EFFECTS OF BIOSOLIDS LOADING RATE AND SAWDUST ADDITIONS ON ROW CROP YIELD AND NITRATE LEACHING POTENTIALS IN VIRGINIA SAND AND GRAVEL MINE RECLAMATION[1]

by

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Abstract. The USEPA 503 biosolids utilization rules recognize the need for higher than agronomic rate applications to mined lands under the assumption that NO_3-N contamination of ground-water will not be significant. We evaluated a range of biosolids loading rates (1x to 7x agronomic rate of 14 Mg ha^{-1}) with and without added sawdust (to adjust the applied C:N ratio to approximately 20:1) on a reclaimed gravel mined soil and an undisturbed prime farmland soil for three growing seasons. The two experimental blocks were cropped to corn (*Zea mays*) in 1996, and winter wheat (*Triticum aestivum*) and soybeans (*Glycine max*) in 1997. Root zone leachates were collected from zero-tension lysimeters under adjacent micro-plots. Effects of biosolids loading rate on crop yields were not as pronounced as expected due to relatively wet weather. Leachate NO_3-N over the winter of 96/97 increased incrementally (from < 20 to > 100 mg L^{-1}) with loading rate (1x to 7x) and then declined sharply in March and April of 1997, finally approaching control level concentrations through the winter of 1997/1998 and beyond. Addition of sawdust significantly decreased NO_3-N leachate levels at all biosolids loading rates except the 5x biosolids + sawdust treatment which exhibited a first winter spike in excess of 100 mg L^{-1}. These data indicate that higher than agronomic loading rates of biosolids lead to enhanced NO_3-N leaching potentials over the first winter following application. However, this "one-time event" supports the original USEPA presumption that some net leaching under elevated loading rates is to be expected, but it is a short-term effect.

Additional Key Words: Prime farmland; ground-water quality; agronomic rate.

Introduction

Municipal wastewater treatment biosolids are commonly applied to surface mined lands as soil amendments to enhance organic matter, nutrient pools, water holding capacity, and overall long-term soil productivity (Haering et al., 2000). Applications of biosolids in conventional farm management scenarios are typically governed by the "agronomic rate" that supplies only the amount of N needed by the subsequently grown crop. Higher than agronomic rates (ranging from 50 to > 200 Mg ha^{-1}) of biosolids are commonly applied in mined land reclamation scenarios (Sopper, 1993) under the assumption that NO_3-N losses to ground-water will have minimal long term negative effects from one-time application. The USEPA 503 biosolids rules (USEPA, 1995) and resultant state regulations recognized the need for higher than agronomic rate biosolids applications to mined lands. The underlying assumptions were (1) that biosolids would only be applied once at the higher rate and (2) that NO_3-N leaching losses would be expected, but would not seriously degrade ground-water quality with a one-time application. Detailed research studies in Pennsylvania

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(Carello, 1990; Sopper and Seaker, 1990) and Virginia (Daniels and Haering, 1994) concluded that application of higher than agronomic rates of various biosolids products to coal mined lands had little, if any, short- or long-term effects on ground water NO_3-N levels under application areas or at permitted surface water discharge points. Significant NO_3-N leaching following heavy biosolids applications to forest lands on gravelly coarse-textured soils in the Pacific Northwest has been reported by Riekirk (1978, 1981), but the observed effects were ephemeral, largely limited to the first two winters after application.

Previous work by the authors reported in a companion paper indicated that addition of high C:N residues (sawdust) to land-applied biosolids could significantly reduce NO_3-N leaching potentials. Our assumption was that if we could adjust the applied bulk C:N ratio to $\geq$ 20:1, that much of the mineralized N would be immobilized in the microbial biomass (Parker and Sommers, 1983), thereby limiting leaching potentials, and then released slowly over succeeding growing seasons. Examples of high C:N materials include: sawdust (C:N = 200-750), wood chips (200-1300), and paper products (400-900).

In 1995, the State of Virginia Dept. of Mines Minerals and Energy developed guidelines for the application of biosolids to coal mined lands (VDMME, 1995) with Virginia Tech's assistance. These guidelines capped loading rates at 75 Mg ha^{-1} (dry) for biosolids cake and at 115 Mg ha^{-1} when the C:N ratio of the applied product was 25:1 or greater. However, the application of higher than agronomic rates of biosolids to very stony and coarse-textured mine soils with shallow ground water within the Chesapeake Bay watershed raised significant regulatory concerns with regard to long-term effects on nutrient loadings to ground water.

In this experiment, we evaluated a range of biosolids loading rates with and without added sawdust (to adjust the applied C:N ratio) in an attempt to gather sufficient data to develop recommendations for the use of biosolids on lands mined for minerals other than coal. Since the research site was a reclaimed gravel mine, and was in row crop production, we replicated the experimental design on adjacent undisturbed prime farmland soil as an external control. Our specific objectives were to compare application rates of unamended and sawdust-amended biosolids on (1) NO_3-N leaching potentials and (2) overall crop yields.

Methods and Materials

A reclaimed sand and gravel mine soil in Charles City County, Virginia, and an undisturbed prime farmland upland soil received a one-time application of varying rates of biosolids (anaerobically-digested secondary biosolids from Chesterfield, VA) in March 1996. The reclaimed land area had been in soybeans (*Glycine Max.*) the year previous while the native upland soil had been in cotton (*Gossypium spp.*) production. The soils in the undisturbed area were predominantly the prime farmland Pamunkey series (Fine-loamy, mixed, thermic Ultic Hapludalfs). The plot area occupied an upland flat grading to a slightly concave landscape and was moderately-well drained. The mined land area was reclaimed in the early 1990's and occupied a lower landscape position that was moderately-well to somewhat- poorly drained in areas. The surface horizon of the reclaimed area was a thick (30 cm) layer of replaced silt loam topsoil (A horizon) over compact stratified sandy tailings and gravels (C horizon). In choosing our experimental blocks, we consciously selected two areas with similar surface soil texture and internal drainage. As such, the particular mined land area chosen was more productive than the "average" sand and gravel mined land in the area, and contained significant carryover fertility.

The ten treatments included unfertilized and fertilized (per Virginia Tech Soil Testing Lab) control treatments and four rates of biosolids (1x, 3x, 5x, and 7x the agronomic rates for the initial corn crop), with and without sawdust to adjust the C:N ratio. Biosolids N composition averaged 4.47 % TKN, 0.64% NH_4-N, and 3.80 % organic N, 3.9% P_2O_5, and 0.14% K_2O, which required a dry biosolids:sawdust ratio of 0.75:1.0 to attain the desired C:N ratio (20:1). The sawdust utilized had a bulk C:N ratio of 198:1. The agronomic rate of biosolids was 14 Mg ha^{-1}. Each of the 10 treatments was replicated four times on each soil. Each plot was approximately 36 x 15 m in size; large enough to be spread and managed with conventional farm equipment. The entire area of each experimental block (mined and unmined) was approximately 3 ha.

Small plots directly adjacent to the mined land study having the same treatments as the large plots (with three replications each) were instrumented with zero-tension lysimeters to collect leachates. The lysimeters were constructed from an 45 cm section of 30 cm diameter ABS plastic drainage pipe fitted with an endcap and sealed to prevent leakage or groundwater intrusion. The bottom of each lysimeter was filled with a 10 cm sand layer to retain leachates and a screened tygon tube was plumbed from the sand pack to the surface. The lysimeter boring was excavated with a tractor-mounted rotary posthole drill, and the soil horizons (A and C) were separated and retained on plastic. After the lysimeter was inserted back into the posthole, the soil horizons were returned to the lysimeter bore in order, and repacked to their approximate field density. The top of the lysimeter bore was located 15 cm below the ground surface to allow for regular tillage and crop management practices above it. The surface crop was free to root into the lysimeter, and did. The sand pack in the bottom of each lysimeter was capable of storing 5 cm of accumulated leachate. The lysimeters were pumped monthly, or more frequently if warranted, and NO_3-N was determined immediately after filtration with a Hach DR/2000 Portable Spectrophotometer. The performance of the unit was periodically checked with NO_3-N standards in the field, and on two occasions, chilled/preserved samples were transported to analytical laboratories at Virginia Tech for confirming analyses. Due to normal water balances, water was not detected in the lysimeters between March and October 1996 and again over the summer of 1997. The lysimeters were sampled monthly from the fall of 1996 to the fall of 1998, and then quarterly through 1999. Three shallow (5 m) ground water sampling wells were also installed around the periphery of the 3 ha mined land block to detect NO_3-N movement to local ground water if it occurred. These wells were purged and re-sampled per USEPA protocols at the same time the lysimeters were pumped monthly.

A crop rotation consisting of corn (*Zea mays*; planted April 1996), wheat (*Triticum aestivum;* planted November 1996), and soybeans (*Glycine max*; planted July 1997) was established in both large plot studies and in the lysimeter plots. Cotton (*Gossypium spp.*) was grown on the plots in 1998, but not monitored for yields. Fertilized control plots received 135 kg N ha^{-1} as 30-0-0 UAN in June 1996, and 67 kg N ha^{-1} as 30-0-0 UAN in two applications (2/3/97 and 3/26/97) applied to the winter wheat. Biosolids amended plots received no N, but appropriate amounts of P and K were applied to all fertilized control and biosolids plots as indicated by Virginia Tech Extension Soil Testing Lab recommendations. Surface (0-15 cm) soil samples were taken from all plots each fall and early spring and analyzed for C, N, and other nutrients via conventional soil testing procedures (Donohue and Heckendorn, 1994). Crop yields were sampled from yield strips with a dedicated research plot combine.

Differences in treatment mean crop yields by experiment and year were analyzed by the least significant difference (LSD) method when the overall ANOVA (F-test) was significant. Mean treatment NO_3-N levels in leachates by sampling date were considered different when their treatment means differed by at least two standard error increments.

Results

The summer of 1996 was an outstanding year for corn production in Virginia due to the large and even rainfall over the summer, and the corn yields from both experimental blocks (mined and unmined) were high (Table 1). No treatment effects were observed in the mined land block. This was due to the wet year coupled with a moderately-well drained landscape position, and perhaps carryover fertility from the previous soybean crop. On the unmined experimental block (Table 1), biosolids application enhanced yields over the unfertilized control at all rates, and over the fertilized control at 3x, 5x, and 7x the agronomic rate. No consistent effect of sawdust application with the biosolids was observed for either mined or unmined land in 1996. Winter wheat grain yields measured in the summer of 1997 (Table 2) revealed increasing yields with increasing rates above 1x at both sites, with or without sawdust additions. Wheat yields in the mined land actually declined at the 7x rate (albeit marginally significant), suggesting the yields had reached a maximum level. Soybean yields showed no consistent treatment effects, but did appear to be favorably affected by the 1x and 3x biosolids rates on the mined land block.

Soil pH and available nutrient levels were optimal for crop production throughout the study and are not reported here. Overall, application of the combined organic amendments had no apparent effect on bulk soil C:N ratios (Table 3) as measured in 1996 and 1999 with the exception of slight differences noted in the unmined land plots in 1996. The lack of a soil C:N effect here may have been due to: (1) The existing soils contained large amounts of pre-existing soil organic matter relative to the addition rates, and (2) the bulk C:N ratio of the biosolids (8:1) and biosolids+sawdust mixes (20:1) were simply not different enough from the background soil C:N ratio of 10:1. Sawdust additions did increase the bulk soil C:N ratio by treatment pair (e.g. 5x vs. 5x+sawdust), however, as would be expected.

The NO_3-N levels in the lysimeter leachates (Figs. 1 and 2) in the mined land area between October 1996 and May 1997 revealed pronounced first winter leaching effects of both biosolids loading rates and sawdust additions. As mentioned earlier, leachates were not detected over the summer of 1996 due to net evapotrans-

Table 1. Corn grain yields in mined and unmined soils (1996).

Treatment	Mined	Unmined
	Yield (Mg ha^{-1})	
Control, unfertilized	10.3 a	8.8 e
Control, fertilized	10.3 a	9.3 de
1x Agronomic rate	10.8 a	9.9 cd
1x Agronomic rate + sawdust	10.9 a	10.2 bcd
3x Agronomic rate	11.2 a	10.6 bc
3x Agronomic rate + sawdust	10.9 a	10.9 ab
5x Agronomic rate	10.9 a	10.8 abc
5x Agronomic rate + sawdust	10.5 a	11.7 a
7x Agronomic rate	10.3 a	10.6 bc
7x Agronomic rate + sawdust	11.2 a	9.8 cd

Mean values of four replications each. Means within columns followed by the same letter within each experiment are not different at $p \leq 0.05$.

Table 2. Wheat grain and soybean yields in mined and unmined soils (1997).

Treatment	Mined	Unmined	Mined	Unmined
	Wheat Yield (Mg ha^{-1})		Soybean Yield (Mg ha^{-1})	
Control, unfertilized	2.61 d	2.98 f	2.38 abc	2.57 a
Control, fertilized	6.48 b	6.46 bcd	1.28 e	1.32 b
1x Agronomic rate	4.73 c	6.34 cd	1.62 de	1.77 b
1x + sawdust	4.14 cd	5.18 d	1.96 cd	1.92 ab
3x Agronomic rate	7.12 ab	7.01 abc	2.73 a	1.82 b
3x + sawdust	6.80 ab	6.46 cd	2.64 ab	1.87 ab
5x Agronomic rate	8.26 a	7.92 a	1.86 cde	2.02 ab
5x + sawdust	8.04 ab	7.97 a	2.21 abcd	1.83 b
7x Agronomic rate	7.02 ab	7.55 ab	2.08 bcd	1.61 b
7x + sawdust	6.96 ab	8.20 a	1.65 de	1.46 b

Mean values of four replications each. Means within columns followed by the same letter within each experiment are not different at $p \leq 0.05$.

Table 3. Carbon:Nitrogen ratios (C:N) in mined and unmined soils in October 1996 and 1999.

Soil:	Mined	Unmined	Mined	Unmined
	---------------- Bulk Soil C:N Ratio ----------------			
Treatment	**1996 ***	**1996**	**1999***	**1999***
Control, unfertilized	10.7	7.9 c	10.5	11.4
Control, fertilized	7.3	9.1 bc	10.5	15.7
1x Agronomic rate	9.0	7.7 c	10.6	13.9
1x + sawdust	9.0	8.2 bc	11.1	14.4
3x Agronomic rate	8.8	9.4 bc	10.6	12.2
3x + sawdust	10.6	9.9 bc	11.2	12.4
5x Agronomic rate	11.1	8.8 bc	10.5	13.8
5x + sawdust	12.0	10.4 b	11.4	15.6
7x Agronomic rate	8.9	8.9 cb	10.8	12.6
7x + sawdust	10.1	13.3 a	11.5	14.5

Mean values of four replications each. Means followed by the same letter within each experiment are not different at $p \leq 0.05$. *Anova was not significant.

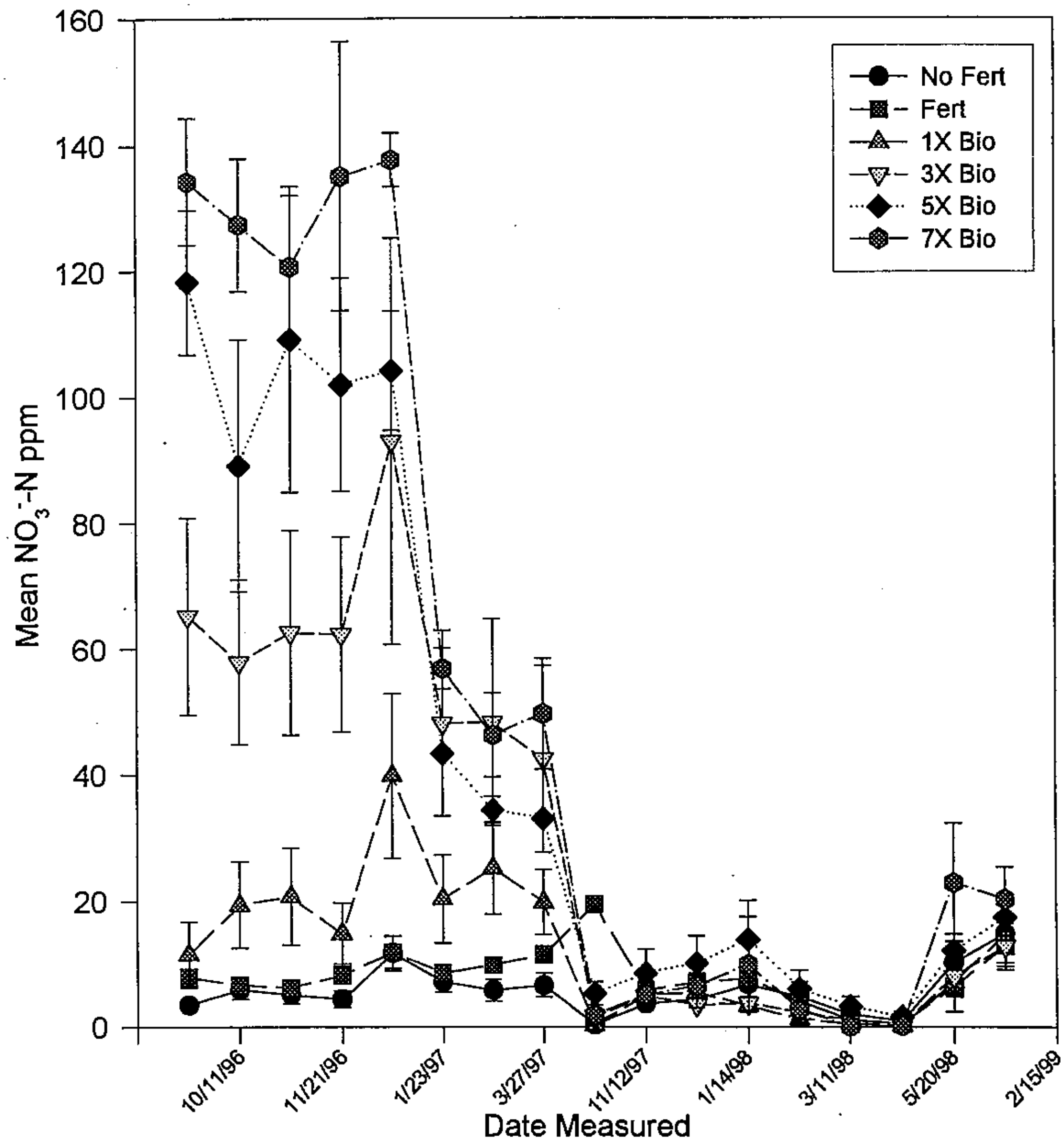

Figure 1. Nitrate-N in shallow (50 cm) root zone leachates as influenced by biosolids cake (C:N = 8:1) loading rates. Biosolids loading rate (X) based upon agronomic rate for N uptake by corn and was approximately 14 Mg ha^{-1}. Biosolids were applied in May, 1996.

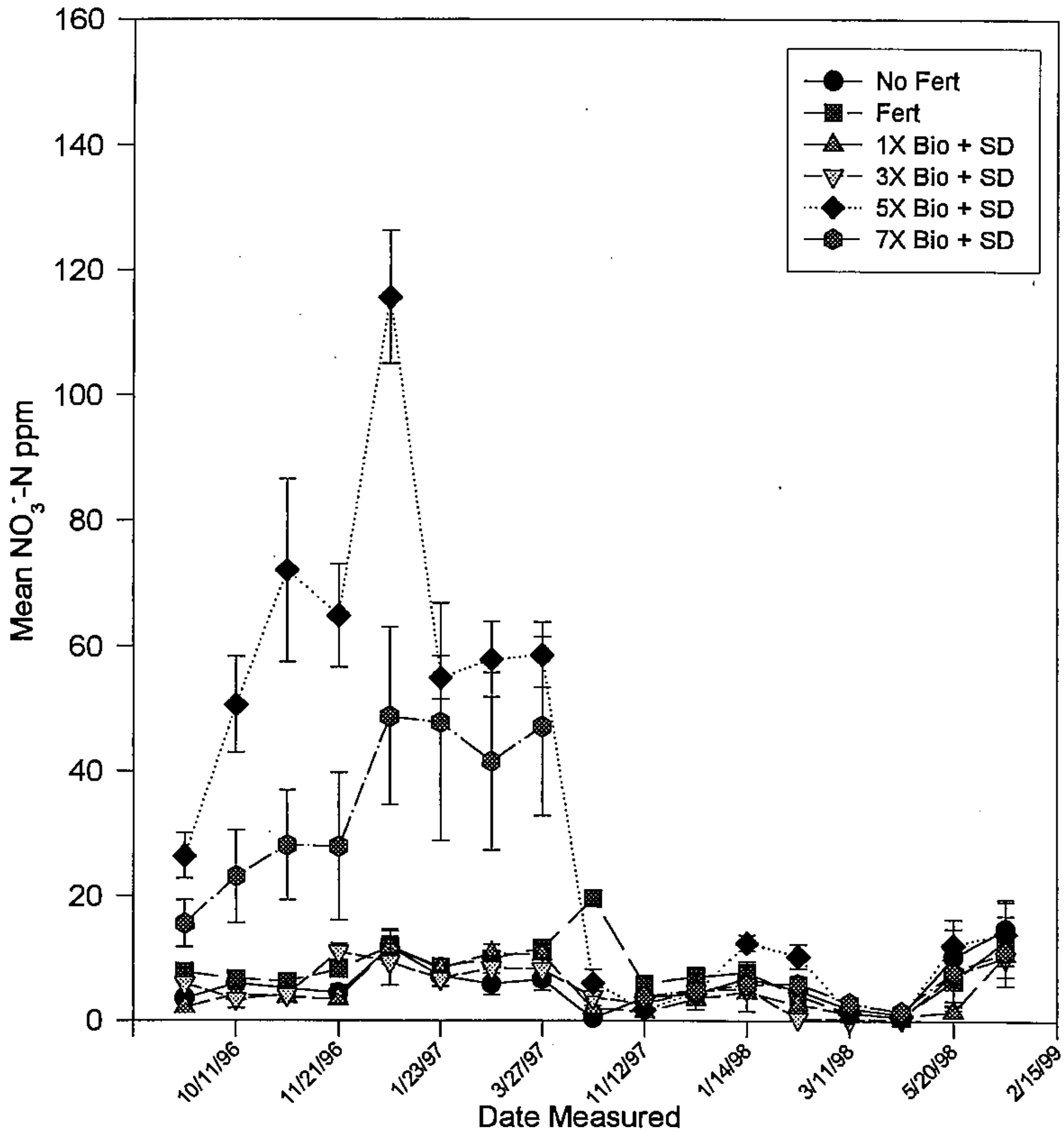

Figure 2. Nitrate-N in shallow (50 cm) root zone leachates as influenced by biosolids + sawdust mixture (C:N = 20:1) loading rates. Biosolids loading rate (X) based upon agronomic rate for N uptake by corn and was approximately 14 Mg ha^{-1}. Biosolids were applied in May, 1996.

piration by the corn crop. However, once the corn desiccated and was harvested, leaching occurred, moving fairly high concentrations (> 100 mg L^{-1}) of NO_3-N from the biosolids treatments (Fig. 1). Leachate NO_3-N over the winter of 96/97 increased incrementally with loading rate (1x to 7x) and then declined sharply in March and April of 1997, finally approaching control level concentrations. Leachate nitrate-N levels remained below 10 mg L^{-1} in November and December 1997, following the soybean harvest.

Addition of sawdust to the applied biosolids significantly decreased NO_3-N leachate levels (Fig. 2) at all biosolids loading rates except the 5x + sawdust treatment which exhibited a mid-winter spike in excess of 100 mg L^{-1}. The behavior of this particular treatment is also perplexing in that it consistently generated higher leachate NO_3-N levels than the 7x + sawdust treatment. Based on the separation of the standard error bars for both of these treatments (see Fig. 2), the effect is real and not experimental error. The total C loadings with the 7x + sawdust treatment were very high, and coupled with the wet summer of 1996, may have been sufficient to induce low soil redox conditions, leading to enhanced denitrification losses in this particular treatment. Leachate NO_3-N levels remained <10 mg L^{-1} in November and December, 1997, following the soybean harvest. We continued monitoring the lysimeters through the early spring of 1999, and did note a slight elevation in NO_3-N levels, presumably due to heavy broadcast N applications by the farmer to the following cotton crop. It is important to point out that these NO_3-N levels represent shallow root zone concentrations only and therefore represent what is leaving the rooting zone, not local ground-water concentrations. Over the monitoring period, no effect of the overall experimental plot loadings was detected for ground-water NO_3-N levels in three shallow well locations directly adjacent to the mined land plot area.

Discussion and Conclusions

This experiment was designed to test if (1) the optimal biosolids loading rates for one-time application to mined lands would range from approximately 3x to 7x of the standard agronomic rate; (2) if the NO_3-N levels in the winter leaching cycle could be reliably related to loading rate; and (3) whether leachate levels would be controlled by a combination of loading rate and C:N ratio adjustment via sawdust additions.

Based on these results, we believe that a loading maximum of 5x the agronomic rate for cake and 7x for C:N ratio adjusted materials would be appropriate for further full-scale biosolids application programs on reclaimed sand and gravel mined lands in the mid-Atlantic region. This conclusion is based upon the fact that crop yields did not rise above the 5x loading rate in this experiment, and upon similar conclusions reached in biosolids loading rate studies in a wide variety of other locations (Haering et al., 2000). Obviously, addition of biosolids at these rates will lead to one-time (first winter) leaching potentials for NO_3-N, but their long-term effects on ground-water concentrations in most situations will be minimal. In contrast, the long term beneficial effects of biosolids applications at elevated rates to mined lands are well-documented and will likely persist for multiple growing seasons.

It should also be pointed out that the particular mine soil landscape utilized here was much higher in productivity potential than "typical" post-reclamation mined lands of this type, and very few of these sand and gravel mined areas are returned to row crop production. Appropriate biosolids applications would probably elicit much stronger vegetation responses on more typical gravel mine soils in this region than were observed in this study with row crops. The mine soil studied here was finer textured than would be expected on the majority of reclaimed sand and gravel mines in the region. Therefore, we would expect winter leachates to move more rapidly through the subsoils at coarser textured sites, but the overall treatment effect differentials would be similar.

Any intensive research effort such as this one answers certain questions while generating new ones. In particular, there is continued need for further research into the concept of C:N ratio adjustment. Additional knowledge on the effects of differing C:N ratios and C substrates (leaves, sawdust, woodchips, newspapers, etc.) over a wide range of loading values and site conditions would be very beneficial to the development of more effective biosolids management and mined land reclamation strategies. Also, follow-up studies to directly determine the actual magnitude of first winter NO_3-N leaching on local ground water quality should be conducted and specifically compared to NO_3-N leaching under conventional fertilizer based revegetation strategies on the same sites.

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