EFFECTS OF BIOSOLIDS LOADING RATE ON NITRATE LEACHING POTENTIALS IN SAND AND GRAVEL MINE RECLAMATION IN VIRGINIA

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ABSTRACT

The USEPA 503 biosolids utilization rules recognized the need for higher than agronomic rate applications to mined lands under the assumption that NO3-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) 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 identically treated micro-plots. Effects of biosolids loading rate on crop yields were not as pronounced as expected due to relatively wet weather. Leachate NO3-N over the winter of 96/97 increased incrementally (from < 20 to > 100 mg/L) 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 NO3-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. Mass leaching losses of NO3-N ranged from 6 to 60 kg/ha, which was from 0.7 to 3.1% of total-N applied. These data indicate that higher than agronomic loading rates of biosolids do lead to enhanced NO3-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, low magnitude effect.

KEYWORDS

Prime farmland, ground water quality, agronomic rate, C:N ratio.

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) of biosolids are commonly applied in mined land reclamation scenarios (Sopper, 1993) under the assumption that NO3-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\textsubscript{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 (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\textsubscript{3}-N levels under application areas or at permitted surface water discharge points. Significant NO\textsubscript{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\textsubscript{3}-N leaching potentials. Our assumption was that if we could adjust the applied bulk C:N ratio to $> 20:1$, 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 (dry) for biosolids cake and at 115 Mg/ha 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 non-amended and sawdust-amended biosolids on (1) NO\textsubscript{3}-N leaching potentials and (2) overall crop yields. Detail on the overall treatment effects on yields as influenced by soil productivity differentials and land use history interactions is given by (Daniels et al., 2001). This paper focuses on the NO\textsubscript{3}-N leaching measurements and treatment interactions.

**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% NH4-N, and 3.80 % organic N, 3.9% P2O5, and 0.14% K2O, 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. 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 a 45 cm section of 30 cm diameter ABS plastic drainage pipe fitted with an end-cap 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 NO3-N was determined immediately after filtration with a Hach DR/2000 Portable Spectrophotometer. The performance of the unit was periodically checked with NO3-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 NO3-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/ha N as 30-0-0 UAN
in June 1996, and 67 kg 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.

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. Mass loss of NO$_3$-N was calculated by multiplying leachate volumes by concentration for each sampling date, and then summing over the entire monitoring period. Differences in mass losses were analyzed by the least significant difference (LSD) method when the overall ANOVA (F-test) was significant.

RESULTS

The 1996 and 1997 cropping seasons at this location in Virginia were outstanding years for row crop production due to the large and even rainfall over the summer months, and the crop yields from both experimental blocks (mined and unmined) were high in both years, with minimal treatment effects evident. Greater detail on differential crop yields, soil properties, and their interactions with mining history are detailed by Daniels et al. (2001).

The NO$_3$-N levels in the lysimeter leachates (Figures 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 transpiration by the corn crop. However, once the corn desiccated and was harvested, leaching occurred, moving fairly high concentrations (> 100 mg/L) of NO$_3$-N from the biosolids treatments (Figure 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 in November and December 1997, following the soybean harvest.

Addition of sawdust to the applied biosolids significantly decreased NO$_3$-N leachate levels (Figure 2) at all biosolids loading rates except the 5x + sawdust treatment which exhibited a mid-winter spike in excess of 100 mg/L. 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 Figure 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 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 at 60 cm, 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.
Figure 1. Effects of biosolids loading rate (1 to 7x agronomic rate of 14 Mg/ha) on root zone Nitrate-N concentration in soil percolates at 60 cm. Biosolids were applied in May of 1996.

Lysimeters with Biosolids

Figure 2. Effects of biosolids loading rate with sawdust added to adjust C:N ratio to 20:1 on root zone Nitrate-N concentration in soil percolates at 60 cm.

Lysimeters: Biosolids + Sawdust
The effects of biosolids and sawdust additions on the total mass of NO$_3$-N leached over the course of the two-year monitoring period are given in Table 1. Total leaching losses ranged from 5.9 to 59.8 kg/ha, with the vast majority moving the first winter as discussed above. Total leaching losses generally increased with biosolids loading rate, but not consistently. The addition of sawdust to increase the C:N ratio effectively lowered NO$_3$-N losses in the 1x and 3x rates to levels similar to the unfertilized control, but appeared to have no effect on suppressing mass losses at the 5x and 7x (plus sawdust) loading rates. Thus, the overall interpretation of treatment effects in this experiment varies somewhat when we use mass loss data versus concentration data as discussed above. As a % of total-N applied in fertilizer or biosolids, the mass losses were lower than expected, ranging only from 0.7 to a maximum of 3.1% of applied N. We suspect that this relatively low and consistent level of % leaching loss is related to denitrification losses at the higher loading rates.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Total-N applied in Biosolids (kg/ha)</th>
<th>Mass NO$_3$–N leached (kg/ha)</th>
<th>Total-N leached (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0</td>
<td>5.9 c</td>
<td>N.A.</td>
</tr>
<tr>
<td>Fertilized</td>
<td>269</td>
<td>7.6 c</td>
<td>2.8</td>
</tr>
<tr>
<td>1X Biosolids</td>
<td>626</td>
<td>19.2 bc</td>
<td>3.1</td>
</tr>
<tr>
<td>3X Biosolids</td>
<td>1252</td>
<td>37.4 abc</td>
<td>3.0</td>
</tr>
<tr>
<td>5X Biosolids</td>
<td>3130</td>
<td>28.2 abc</td>
<td>0.9</td>
</tr>
<tr>
<td>7X Biosolids</td>
<td>4382</td>
<td>59.8 a</td>
<td>1.4</td>
</tr>
<tr>
<td>1X + Sawdust</td>
<td>626</td>
<td>4.9 c</td>
<td>0.8</td>
</tr>
<tr>
<td>3X + Sawdust</td>
<td>1252</td>
<td>7.6 c</td>
<td>0.6</td>
</tr>
<tr>
<td>5X + Sawdust</td>
<td>3130</td>
<td>58.4 ab</td>
<td>1.9</td>
</tr>
<tr>
<td>7X + Sawdust</td>
<td>4382</td>
<td>31.9 abc</td>
<td>0.7</td>
</tr>
</tbody>
</table>

$^1$ Mean mass NO$_3$-N levels followed by the same letter are not significantly different (p≤0.05).

DISCUSSION AND CONCLUSIONS

This overall 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 data from 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. Finally, it is important to point out the mass loss of N from these treatments was generally low, and typically represented < 2.0 % of the total-N applied.

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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REFERENCES


