GROWTH OF CORN IN VARYING MIXTURES OF PAPER MILL SLUDGE AND SOIL

by

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ABSTRACT

To evaluate different levels of paper mill sludge as a soil amendment for the production of corn (*Zea mays* L.), sludge was added to 15-cm pots of soil in a greenhouse experiment. Mixtures were made from paper mill sludge (0 to 560 Mg/ha wet weight) mixed with field soil (Hadley fine sandy loam with coarse, mixed, mesic, Fluventic, Dystrochrept deposits). Nitrogen was added as ammonium nitrate at 0 or 200 kg N/ha. Eight corn seeds of 'Pioneer Max 21' were seeded into each pot immediately after mixing the paper mill sludge and soil or at 21 days after mixing the media. Seven days after sowing, seedlings were counted in each pot to assess germination (emergence). Delaying of sowing of seeds for 21 days increased the number of seeds that germinated. Corn plants were harvested after 35 days of growth. Plant biomass declined as amounts of sludge increased. Adding N and delaying sowing for 21 days produced the greatest amount of dry mass. Tissue (leaf) total N decreased with increasing amounts of sludge. Addition of N to the mixtures increased the average total N in corn leaves. However, leaf total N still decreased with increasing amounts of sludge added even if N at 200 kg /ha was added to the media. Sowing immediately after setup showed the highest leaf total N if no sludge was added to the mixture. Sowing immediately after setup of the experiment and adding paper mill sludge at 560 Mg/ha produced the lowest total N in corn leaves. Generally, the P concentration in plants increased as the amount of paper sludge increased, but the increase was less with N added than in treatments without N added. At 21 days, carbon:nitrogen, pH, and salinity of the media declined relative to the initial values. Total N in the media was higher after a 21-day delay than immediately after setup. Organic matter content increased with increasing amounts of paper sludge. Results indicated that addition of paper sludge to soil increased media organic matter and P contents. Germination was hindered when seeds were sown immediately after setup of the experiment, but delaying seeding for 21 days eliminated the germination problem. Nitrogen deficiency was problematic, and more than 200 kg/ha of supplemental N is recommended to overcome immobilization of N.

INTRODUCTION

Concern for disposal of paper mill sludge in landfills has increased over the last 10 years. Landfilling and incineration of by-products have become unfavorable means of disposal (1, 2, 3). Alternatives for disposing of paper mill sludge currently are being sought. The high organic matter content and low trace metal and organic pollutants in pulp and paper mill sludge suggest that these residuals may provide a valuable resource for soil amendments (2). As supplies for traditional organic amendments including peat moss, composts, and farm manures are diminishing near urban areas, opportunities for beneficial use of paper mill sludge on land have increased (3, 4, 5).

At paper mills, primary treatment produces sludge that is high in wood fiber, clay, and lime. Primary-treatment sludge settles out readily coagulable solids and is 3 to 7 % solids. Primary treatment does not incorporate a biological treatment (6). Secondary sludge contains 0.5 to 2.0 % solids (6) after a biological treatment (secondary treatment). In general, primary sludge has a high carbon:nitrogen (C:N) ratio whereas the secondary sludge has a higher P and N content resulting in a lower C:N ratio than the primary sludge (7, 8). Some nutrients such as P, K, Ca, and Mg increase with additions of paper mill sludge to the soil (5, 9). Aluminum is inherent in the manufacturing of paper and may be a problem element with paper mill sludge as a soil amendment (5). Addition of paper mill sludge to soil can increase plant growth and yield (2), increase N and P availability (9), and increase soil organic matter content (3, 10). Nitrogen immobilization has been documented in sludge-amended soils, but corn plants have been shown to recover quickly following the treatments (3). Nitrogen immobilization has been corrected by delaying seeding after application of paper mill sludge, by reducing sludge application, or by applying supplemental fertilizer (11).

Successful use of paper mill sludge in agriculture must demonstrate, without adverse effects, that crops benefit or soil properties improve from the addition of the sludge as a soil amendment. The purpose of this research was to demonstrate the utility of paper mill sludge as a soil amendment for corn growth.

MATERIALS AND METHODS

Paper mill sludge (Erving Paper Mill, Erving, Massachusetts) was used to prepare treatments to simulate field applications of 0, 112, 224, 336, 448, or 560 Mg wet mass/ha. Media were prepared to simulate field conditions by mixing sludge 0, 50, 100, 150, 200, or 250 g per 1000 g soil (Hadley fine sandy loam with coarse, mixed, mesic, Fluventic, Dystrochrept deposits). In a wheelbarrow, 4 pots of medium were mixed with sludge or N by hand. This method ensured complete mixture of treatments and the N. Treatment were arranged in 4 randomized complete blocks in a greenhouse at the University of Massachusetts at Amherst.

The Erving Paper Mill treatment plant accepts municipal wastewater from the town of Erving so that about 2% on average of the paper waste is sewage sludge. Analysis of the paper mill sludge used is shown in Table 1. Nitrogen was added (mass basis) as ammonium nitrate at 0 or 200 kgN/ha. Eight corn seeds (*Zea mays* L. 'Pioneer Max 21') were sown into each pot, immediately after mixing the sludge and soil media or at 21 days later to assess the impact of seeding time on germination and growth of corn. The seedlings that emerged were counted to assess germination. Shoots of corn plants were harvested after 35 days of growth, and dry weights were recorded. Tissues were analyzed for total nitrogen (Kjeldahl-N, 12) and P (molybdovanadophosphoric acid procedure; 13). Growth was assessed as dry mass to determine the suitability of the different mixtures for growing corn.

Samples of the media were taken initially and 21 days later for determinations of of organic matter (14), total N (Kjeldahl-N, 12), pH, and electrical conductivity (14) of extracts (2:1 v:w, water:medium).

RESULTS

Corn Germination

Seven days after sowing, the number of seeds that emerged of the 8 seeds sown was the assessment of germination. Delaying seeding for 21 days after mixing the paper sludge and soil, increased the average percent germination from 88 % with immediate seeding to 100 % with delayed seeding.

Corn Growth

Thirty-five days after sowing, growth of corn was assessed by determining the dry mass of shoots (Table 2). The interaction of amount of paper sludge, N addition, and seeding time was significant. Plant growth was suppressed by increased applications of paper sludge, but the suppression was less with N added than in treatments

without N added. Also, the paper sludge additions were less suppressive with the delay in planting than without the delay. The mean dry mass of plants grown with N addition was 2.8 g/plant and without N addition was 2.2 g/plant. The mean dry mass per plant was 2.4 g with seeding immediately following application of sludge and 2.6 g with the 21-day delay in seeding.

Nitrogen Accumulation

The interaction of amount paper sludge added, N addition, and seeding time was significant (Table 3). In all cases, total N concentration in corn leaves decreased with increasing amounts of sludge; however, the decline in total N concentrations was less with N fertilization than without fertilization (Figure 1). The mean N concentration in leaves with N fertilization was 1.67 % and with no fertilization was 1.42 % (Table 3). Delaying of seeding lessened the suppression of N accumulation at the higher levels of sludge addition (Figure 2). The mean N concentration in leaves with no seeding delay was 1.51 % N and with the 21-day seeding delay was 1.58 % N. (Table 3)

Phosphorus Accumulation

The interaction of amount of paper sludge addition, N addition, and seeding time was significant (Table 4). Generally, the P concentration in plants increased as the amount of sludge was increased, but the increase was less with addition of N than without N (Figure 3). The seeding time component of the interaction seemed to be small in that the increase in P concentration was about the same with or without seeding delay (Table 4). The main effect of seeding time had no effect on P concentration, with the mean concentration being 0.20 % P.

Media Composition

The C:N ratio of the media was lower at 21 days after application (C:N,12:1) of the paper mill sludge than immediately after application (C:N,14:1) of the waste (Table 5). The pH and electrical conductivity of the media were significantly lower after 21 days than immediately after application (Table 5). The mean total N of the media was higher after 21 days (0.19 %) than immediately (0.15 %) after the setup of the experiment. Total N (Kjeldahl-N) in the media varied little with the application of paper sludge (Figure 4). Soil organic matter increased with the application of paper mill sludge, but N addition had little effect on the soil organic matter (Figure 5).

DISCUSSION

Increasing amounts of paper mill sludge in the media suppressed growth of corn plants. Nitrogen deficiency appeared to be responsible for the decrease in biomass with increasing paper sludge. The C:N ratio of the paper mill sludge was 84:1 (Table 1). The C:N ratio of the media did not vary with increasing amounts of paper sludge as the amount of sludge added was small relative to the mass of the soil. Corn leaf analysis N indicated that all plants were N deficient and that most were P deficient. Hence, it appears that the paper sludge led to immobilization of soil-available N and P. Corn plants less than 30-cm tall should have tissue total N of 3.50 to 5.00 % N and P levels 0.3 to 0.5 % P (16). The highest average tissue total N was 2.31 % N, and adding paper sludge enhanced the deficit in tissue total N (Figure 2). Even with no paper sludge amendment and N (200 kg N/ha) added, tissue total N was deficient (2.31 % N). Phosphorus deficiency is likely if total P concentration is below 0.2 %, and in the experiment, P values were often below this level.

Symptoms of N and P deficiency were widespread and began developing after 2 weeks of growth. Nitrogen deficiency appeared in old leaves as light green to yellow coloration. Later stages of N deficiency showed some necrosis. Phosphorus deficiency symptoms included dark-green color of old leaves with purplish color particularly on the underside of the leaf. Differentiation between N and P deficiency symptoms became difficult after about 4 weeks of growth, as all deficient plants showed advanced stages of chlorosis and necrosis.

Media organic matter increased with increased additions of paper mill sludge. These results were similar to those of Thiel et al. (3), who showed an increase in organic matter with paper sludge as a soil amendment for growth of potatoes and corn. Additions of sludge also have enhanced the P and N contents of media (8). Erving Paper Mill sludge increased the available P to plants (Figure 4). The total N content of the media slightly increased from 0.16 to 0.18 % N with additions of paper sludge. This increase was not reflected in leaf total N. In fact, total N concentration and accumulation of plants decreased with increasing paper mill sludge, suggesting immobilization of available N (Table 5).

Delaying of seeding increased germination. Electrical conductivity (EC) and pH of the media were lower at 21 days after setup of the experiment than immediately after mixing the media. Electrical conductivity of the media can influence the water relations of the media thereby influencing germination, but in this experiment, EC was too low to have an effect on plant growth. Initially, the average EC of the media was 0.21 dS/m in a 2:1

water:soil extract, which would be about dS/m in a saturation extract. This value is far below the 2.0 dS/m limit noted Richards (15) as having negligible effects on plant growth. It is likely that decomposition products had suppressive effects on germination of seeds that were sown immediately after mixing the media. The EC was probably due to soluble organic carbon and N constituents.

Addition of Erving Paper Mill sludge to soil improved media organic matter and P content. Nitrogen was deficient, and supplemental N at 200 kg/ha was not sufficient to overcome the deficiency. Germination was hindered when seed were sown immediately after the start of the experiment but not if sowing was delayed for 21 days. Use of Erving Paper Mill sludge did demonstrate some utility in agriculture, such as enrichment of soil with N, P, and organic matter. However, some strategies such as supplementing N or delaying seeding may be recommended to eliminate deficiency symptoms and biomass suppression.

Table 1. Properties of paper mill sludge.

Elemental composition (total)		Other properties	
----------mg/kg----------			
Total N	2,800	pH	7.8
Ammonium N	18	Soluble salts, dS/m	3.29
Nitrate-N	27	Organic matter, %	44.0
P	57	Estimated organic carbon, %	23.8
K	151	Carbon:Nitrogen ratio	84.9
Ca	76,292	Bulk density, g/cm^3	0.28
Mg	364		
B	0.5		
Mn	27		
Zn	31		
Cu	5		
Fe	143		
Pb	5		
Cd	0.0		
Ni	0.4		
Cr	0.4		

Table 2: Dry weights of corn plants after 35 days of growth in paper mill sludge media with or without N fertilization and with or without delay in planting

Sludge added	Seeding time after mixing				
	No delay		21-day delay		
Mg/ha	0 N	200N†	0 N	200N†	Mean
0	3.52	4.16	3.50	4.18	3.84
112	2.69	3.76	3.35	4.31	3.52
224	2.44	3.32	2.26	2.82	2.71
336	1.67	1.83	2.19	2.15	1.96
448	1.08	1.69	1.22	1.23	1.31
560	1.23	1.25	1.12	2.70	1.57
Means	2.10	2.67*	2.27	2.89*	
Trend	L*	L*	L*	L*	L*

†kg N/ha

L, linear regression; *, $P \leq 0.05$

Table 3. Total N in leaves of corn plants grown in paper sludge in paper mill sludge media with or without N fertilization and with or without delay in planting

	Seeding time after mixing				
Sludge added	No delay		21-day delay		
Mg/ha	0 N	200N†	0 N	200N†	Mean
	----------% N----------				
0	2.13	2.52	2.04	2.11	2.20
112	1.30	2.39	1.45	1.66	1.70
224	1.23	1.57	1.39	1.49	1.42
336	1.19	1.23	1.47	1.49	1.35
448	1.06	1.27	1.32	1.36	1.25
560	1.14	1.11	1.38	1.81	1.36
Mean	1.35	1.68	1.51	1.65	
Trend	L^{**}, Q^{**}	L^{*}	L^{**}	L^{**}, Q^{**}	L^{**}, Q^{**}

†kg N/ha

L, linear regression; Q, quadratic regression; *, $P \leq 0.05$; **, $P \leq 0.01$

Table 4. Total P in leaves of corn plants grown in paper mill sludge media with or without N fertilization and with or without delay in planting

Sludge added	Seeding time after mixing: No delay		21-day delay		
Mg/ha	0 N	200N†	0 N	200N†	Mean
0	0.13	0.14	0.13	0.12	0.13
112	0.16	0.13	0.15	0.14	0.15
224	0.20	0.14	0.20	0.18	0.18
336	0.23	0.21	0.20	0.21	0.21
448	0.30	0.25	0.29	0.28	0.28
560	0.27	0.25	0.28	0.18	0.24
Mean	0.22	0.19	0.21	0.18	
Trend	L^{**}	L^{*}	L^{**}, Q^{**}	L^{**}	L^{**}, Q^{**}

†kg N/ha

L = linear regression; Q = quadratic regression; * $P \leq 0.05$; ** $P \leq 0.01$

Table 5. Media carbon:nitrogen ratio, pH, total nitrogen (TN), and electrical conductivity (EC) at two different seeding times.

	Measurement			
Seeding time	C:N	TN (%N)	pH	EC (dS/m)
No delay	14:1	0.15	6.42	0.210
21-day delay	12:1*	0.19*	6.05*	0.127*

pH and EC extracts: 2:1 v:w, water:medium

*, means in columns significantly different, $P \leq 0.05$

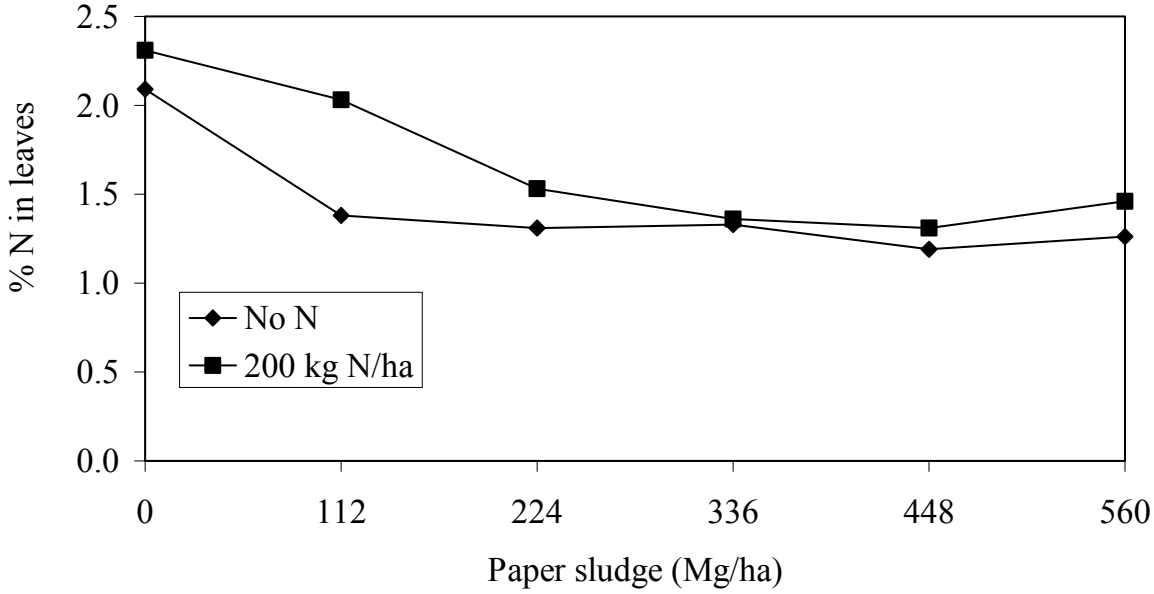

Figure 1. Total N in corn leaves with increasing amounts of paper sludge and with two N treatments.

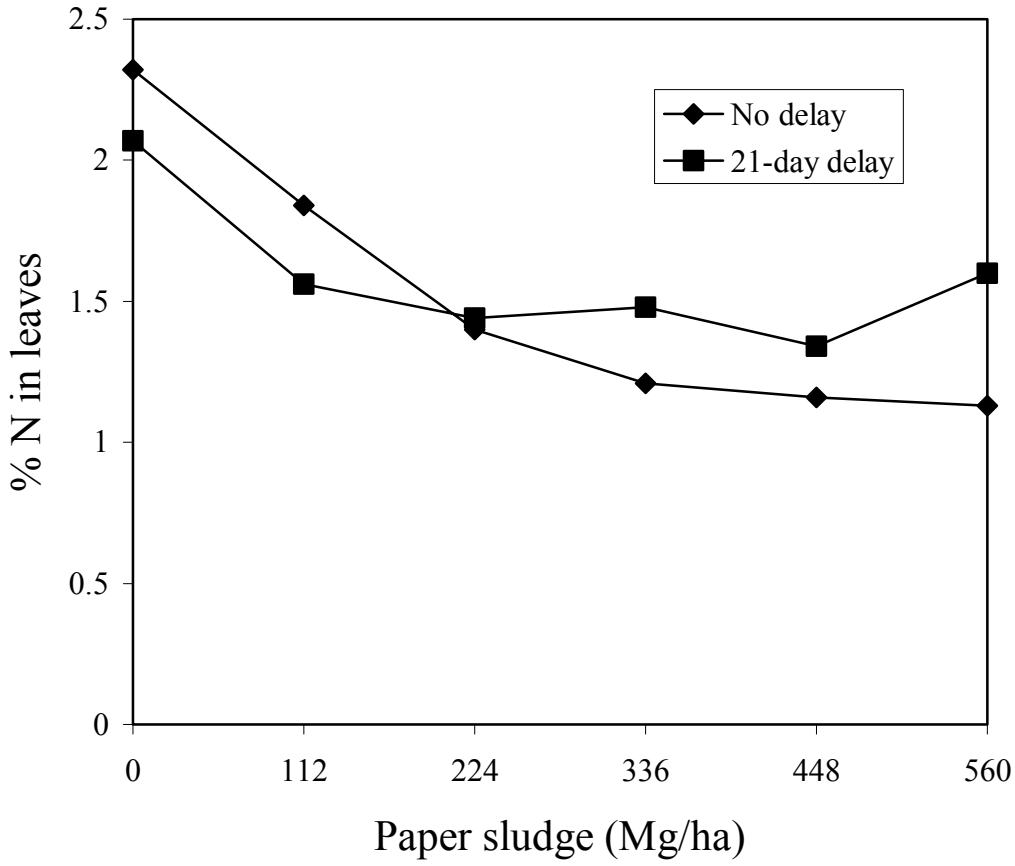

Figure 2. Total N in corn leaves with increasing amounts of paper sludge and with two seeding times.

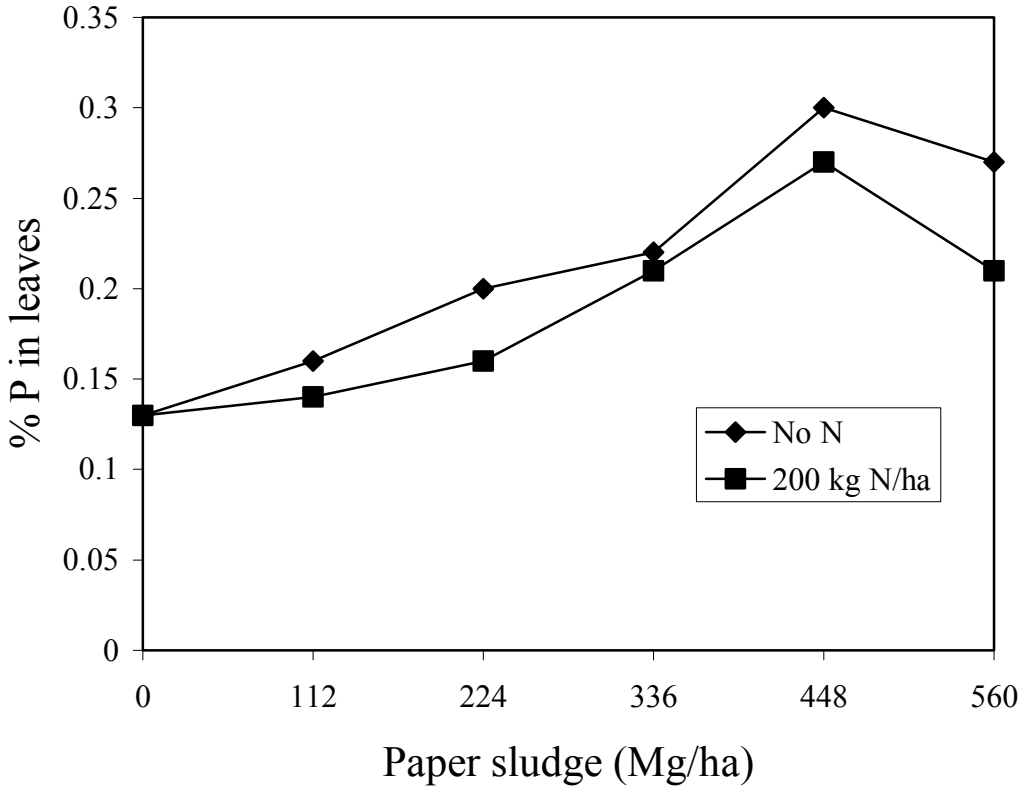

Figure 3. Percent P in corn leaves with increasing amounts of paper sludge and with two N treatments.

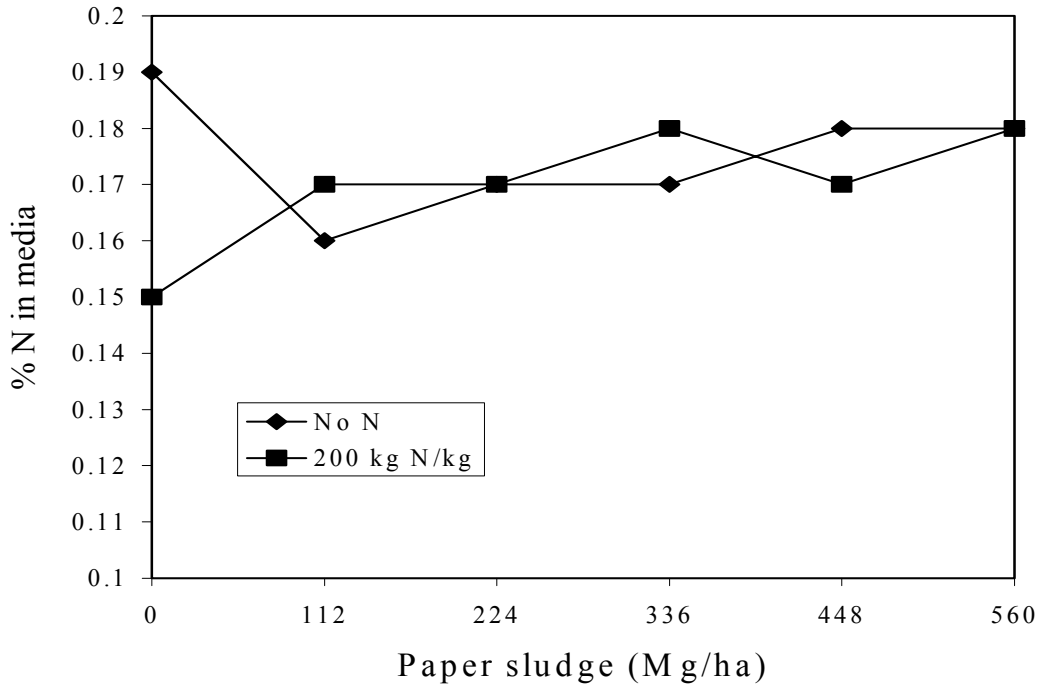

Figure 4. Total N in media with increasing amounts of paper sludge and with two N treatments.

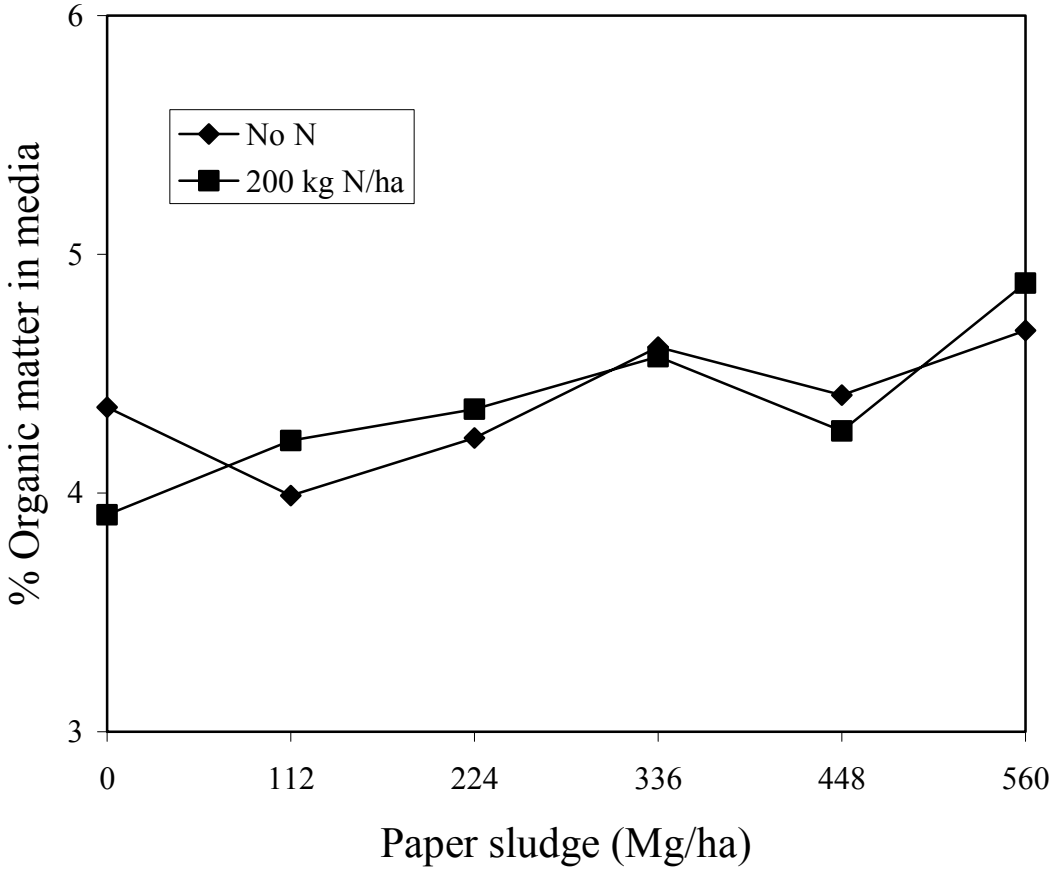

Figure 5. Variation in organic matter content in media with increasing amounts of paper sludge and with two N treatments.

REFERENCES

1. Basta, N. T. 2000. Examples and case studies of beneficial reuse of municipal by-products. p. 481-504. *In* Soil Science of American, Inc. Land Application of Agricultural, Industrial, and Municipal By-Products. SSSA American Book Series 6, Madison, Wis.

2. Bellamy, K.L., C. Chong, and R.A. Cline. 1995. Paper sludge utilization in agriculture and container nursery culture. J. Environ. Qual. 24:1074-1082.

3. Thiel, D. A. 1985. Combined primary/secondary sludge proves beneficial for potatoes and corn. p. 261-278. *In* TAPPI Proceedings, Environ. Conf. TAPPI Press, Atlanta, Ga.

4. Carpenter, A.F. and I.J. Fernandez. 2000. Pulp sludge as a component in manufactured topsoil. J. Environ. Qual. 29:387-397.

5. Edwards, J.H. 1997. Composition and use of uncomposted waste paper and other organics. p. 163-184. *In* J.E. Rechcigl and H.C. MacKinnon (ed.) Agricultural Uses of By-Products and Wastes. ACS Symposium Series 668, American Chemical Society, Washington, DC.

6. Hue, N.V. 1995. Sewage Sludge. p. 199-247. *In* J.E. Rechcigl (ed.) Soil Amendments and Environmental Quality. Lewis Publishers, Boca Raton, Fla.

7. Camberato, J.J., E.D. Vance, and A.V. Someshwar. 1997. Composition and land application of paper manufacturing residuals. p. 185-203. *In* J.E. Rechcigl and H.C. MacKinnon (ed.) Agricultural Uses of By-Products and Wastes. ACS Symposium Series 668, American Chemical Society, Washington, D.C.

8. Dolar, S.G., J.R. Boyle, and D.R. Keeney. 1972. Paper mill sludge disposal on soils: Effects of yield and mineral nutrition of Oats (*Avena sativa* L.). J. Environ. Qual. 4:405-409.

9. Brockway, D.G. 1983. Forest floor, soil, and vegetation responses to sludge fertilization in red and white pine plantations. Soil Sci. Soc. Am. J. 47:776-784.

10. Einspahr, D., M.H. Fiscus, and K. Gargan. 1984. Paper mill sludge as a soil amendment. *In* TAPPI Proceedings, Environ. Conf. TAPPI Press, Atlanta, Ga. p. 253-257.

11. Simpson, G.G., L.D. King, B.L. Carlise, and P.S. Blickensderfer. 1983. Paper mill sludges, coal fly ash, and surplus lime mud as soil amendments in crop production. TAPPI J. 66(7):71-74.

12. Bradstreet, R.B. 1965. The Kjeldahl method for organic nitrogen. Academic Press, New York.

13.Olsen, S.R. and L.A. Dean. Phosphorus, pp. 1035-1049. *In* C.A. Black (ed.) Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. Agronomy 9. American Society of Agronomy, Madison, Wis.

14. Storer, D.A. 1984. A simple high sample volume ashing procedure for determination of soil organic matter. Commun. Soil Sci. Plant. Anal., 15(7):759-772.

15. Richards, L.A. (ed.) 1954. Diagnosis and improvement of saline and alkali soils. Agriculture Handbook No. 60. United States Department of Agriculture. Washington, D.C.

16. Mills, H.A. and J. Benton Jones, Jr. 1996. Plant Analysis Handbook II. MicroMacro, Publishing, Inc., Athens, Ga.