre^{-1} and 28 ton acre^{-1} sludge rates produced yields equivalent to that of 68 and 80 lbs fertilizer-N acre^{-1}. The average N fertilizer equivalency of the total organic N in the sludge was 11, 17 and 6% from the dryland corn, irrigated corn and dryland sorghum sites, respectively.

Introduction

The United States Environmental Protection Agency part 503 regulations, state that land application of municipal sludge is to be applied at an "agronomic" rate to agricultural fields. The meaning of agronomic rate is left open but is usually interpreted as the amount of sludge required to meet the N demands of the crop. Since most N in sludge is found in organic forms and is unavailable, crop yield response to sludge is largely dependent on the amount of N mineralized during the growing season.

The soil biomass is able to decompose (mineralize) the sludge eventually converting the organic forms of N to forms available to crops. Several soil properties including temperature, moisture, pH, porosity, permeability and microbial population affect the mineralization rate. The complexity of factors affecting N mineralization can result in an N supply that is poorly synchronized with crop N demand. Therefore making recommendations for agronomic rate requires information on how the crop responds to sludge application as well as the rate of organic N mineralization.

Objectives

To determine the N value of sludge in terms of inorganic N fertilizer and the rate of N mineralization.

Materials and Methods

Three experiment sites representing typical agricultural soils in Lancaster County Nebraska were selected. The sites included a Sharpsburg silty clay loam soil with dryland corn, Butler silt loam soil with dryland sorghum and a Judson silt loam soil with irrigated corn. Soil characteristics of each location are shown in Table 1. A combination of five rates of dewatered (80% H_2O) anaerobically digested sludge and five rates of N fertilizer (NH_4NO_3) were applied before planting and incorporated by discing within three days of sludge application. Sludge characteristics are shown in Table 2. Treatments were set up in a split plot randomized complete block experimental design with four replications. Sludge was applied in the main plot and N fertilizer in the subplots. All cultural practices of planting, herbicide and insecticide application and irrigation were conducted by the cooperating farmer. Phosphorus and zinc fertilizer were broadcast over the entire plot area at rates recommended by the UNL soil and plant analytical laboratory.

Table 1. Soil characteristics from each experimental site.

Site	Dryland Corn	Irrigated Corn	Dryland Sorghum
Soil Series	Sharpsuburg; Fine, montmorillonitic, mesic Typic Argiudolls	Juds on; Fine-silty, mixed, mesic Cumulic Hapludolls	Butler; Fine, montmorillonitic, mesic Abruptic Argiaquolls
Soil Texture	silty clay loam	silt loam	silt loam
Nitrate-N(lb-N acre^{-1}) (183 cm profile)	40	48	22
Soil pH	5.5	5.7	5.7
Soil Organic Matter (%)	2.2	2.6	2.9
Bray P1 (ppm)	9.0	4.6	12.6
Potassium (ppm)	303	186	246
DTPA Zinc (ppm)	0.24	0.51	0.72

Table 2. Characteristics of sludge applied at each location.

Site	Dryland Corn	Irrigated Corn	Dryland Sorghum
Solids (%)	20	22	24
Total C (%)	27.9	23.0	23.4
Total N (%)	4.5	3.7	3.9
NO_3^--N (ppm)	3.9	5.7	8.4
NH_4^+-N (ppm)	2219	1591	2651
C:N ratio	6.2	6.3	6.0

Incubation soil cores were prepared by driving aluminum tubing (2 inch outside diameter X 9 inches long) 6 inches into soil from each plot with applied sludge. The bottom quarter inch of soil was removed from each "undisturbed" soil core (still in the tube) and replaced with a nylon bag filled with ion exchange resin. The entire assembly was then returned to the hole. The tubes were open to the atmosphere thus allowing products of N mineralization to leach from each soil column into the resin bags. Tubes were taken out at the eight leaf stage, tassel and harvest at the irrigated corn site and at harvest from the dryland sorghum site. Soil and ion exchange resins were extracted and analyzed for NO_3^--N and NH_4^+-N. Net N mineralization during each incubation period was calculated for each treatment using the combined amounts of NO_3^--N and NH_4^+-N in both soil and resin analysis. The concentration of N in all soil samples was converted to lbs acre^{-1} using an average bulk density of the study area for the depth of the cores.

Results and Discussion

N Fertililzer Equivalency Based on Grain Yield

Grain yield response to N fertilizer was affected by the amount of sludge applied (Table 3) at all three locations. Nitrogen fertilizer alone increased grain yield 32, 42 and 24 bushels acre^{-1} for the dryland corn, irrigated corn and dryland sorghum sites respectively (Table 4). In general there was less grain yield response to N fertilizer the higher the sludge rates (significant S X N interaction). Sludge alone increased grain yield approximately the same as N fertilizer, 30, 41 and 21 bushels acre^{-1} respectively, for the above crops. Late planting and an early freeze affected grain response to N fertilizer and sludge at the sorghum site. The more mature plants were those that received N fertilizer or high rates of sludge and thus were the least affected by the freeze.

Table 3. Analysis of variance for sludge rate and nitrogen rate effects on grain yield of dryland corn, irrigated corn or dryland sorghum in 1995.

Source of Variation	Degrees of Freedom	Dryland Corn	Irrigated Corn	Dryland Sorghum
			Pr > F	
Sludge Rate (S)	4	0.0676 *	0.1341 NS	0.5773 NS
Nitrogen Rate (N)	4	0.0373**	0.0001 ***	0.0001 ***
S X N	16	0.0623 *	0.0395 **	0.0107 **

*, **, *** Significant at the 0.10, 0.05 and 0.01 probability levels respectively.

A quadratic grain response to sludge at the dryland corn and sorghum sites resulted in the highest sludge rate being worth less N fertilizer than the previous sludge rate (Table 5). Whereas grain yield increased for each increase in sludge rate at the irrigated corn site. Thus the N fertilizer equivalency for irrigated corn increased from 27 lbs of N fertilizer for 7 tons acre^{-1} of sludge to 80 lbs of N fertilizer for 28 tons acre^{-1} of sludge. Since grain response generally plateaus, the amount of N fertilizer that each ton of sludge was worth decreased for higher sludge rates. On average each ton of sludge was worth 2.94, 3.30 and 2.32 lbs of N fertilizer for dryland corn, irrigated corn and dryland sorghum, respectively. Assuming 100% availability of the inorganic N from sludge, the N fertilizer equivalency of the organic N from the sludge was on average 11, 17 and 6% for the dryland corn, irrigated corn and dryland sorghum sites, respectively.

Table 4. Effect of sludge rate and N fertilizer rate on grain yield from each location in 1995.

Dryland Corn			Irrigated Corn			Dryland Sorghum		
Sludge Rate	N Rate	Grain Yield	Sludge Rate	N Rate	Grain Yield	Sludge Rate	N Rate	Grain Yield
tons acre^{-1}	lbs acre^{-1}	bushels acre^{-1}	tons acre^{-1}	lbs acre^{-1}	bushels acre^{-1}	tons acre^{-1}	lbs acre^{-1}	bushels acre^{-1}
0	0	70	0	0	109	0	0	40
	30	86		45	120		40	54
	60	102		90	143		80	64
	90	88		135	146		120	57
	120	92		180	151		160	64
6	0	89	7	0	92	5	0	36
	30	96		45	124		40	51
	60	91		90	152		80	72
	90	104		135	134		120	85
	120	87		180	149		160	86
12	0	84	14	0	140	10	0	53
	30	91		45	129		40	68
	60	82		90	146		80	65
	90	94		135	146		120	74
	120	110		800	155		160	71
18	0	101	21	0	136	15	0	60
	30	102		45	143		40	63
	60	98		90	147		80	73
	90	95		135	157		120	55
	120	108		180	156		160	64
24	0	88	28	0	150	20	0	46
	30	95		45	152		40	65
	60	106		90	161		80	62
	90	92		135	169		120	61
	120	97		180	142		160	73

Table 5. Quantity of N fertilizer required to produce grain yields equivalent to yields from each sludge rate in 1995.

Site	Sludge Rate	N fertilizer equivalency	
	Tons acre^{-1}	lbs-N acre^{-1}	lbs-N Ton^{-1}
Dryland Corn	6	21	3.54
	12	41	3.54
	18	52	2.98
	24	39	1.70
average			2.94
Irrigated Corn	7	27	3.76
	14	49	3.44
	21	68	3.16
	28	80	2.82
average			3.30
Dryland Sorghum	5	12	2.36
	10	30	3.10
	15	37	2.48
	20	27	1.36
average			2.32

Sludge N Mineralization Based on Field Incubation Cores:

On the irrigated Judson silt loam soil, 27% of the organic N was mineralized by harvest (Fig. 1). Whereas only 10% of the organic N was mineralized on the dryland Butler silt loam soil. Since 1995 was abnormally dry, the difference in soil moisture was thought to be the major difference between net N mineralization from the two locations. Net N mineralization from the two sites where incubation cores were installed was affected by the amount of time that elapsed after sludge application (Table 6). Sludge rate did not affect net N mineralization.

Table 6. Analysis of variance for the effect of sludge rate and time on net N mineralization on two soils in 1995.

Source	df	Irrigated Judson	df	Dryland Butler
		Pr > F		Pr > F
Sludge Rate (S)	3	0.5682 NS	3	0.8881 NS
Time (T)	3	0.0002 ***	2	0.0751 *
S X T	9	0.6787 NS	6	0.8418 NS

*, **, *** Significant at the 0.10, 0.05 and 0.01 probability levels respectively

Of equal importance to the amount of N mineralized is when it was mineralized. Only thirty seven percent of the N mineralized in 1995 was mineralized by tassel on the

Judson silt loam soil (Fig. 1). This poses a problem because the rate of corn N uptake begins to decline substantially at about tassel. Ideally the majority of N mineralization should occur before the maximum rate of N uptake. Therefore in order to maintain an adequate supply of available N, higher rates of sludge have to be applied which results in even more N being mineralized after the plant no longer requires N. The amount of inorganic N that was mineralized exceeded total (residual N + mineralized N) N uptake shortly after tassel. (Fig. 2). The N mineralized in excess of that taken up is available for fall and spring leaching and thus undesirable. More research is needed to determine how well N mineralization from the sludge is synchronized with crop demand relative to crop N requirements and seasonal differences.

Figure 1. Percent of organic N from sludge mineralized during the 1995 growing season

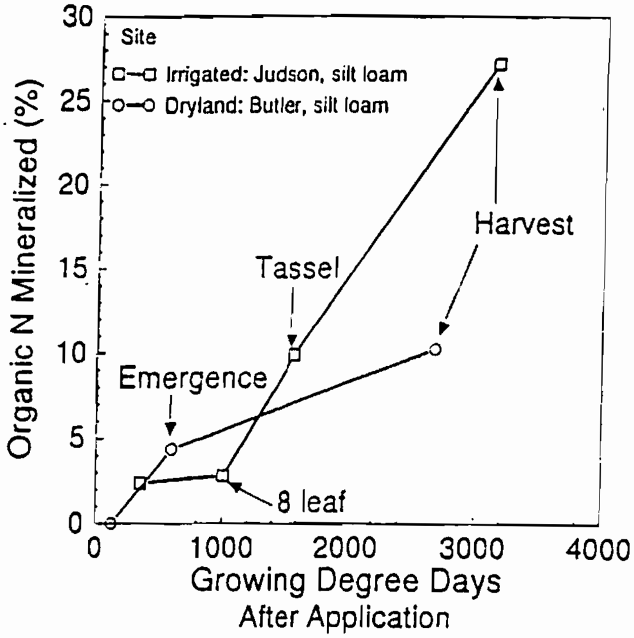
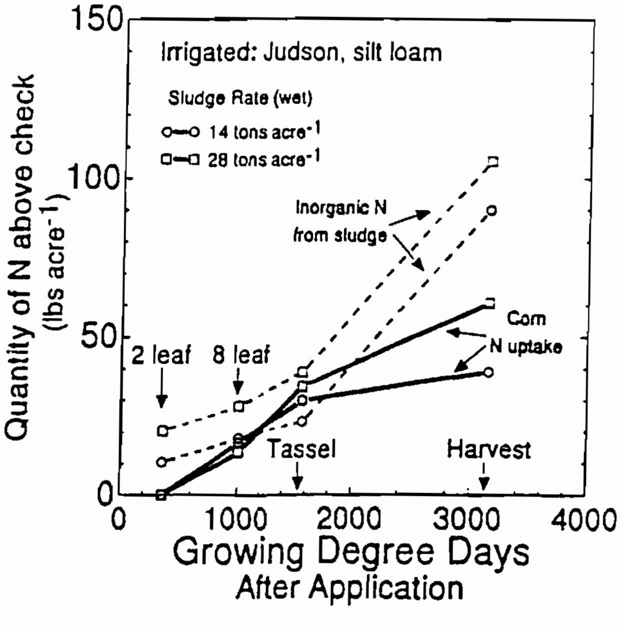


Figure 2. Accumulation of inorganic N mineralized from sludge and the amount taken up by corn at two sludge rates in 1995.



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