TRANSFORMATION OF PHOSPHORUS AND NITROGEN IN DEEP ROW BIOSOLIDS INCORPORATION TECHNOLOGY IN COASTAL PLAIN MINING SITES IN VIRGINIA[1]

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Abstract: Deep row incorporation of biosolids is a unique alternative land application method that will prevent odor problems and may permit the application of considerably higher than currently permitted biosolids rates. The goal of our research is to assess environmental consequences of employing deep row incorporation of biosolids to restore productivity of mined land for the production of hybrid poplar as a potential bioenergy crop. Our objectives are to quantify the transformations of nitrogen and phosphorus applied to the soil as entrenched biosolids. The study is being conducted on a mineral sands mine reclamation site near the Coastal Plain-Piedmont fall line in Dinwiddie County, Virginia. The experimental design consists of 5 treatments – two biosolids types each applied in subsurface trenches at two rates and an unamended control. Application rates were 328 and 656 Mg ha^{-1} for the lime-stabilized biosolids and 213 and 426 Mg ha^{-1} for the anaerobically digested biosolids. Each treatment was replicated four times and arranged in a randomized complete block design. The site has been instrumented with suction and zero-tension lysimeters for collection and analysis of leachate from which were determined subsurface loss of nitrogen and phosphorus. Gas chambers have been used to collect soil air samples for accounting of denitrification rates from the entrenched biosolids. Redox potential was determined in the incorporated biosolids to describe the biosolids environment influencing nitrogen and phosphorus chemical transformations. During the first 10-14 months following biosolids application, initial nitrogen loss occurred largely as ammonium and organic N and, after 7-10 months, mostly as nitrate N. There was no significant leaching of phosphorus. Low redox potential in the biosolids' seam validated the occurrence of anaerobic conditions. Higher nitrous oxide emissions occurred from the anaerobically digested biosolids than from the lime stabilized biosolids. The deep row biosolids incorporation technology, when applied to coarse-textured soils, does not appear to be environmentally viable with respect to potential nitrogen loss to groundwater.

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Introduction

Agricultural land application of biosolids provides essential plant nutrients, enhances soil productivity, and improves soil properties; however, offensive odors and perceptions of health and environmental problems result in application restrictions. Deep row incorporation of biosolids (Making, 1982, Sikora and Colacicco, 1979; Sikora et al., 1982) is a unique alternative land application method that solves many of the problems associated with surface application techniques. The practice involves placement of biosolids into trenches that are immediately covered with overburden, eliminating odor problems and maintaining biosolids in an anaerobic environment (Kays et al. 1999). The area is then planted to cultures that have high nutrient consumption rates (e.g., hybrid poplar) and managed intensively as a short-rotation plantation. Previous use of this system resulted in transformation of biosolids into stable-like media within four years of placement (Sikora et al., 1979).

The benefits of this system include the production of non-food chain, forest products and wildlife habitat and the restoration of abandoned, organic matter-depleted soils resulting from surface mining. The trees can be harvested for wood products or a source of bioenergy at the completion of the six-year rotation, during which period most of the available nitrogen should be utilized.

Deep row incorporation of biosolids establishes an organic matter rich anoxic system with high water holding capacity, which may present risks of leaching of nitrogen and phosphorous and impairment of groundwater quality. Observations on the changes of the sewage sludge in the trenches reported that the entrenched biosolids dewatered from the top down, which resulted in the tops of the trenches becoming dry before the bottom. Therefore biochemical transformations throughout the trench profile are controlled by oxidation-reduction chemical reactions. Electron acceptors used by bacteria for respiration in anaerobic conditions are reduced in the order: NO_3^-, MnO_2, $Fe(OH)_3$, SO_4^{2-} and CO_2 (Ponnamperuma, 1972, Turner and Patrick, 1968). Rates of ammonification, nitrification, denitrification and immobilization of nitrogen are highly dependent on redox conditions in the biosolids. Sikora et al. (1979 a, b) hypothesized that mineralization and nitrification occurred earliest in the top of the biosolids seam, while denitrification may have been favored at the bottom of the seam as leachate flowed into the wetter, lower portions of the entrenched biosolids.

Phosphorus solubility and, hence, potential for leaching through coarse-textured soils possessing little P-sorption capacity is controlled by the relative amounts of P-binding Fe and Al constituents in biosolids. The downward movement of P through coarse-textured soils of low P-sorbing capacity in areas with shallow ground water may be significant (Lu and O'Connor, 2001; Elliott et al., 2002).

The practice of entrenching biosolids offers a potentially environmentally beneficial approach for the production of fast-growing, high N-assimilating perennial crops, but must be demonstrated to not impair water quality. The objectives of the current research is to assess the environmental effects of deep row incorporation of biosolids for production of hybrid poplar by comparing the effects of biosolids type and rate on (i) chemical properties in the biosolids seam, (ii) leaching concentrations and masses of N and P, and (iii) N_2O emissions.

Materials and Methods

Site Characteristics

The study is being conducted on a mine reclamation site in Dinwiddie County in Virginia with soil structure resulting from mineral sands processing in high clay deposits (Daniels et al., 1996). Seasonal water table on the site is within several feet of the soil surface. Semi-confining beds do typically underlie these mines, but the local water table is perched above them. The chemical and physical properties of the soil materials at the site are shown in Table 1.

Table 1. Chemical and physical properties of soil materials at the Iluka mining site where the biosolids trench study was established.

Soil texture fraction	pH	Mehlich I P	Exch Ca	Exch Mg	Exch K	Zn	Mn	Fe	Cu	CEC
		---------------------------------- mg/kg							----------------------------	cmol(+)/kg
Fine	6.8	63	752	152	101	3.9	9.1	15.6	0.5	5.3
Coarse	6.1	11	149	31	15	0.6	1.2	9.9	0.1	1.1

Experimental Design

We established 5 treatments: two biosolids rates for each of two biosolids treatment processes (anaerobically digested and lime-stabilized) designed to supply incremental N rates for poplar and the control. The specific treatments were:

1. Control - unamended
2. Lime stabilized (Source: Blue Plains) biosolids applied in trenches 45cm (w) x 75cm (d) = 1125 m^3/ha (605 yd^3/ac) resulting in 328 Mg/ha
3. Lime stabilized (Source: Blue Plains) biosolids applied in trenches 90cm (w) x 75cm (d) = 2250 m^3/ha (1210 yd^3/ac) resulting in 656 Mg/ha
4. Anaerobically digested (Source: Alexandria) biosolids applied in trenches 45cm (w) x 75cm (d) = 1125 m^3/ha (605 yd^3/ac) resulting in 213 Mg/ha
5. Anaerobically digested (Source: Alexandria) biosolids applied in trenches 90cm (w) x 75cm (d) = 2250 m^3/ha (1210 yd^3/ac) resulting in 426 Mg/ha

The five treatments were each replicated 4 times and arranged in a randomized complete block design. Each treatment plot was 6 m wide x 15 m long and contained two rows (trenches) with a row spacing (center-to-center) of 3m; thus, the area of each of the 20 plots is 90 m^2 (6 m x 15 m).

The biosolids rates were calculated from composition and bulk density of the biosolids applied into the known trench volumes. The sources of the anaerobically digested and lime-stabilized biosolids were the Alexandria (Virginia) and Blue Plains (Washington, DC) Wastewater Treatment Plants, respectively. Phosphorus (as triple superphosphate), K (as muriate of potash), and other essential elements not sufficiently supplied by the mine soil (as determined by soil testing) are being added annually as inorganic fertilizers to the control plots to prevent tree growth limitations due to those elements.

Trench Establishment

Biosolids were delivered to the site on June 26-28, 2006 (Alexandria) and July 17-19, 2006 (Blue Plains) and immediately placed into backhoe-dug and instrumented trenches with skid steer loaders. The biosolids were covered with fill from the trenches, and the entire area was graded to provide a soil cover of approximately 30 cm over the entrenched biosolids.

Instrumentation for Sampling and Monitoring

Zero-tension lysimeters fabricated from plastic drainage pipe and measuring 25 cm in diameter and 55 cm in length were installed so that their upper rims were 15 cm below the bottom of the trench (Fig. 1). Ten cm of acid-washed sand were placed in the bottom of the lysimeters, and the remaining volume of the lysimeter was filled with coarse-textured sand from the mine site trench. Each trench was finally filled with another 15 cm of coarse-textured fill that formed the base of the trench. Kynar tubing was extended from the bottom of the lysimeter reservoir to above the top of the trench. This tubing is being used to evacuate the lysimeter with a portable electric pump. The tube opening at the bottom of the lysimeter was covered with a fabric filter designed to prevent the transport of large particles to the pump. A lysimeter was placed below each biosolids-filled trench and below one of the two trenches in each control plot.

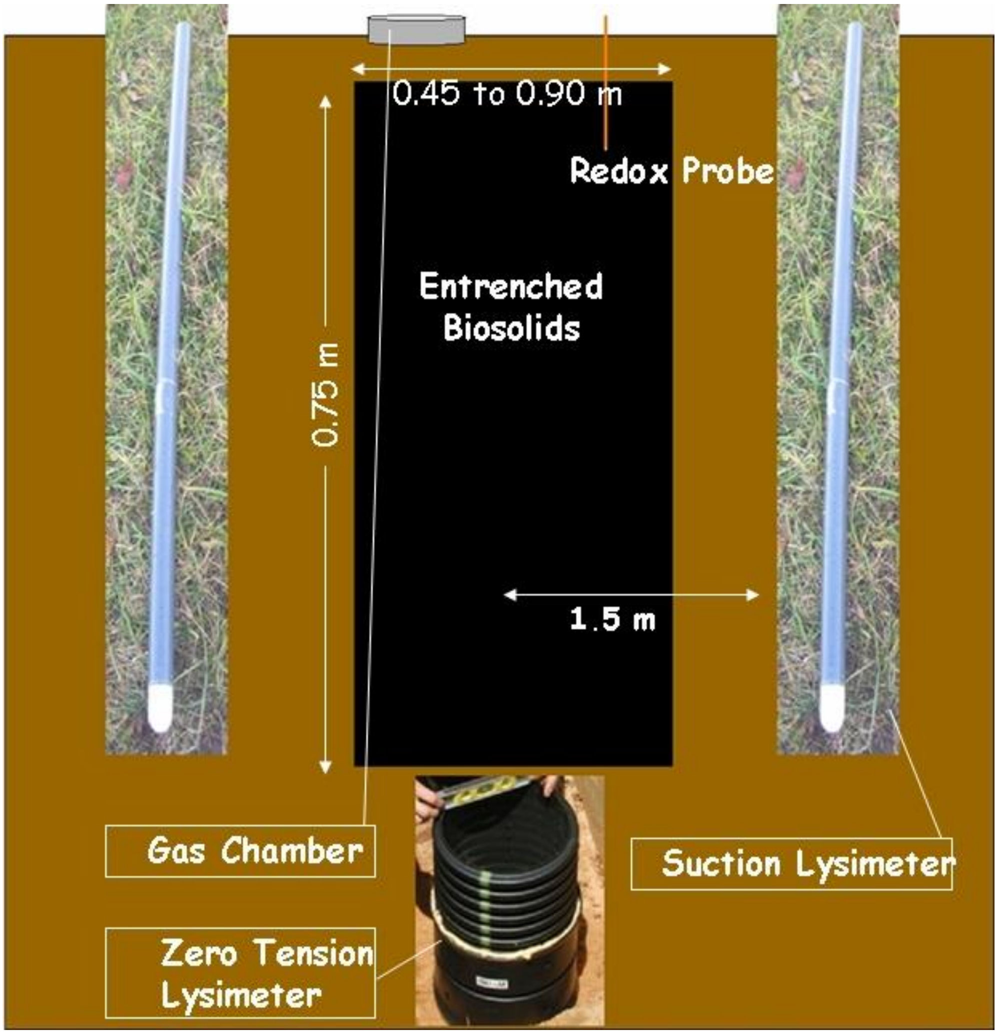

Figure 1. Schematic trench instrumentation design

Suction lysimeters were installed to determine horizontal flow or gradient adjacent to the entrenched biosolids. Sixteen lysimeters were placed between the two trenches in each of the biosolids plots at a distance of 1.5 m from the trench center. For trenches with 45 cm and 90 cm widths, the lysimeters were installed at 1.3 m and 1.06 m, respectively, from the edge of the biosolids trench. The bottom of the suction lysimeter was installed to the same depth as the bottom of the trench. Construction of the lysimeters involved attaching a porous ceramic cup to the end of 5.1cm diameter "H-P VACUFCD" PVC piping. The cup was attached to the piping with 2-part epoxy. Silica flour was placed in the bottom of each augered hole to provide a contact surface between the ceramic cup and the soil. The rest of the hole surrounding the lysimeter was filled with a 50/50 mixture of playground sand and bentonite, which reduces the likelihood of preferential flow along the lysimeter. Kynar tubing is used as a conduit through which to pump soil water from the bottom of the lysimeter to the surface for chemical analysis.

Platinum electrode assemblies with Ag/AgCl reference electrode were used to measure redox conditions in the biosolids amended and unamended trenches in order to understand conditions that may affect N and P transformations. Potential between the electrodes was measured by DM 383B digital multimeter. Monthly sampling of air emanating from the biosolids and control treatments from an incubation chamber was performed for subsequent analysis of N_2O for Denitrification potential.

Vegetation Establishment

Hybrid poplar (*Populus deltoides* L. 'OP367') stem cuttings were planted within each trench at a spacing of 3 m between plants for a total of 10 trees/plot on March 5-6, 2007. The cuttings were purchased from Broadacres Nursery, Inc. (18335 Butteville Road N.E., Hubbard, OR 97032) and shipped frozen via U.S. Postal Service to Blacksburg, VA in late February. The 30-cm length cuttings were placed about 20-25 cm into the soil and protected with 30-cm tall, 5-cm diameter staked plastic tree shelters. Irrigation was provided during the months of May to September 2007 via sprinklers to prevent saplings from succumbing to drought stress.

Initial Biosolids Sampling and Analysis

Biosolids were sampled at time of application (June and July 2006) and analyzed by A&L Eastern Laboratories, Inc. (Richmond, VA) for chemical and physical properties that enabled us to assess the biosolids quality and calculate the constituent loading rates. The variables analyzed included total and volatile (organic matter) solids by SM2540G (APHA, 1998); total Kjeldahl N (TKN-N) by USEPA 351.3 (USEPA, 1983b); NH_4-N by USEPA 350.2 (USEPA, 1983a); NO_3-N by SM4500-NO3F (APHA, 1998); P, K, S, Ca, Mg, Na, Fe, Al, Mn, Cd, Cu, Pb, Mo, Ni, and Zn by SW846-6010B (USEPA, 2002); As by SW846-7061A (USEPA, 2002); Hg by SW846-7471A (USEPA, 2002); Se by SW846-7741A (USEPA, 2002); pH by SW846-9045C (USEPA, 2002);

calcium carbonate equivalent (CCE) by AOAC 955.01 (AOAC, 2000); and total organic carbon (TOC) by EPA 415.1 (USEPA, 2002). Bulk density of the biosolids was calculated by weighing samples in a bucket of known volume of each of the two types of biosolids in triplicate and drying subsamples of each at 105°C for 72 hrs or until no change in weight was measured. The analyses of biosolids employed in the study are presented in Table 2, and the total loading rates of the biosolids' constituents (based on constituent concentrations and total biosolids loading rates) are presented in Table 3.

Water Sampling and Analysis

Water has been sampled at least monthly (more often when necessitated by heavy rain events and less often during the summer when high evapo-transpiration limits leaching) from all lysimeters. Leachate was evacuated from the zero tension and suction lysimeters via an electric pump powered by an electric gasoline-powered generator. Water volume was measured and subsamples were collected from a composite sample and placed in coolers with dry ice for freezing until thawing, processing, and further analysis in the laboratory. Samples in the field were analyzed for pH, electrical conductivity, temperature, and dissolved oxygen (data not shown).

Determination of Total Nitrogen and Phosphorous. Total Kjeldahl nitrogen (TKN) analysis was performed with a Lachat A85100 on unfiltered water samples previously digested with sulfuric acid in a block digestor with a mercuric oxide catalyst, by flow injection analysis colorimetry using the QuikChem Method 10-107-06-2-D (Lachat Instruments, 1995). Total phosphorous was determined by flow injection analysis colorimetry in the same Kjeldahl digests as TKN, described in QuikChem Method 10-115-01-1-C (Lachat Instruments, 2001).

Determination of Dissolved Nitrogen and Phosphorous. Nitrate in water was determined by flow injection analysis colorimetry described in QuikChem Method 10-107-04-1-A (Lachat Instruments, 6645 1995). Ammonia in water was determined by flow injection analysis colorimetry described in QuikChem Method 10-107-06-2-A (Zellweger Analytics, 1992). Orthophosphate in water was determined by flow injection analysis colorimetry described in QuikChem Method 10-115-01-1-A (Lachat Instruments, 1995).

Table 2. Analyses of Blue Plains lime-stabilized and Alexandria anaerobically digested biosolids employed in the trenching study. All the values are on dry weight (except moisture content).

Biosolids property	Blue Plains Biosolids	Alexandria Biosolids
	Concentration, mg/kg (except moisture content)	
Moisture content, mg/g	685	727
N, total Kjeldahl	44,533	53,133
P	8,667	26,533
K	1,367	933
S	6,367	7,033
Ca	114,533	23,467
Mg	2,233	2,900
Na	200	367
Fe	34,333	43,000
Al	3,893	24,700
Mn	216	1,021
Cu	197	328
Zn	490	1,473
N, $NH_3 + NH_4^+$	1,967	12,900
N, organic	42,567	40,233
N, $NO_2^- + NO_3^-$	15	8
Cd	2.0	2.3
Ni	16	27
Pb	53	66
As	1.7	3.1
Hg	0.7	1.9
Se	2.1	5.3
pH	12.3	8.5
Calcium carbonate equivalent, CCE	176,200	5,700
Volatile solids	601,600	604,366
Mo	11	9

Table 3. Total loading rates (kg/ha) of constituents in both application rates of Blue Plains and Alexandria biosolids applied in trenches.

Constituent	Blue Plains (lime stabilized)		Alexandria (anaerobically digested)	
	Trench width, m		Trench width (m)	
	0.45	0.90	0.45	0.90
	Total loading rates, kg/ha			
N, total Kjeldahl	14,606	29,212	11,301	22,601
N, $NH_3 + NH_4^+$	645	1,290	2,744	5,487
N, organic	13,961	27,922	8,557	17,114
N, $NO_2^- + NO_3^-$	5	10	2	3
P	2,842	5,685	5,643	11,286
K	448	896	199	397
Al	1,278	2,556	5,253	10,507
Fe	11,261	22,521	9,145	18,290
Mn	71	142	217	434
As	0.6	1.1	0.7	1.3
Cd	0.4	0.9	0.5	1.0
Cu	64.5	129	69.7	139.4
Pb	17.4	34.8	14	28
Hg	0.2	0.5	0.4	0.8
Mo	3.7	7.4	2.7	5.4
Ni	5.2	10.5	5.7	11.5
Se	0.7	1.4	1.1	2.2
Zn	161	322	313	627

Determination of Nitrous Oxide. Nitrous oxide, N_2O, was determined in vacutainer-preserved field gas samples on GC-14A Gas Chromatograph (Shimadzu, Kyoto, Japan) with an electron capture detection, using a Hayesep Q 80/100 column (AllTech) and a P5 gas (5% methane/argon) as a carrier.

Statistical Analysis

We performed statistical analysis of the data with the Statistical Analysis System (SAS Institute, 1999) to determine the net effect of the practices on shallow root zone percolates and net mass balances for N and P.

Statistical analysis of the data was conducted using SAS GLM procedure to perform analysis of variance (ANOVA) and Fisher LSD procedure for contrast comparisons for N and P. In addition, linear contrasts were performed to compare two biosolids rates for each of two biosolids treatment processes (anaerobically digested and lime-stabilized) and the control. Concentration data were analyzed separately for each sampling date, but leaching rates of constituents were analyzed on a cumulative basis.

Results and Discussion

Composition of Biosolids

Both the Blue Plains (Blpl) lime stabilized and the Alexandria (Alex) anaerobically digested biosolids had similar moisture and volatile solids contents (Table 2). The higher concentrations of total and readily-available inorganic N in the Alex than in the Blpl may increase the risk of N leaching. Although the total P concentration in the Alex was 3x the total P concentration in the Blpl, the higher Fe, Al, and Mn in the Alex may serve to immobilize the P. The higher pH, Ca concentration, and CCE in the Blpl than in the Alex biosolids were a result of differences in biosolids stabilization processes (i.e., lime stabilization vs. anaerobic digestion). Concentrations of 503 Rule trace inorganic elements were all well below the Pollutant Concentration Limits for every element.

Greater masses of N were applied to the trenches with the Blpl than with the Alex biosolids, largely because the bulk density of the Blpl was nearly twice that of the Alex (Table 3). The masses of P applied with the Alex was 2x that applied with the Blpl for each trench width, but the masses of Al and Mn applied with the Alex were 4x and 3x that applied with the Blpl. The total pollutant loading rates of the inorganic trace elements were one or more orders of magnitude lower than the 503 Rule cumulative pollutant loading rates.

Leachate Nutrient Concentrations from the Suction Lysimeters

Ammonia. Ammonium-N in suction lysimeters was higher in Alex than in Blpl treatments during September 2006 - January 2007 period. In February 2007 - April 2007 Ammonium-N decreased to negligible concentrations in both Alex and Blpl treatments (Fig. 2). The data show initially significant preferential flow of ammonium-N. The subsequent reduction in the concentrations of ammonium-N is possibly a result of seasonal decrease in the watertable towards the spring 2007 and higher nitrification rates.

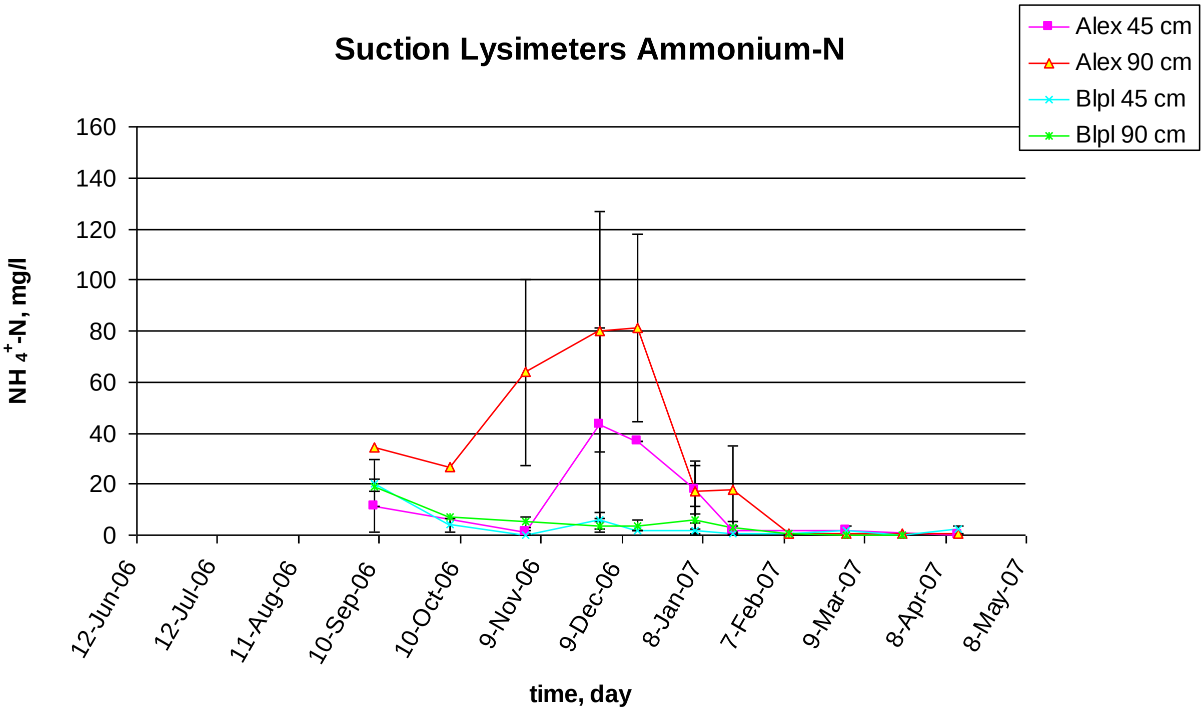

Figure 2: Concentration of Ammonium-N in suction lysimeters with time.

Total Nitrogen. Total-N in suction lysimeters was higher in Alex than in Blpl treatments during September 2006 - January 2007 period. In February 2007 - April 2007 Total-N decreased to negligible concentrations in both Alex and Blpl treatments (Fig. 3). Reduction in the Total-N concentrations in the suction lysimeters is likely due to increased aeration of the soil in the spring and decrease in the local watertable, which led to mineralization of organic forms of nitrogen and nitrification of ammonium-N.

Nitrate. Suction lysimeters showed significant amounts of nitrate-N in soil solution (i.e. available for plant uptake but having potential for leaching into groundwater) (Fig. 4).

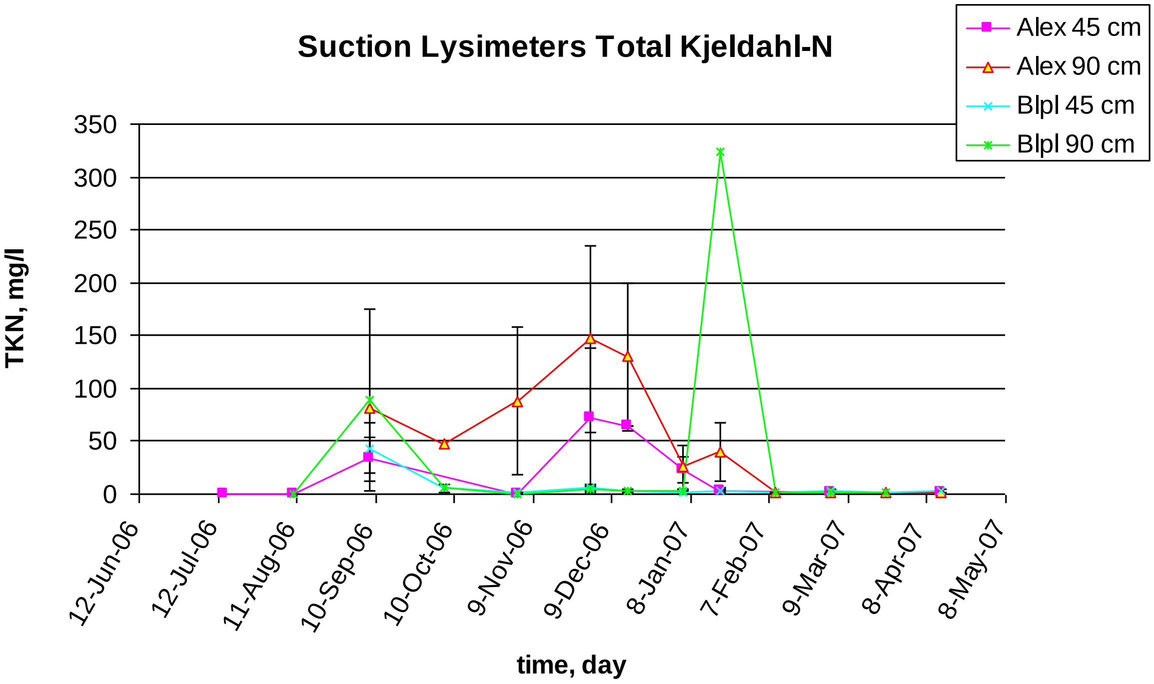

Figure 3: Concentration of Total Kjeldahl-N in suction lysimeters with time.

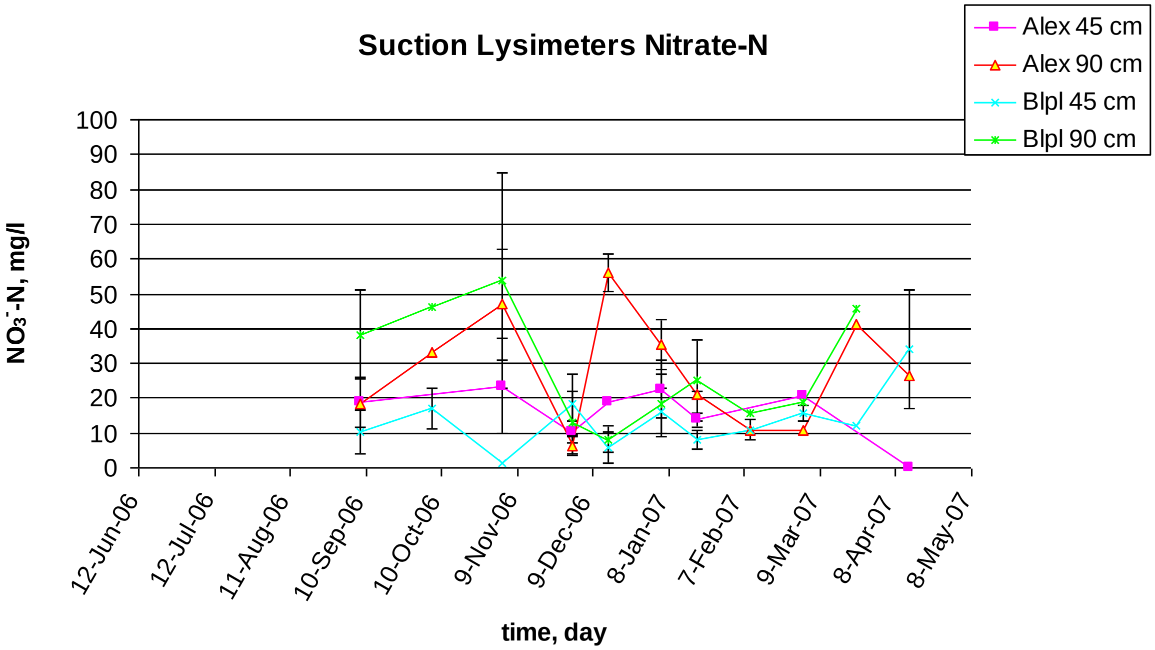

Figure 4: Concentration of Nitrate-N in suction lysimeters with time.

Total Kjeldahl P (TKP). The TKP concentrations in suction lysimeters were an order of magnitude higher than the Ortho-P concentrations (Fig. 5).

Ortho-phosphate (O-P). Suction lysimeters showed levels of O-P lower than published eutrophic critical values of 0.035 mg TP/l (OECD, 1982) in both Blpl and the Alex treatments, except at their peak during September - October 2006 when the wide Alex and Blpl treatments reached the levels of 0.040-0.042 mg/l and then further declined with time (Fig. 6).

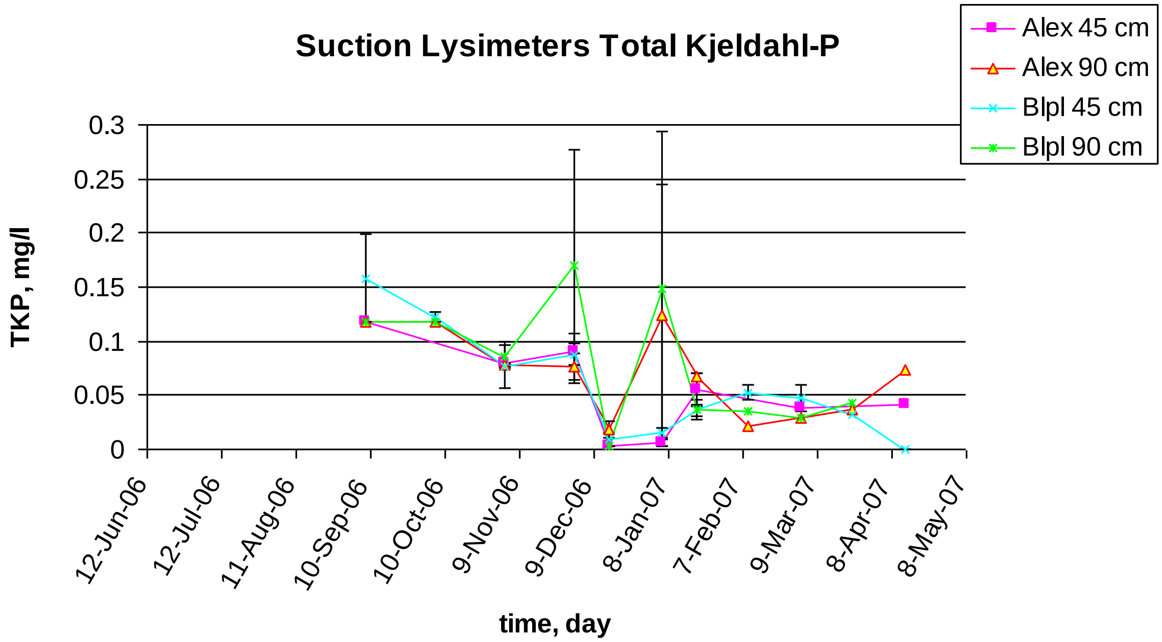

Figure 5: Concentration of Total Kjeldahl-P in suction lysimeters with time.

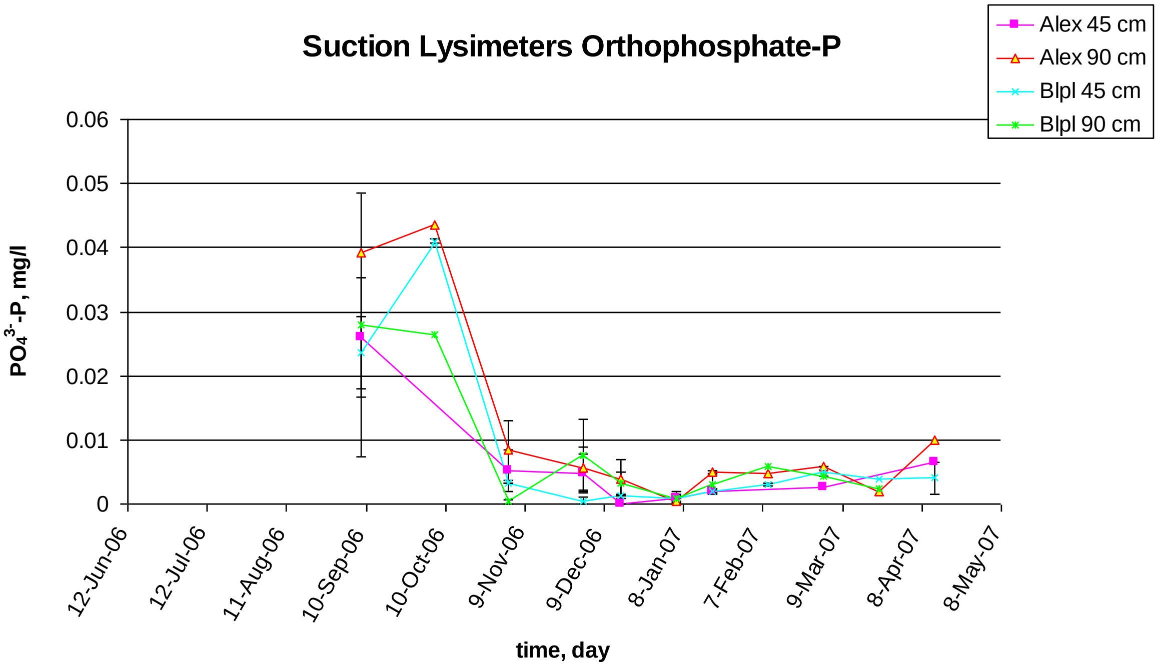

Figure 6: Concentration of Orthophosphate-P in suction lysimeters with time.

Leachate Nutrient Concentrations from the Zero Tension Lysimeters

Ammonia. Ammonium-N concentration in the zero tension lysimeter leachate followed initially the same patterns as nitrate-N, but higher concentrations were measured both initially and into the fall. Higher concentrations of ammonium-N were found under all biosolids treatments than under the control, and ammonium was higher under Blpl than Alex, but by July – October 2007 decreased under both treatments (Fig. 7). Decline in ammonium-N concentrations in the zero tension lysimeters is possibly due to increased nitrification several months after the biosolids entrenchment.

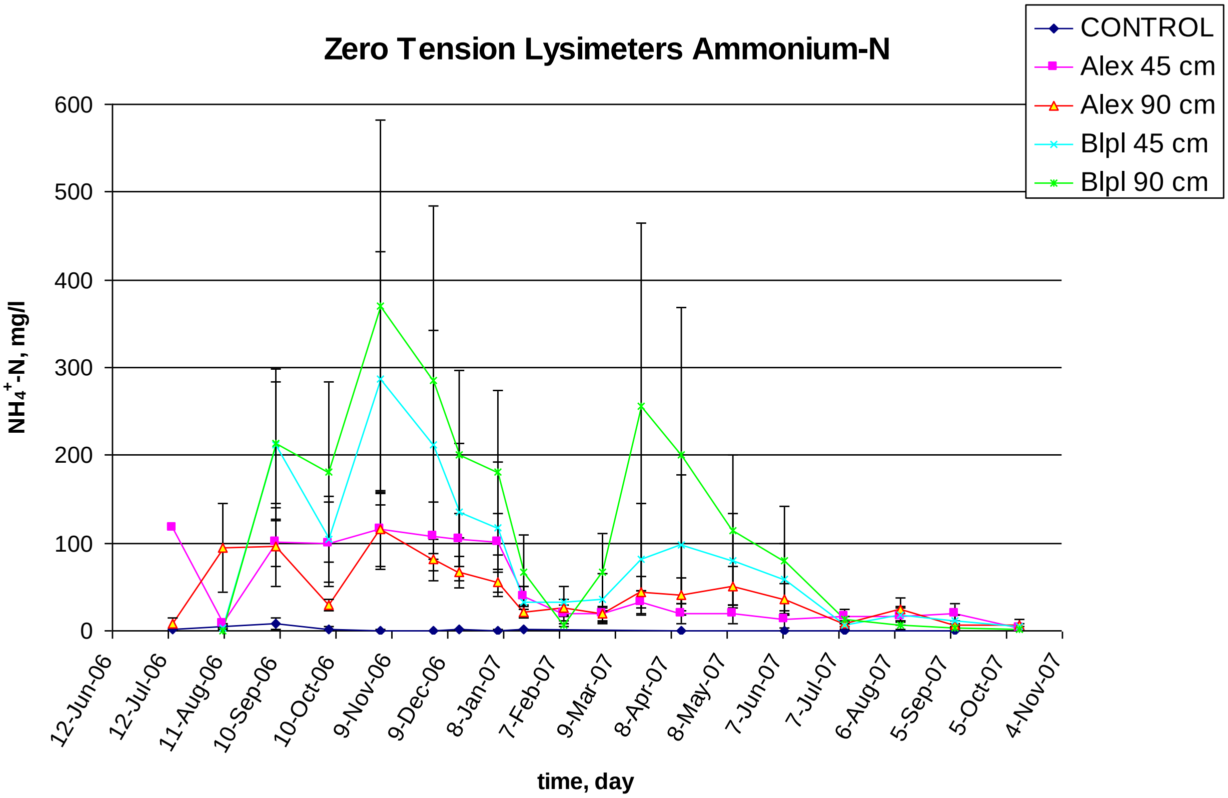

Figure 7: Concentration of Ammonium-N in the zero tension lysimeters with time.

Total Nitrogen. Approximately 1/3 of the total-N that collected in the zero tension lysimeters was organic N. This colloidal fraction of N is apparently easily transported through coarse-textured soils. By fall 2006, higher concentrations of total-N were found under all biosolids treatments than under the control, but in spring 2007 concentrations of total-N decreased under both treatments. Blpl tended to have higher total-N concentrations than Alex. (Fig. 8). Reduction of the total-N levels shows increase in the mineralization rate in the biosolids.

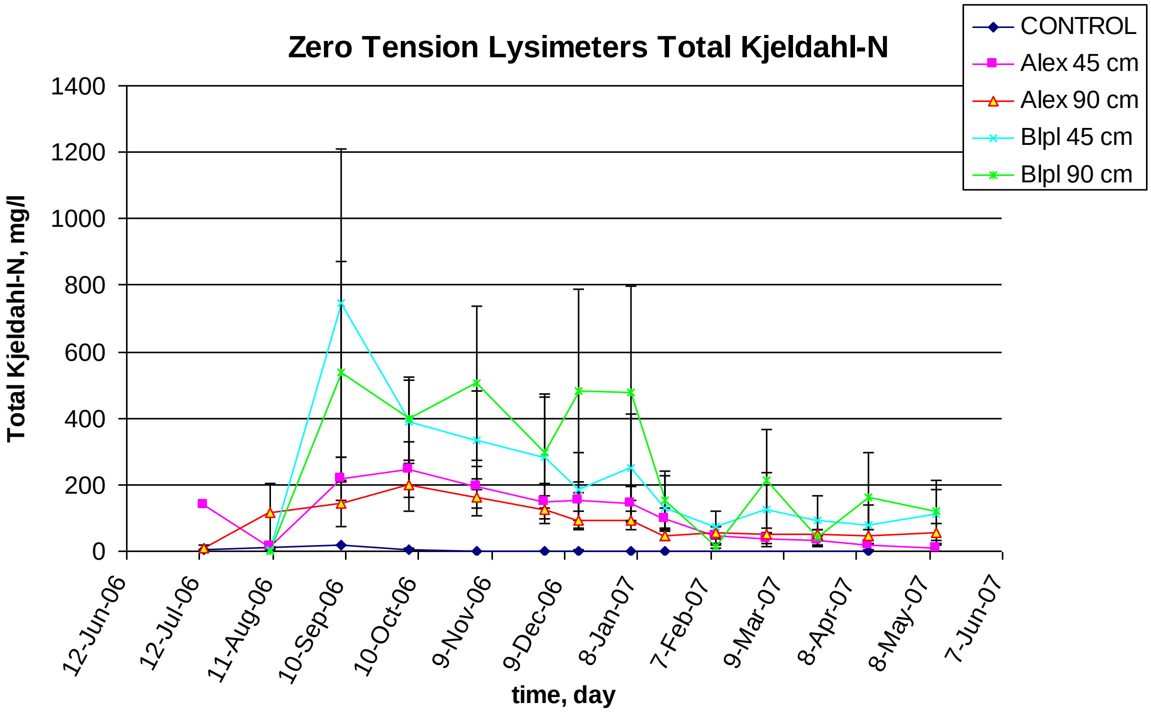

Figure 8: Concentration of Total Kjeldahl -N in the zero tension lysimeters with time.

Nitrate. Leachate nitrate-N concentration in the zero tension lysimeters below the biosolids treatments began to exceed the control treatments by the September to November period. Greater concentrations of nitrate-N were detected below the Blpl than the Alex. The nitrate-N concentration from the Alex was not statistically higher than the control for the period from July 2006 to February 2007, and then started to increase. Concentration of the nitrate-N increased significantly below the Alex and the Blpl treatments in the period of April 2007 to October 2007 (Fig. 9). Increased concentrations of nitrate-N in zero tension lysimeters towards the summer and fall 2007 shows that mineralization of the biosolids and nitrification of ammonium-N increases with time.

Total Kjeldahl P (TKP). Total Kjeldahl P concentrations in the zero tension lysimeter leachate were initially highest shortly after application of biosolids and declined with time. The TKP concentrations were an order of magnitude higher than the O-P concentrations, which indicated that nearly all of the transported P was either bound to some particulate matter (e.g., Fe, Al, organic matter) or moved in dissolved organic form. The reduction in TKP with time indicates an increase in P binding with aging. Many of the TKP concentrations under the biosolids treatments were higher than published eutrophic critical values (0.035 mg/l) ranging from <0.01 mg/l to as high as 1.5 mg TKP/l, but the likely effect of aging (with potential formation of P-binding surfaces vie oxidation of Fe and Al) decreased the concentrations of TKP with time (Fig. 10).

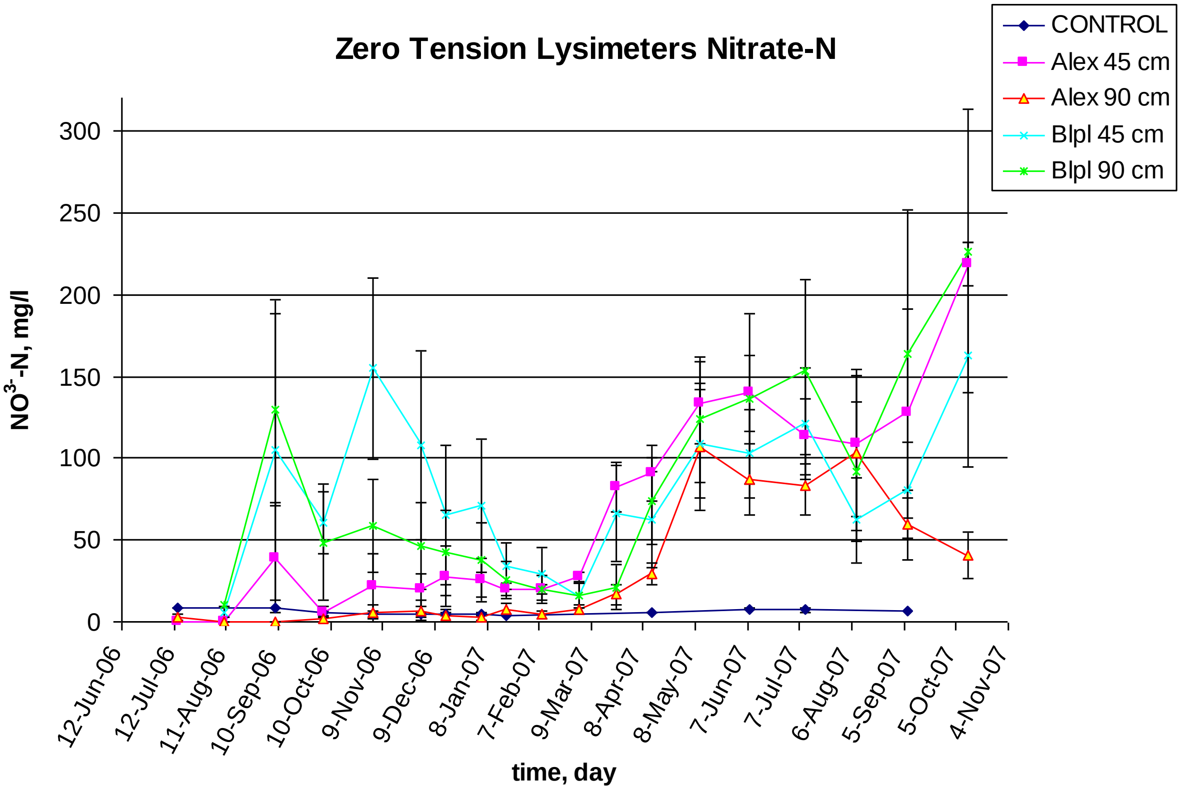

Figure 9: Concentration of Nitrate -N in the zero tension lysimeters with time.

Ortho-phosphate (O-P). Ortho-phosphate concentration in the zero tension lysimeter leachate were very much lower than N. Blpl biosolids tend to have more O–P than Alex. The high P-binding capacity of the biosolids, likely due to the high concentrations of Fe and Al, reduced P leaching despite the high P loadings of as much as 11,286 kg/ha (Fig. 11).

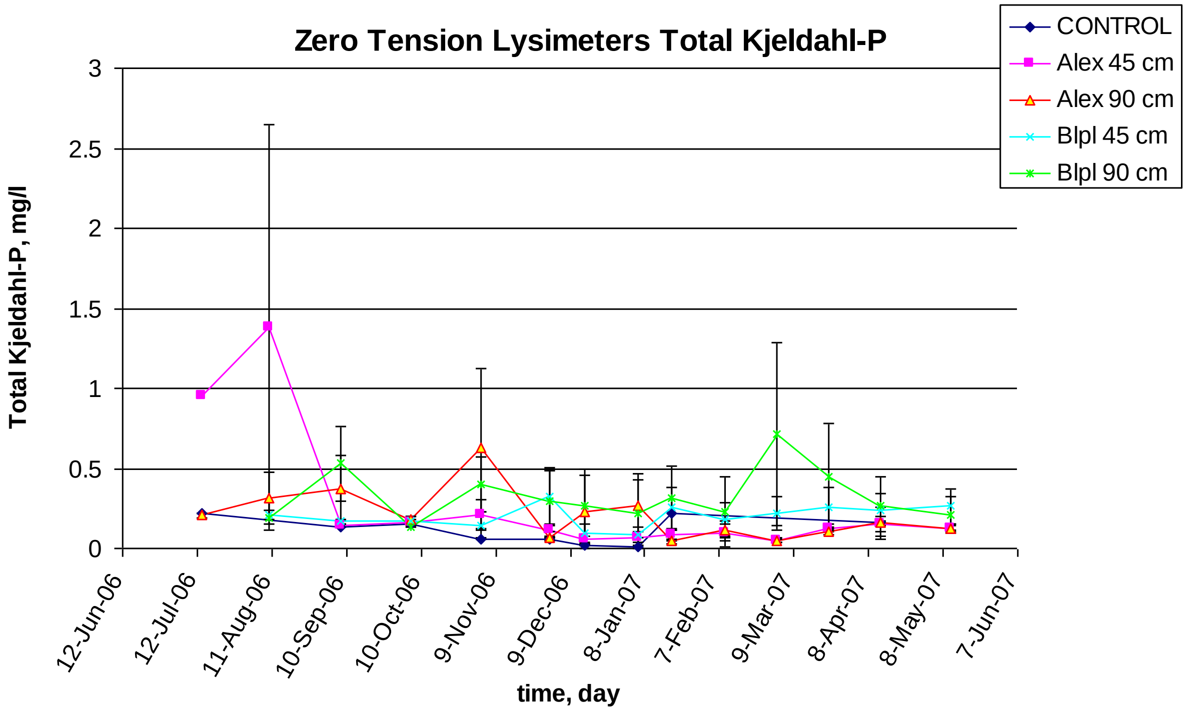

Figure 10: Concentration of Total Kjeldahl -P in the zero tension lysimeters with time.

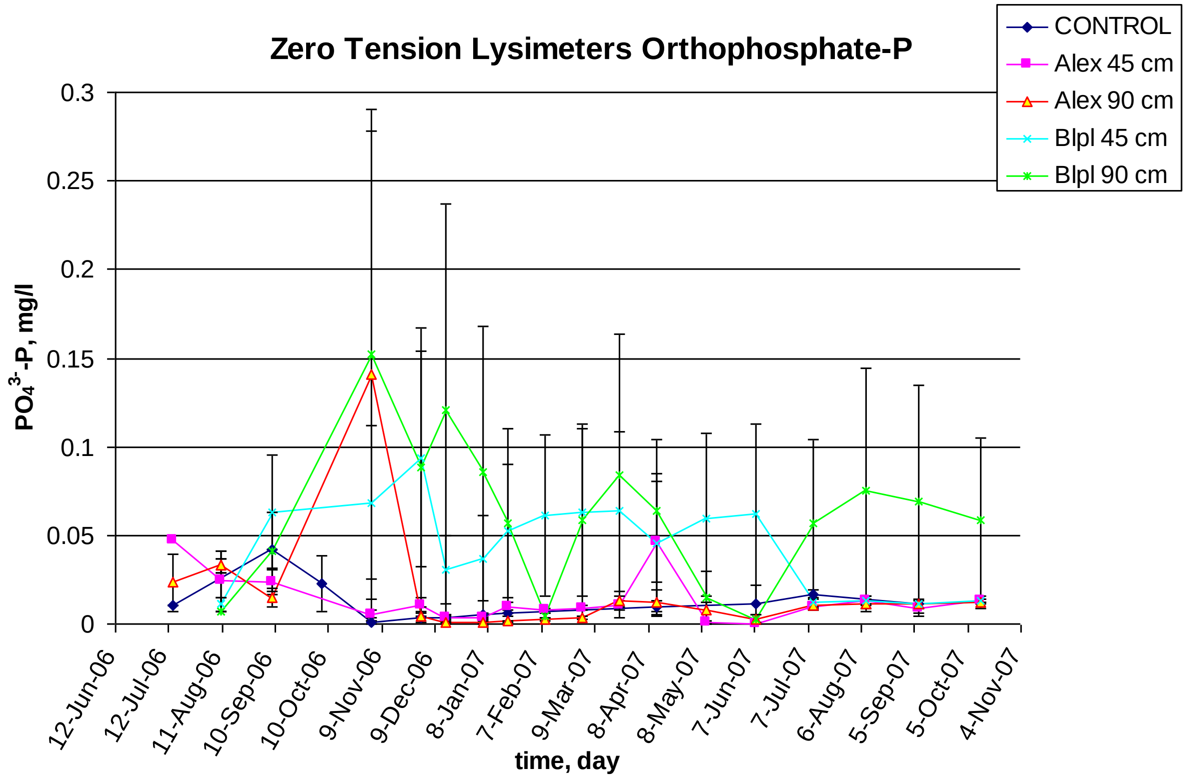

Figure11: Concentration of Orthophosphate-P in the zero tension lysimeters with time.

Leaching Masses in the Groundwater

Ammonia, Total Kjeldahl-N and Nitrate-N. Significantly greater amounts of ammonia-N were leached from the wide Blpl than from the Alex treatments and the control. Significantly greater amounts of TKN were leached from the wide Blpl treatment than from the control. Significantly greater amounts of nitrate-N were leached from the narrow Blpl than from the Alex treatments or control (Table 4).

Total Kjeldahl P and Orthophosphate-P (O-P). Significantly greater amounts of Total Kjeldahl P were leached from the wide Blpl than from the narrow Alex treatment and the control. Higher total Kjeldahl P leaching rates from the biosolids indicate transport of P with colloids and possible leaching of organic P in the biosolids. Both of these mechanisms result only in extremely low losses of total P (up to 0.484 kg/ha per 10 months) to the groundwater. Amounts of O-P leached from the both Blpl than the Alex treatments were not significantly different from the control treatments (Table 4). This is possibly a result of high biosolids phosphorus binding capacity.

Table 4. Leaching rates of N and P-forms to the groundwater from the biosolids treatments and the control for the period from July 2006 to May 2007.

Treatment	NO_3^- -N	NH_4^+-N	Total Kjeldahl-N	Ortho-P	Total Kjeldahl- P
			Leaching rates, kg/ha		
CONTROL†	0.243 c	2.446 b	3.482 b	0.008 a	0.037 b
Alex 45 cm	10.615 bc	53.679 b	108.308 ba	0.012 a	0.092 b
Alex 90 cm	17.12 bca	121.884 ba	208.42 ba	0.019 a	0.384 ba
Blpl 45 cm	37.309 a	90.235 ba	230.248 ba	0.054 a	0.145 ba
Blpl 90 cm	34.048 ba	224.967 a	492.546 a	0.054 a	0.484 a

† Values in each column followed by the same letter(s) are not significantly different at p-level=0.05 according to Fisher LSD.

Nitrous Oxide Emission

Nitrous oxide emission was greater from the Alex than from the Blpl treatments and also both Blpl and the Alex were higher than the control. Emission rates were high in summer 2006 following the biosolids application, then decreased during the cooler winter months, and increased again as the air and soil temperatures increased in spring and summer 2007 (Fig. 12).

Higher nitrous oxide emissions in the Alex compared to Blpl biosolids occur possibly due to high pH of the latter which inhibits microbial activity.

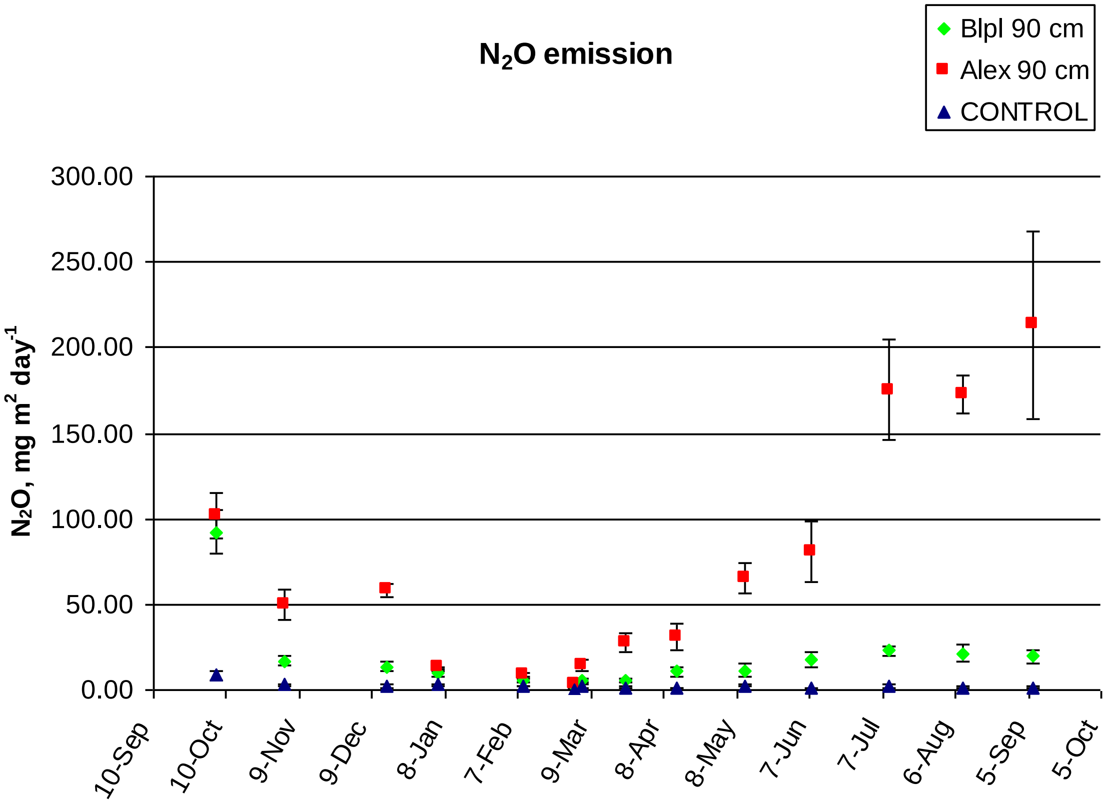

Figure 12: Nitrous oxide emission rates with time.

Oxidation-Reduction Potential

Redox potential was lower in both Blpl and the Alex treatments than in the control (Fig. 13). This is attributed to anaerobic conditions maintained within the biosolids seam.

Conclusions

Based upon the limited sampling period following biosolids application (10 months) represented by this report, entrenchment of biosolids in very coarse-textured soils containing little organic matter poses environmental risks of nutrient leaching. Nitrogen loss is most likely, typically occurring initially as ammonium N. A considerable amount of organic N was also leached. Nitrate N leaching increased as nitrification proceeded. The magnitude of this loss will depend on the capability of the poplar trees to assimilate N.

While the concentrations of P in leachate were initially higher than eutrophication standards, P transport began to decline quickly. The potential loss of P via leaching through coarse-textured soils will likely be controlled by the content of P-binding capacity constituents (i.e., Fe, Al) in the biosolids. The Fe and Al contents of the Alexandria and Blue Plains biosolids provide high binding capacity media that should limit P solubility and transport.

Low redox potential in the biosolids verifies that anaerobic conditions occurred within the trenches and explains high levels of ammonium N compared to nitrate N levels during most of the first year of entrenchment.

Lower N_2O emission from lime stabilized (Blue Plains) biosolids than from anaerobically digested (Alexandria) biosolids is possibly due to higher pH of the latter which significantly decreased microbial activity.

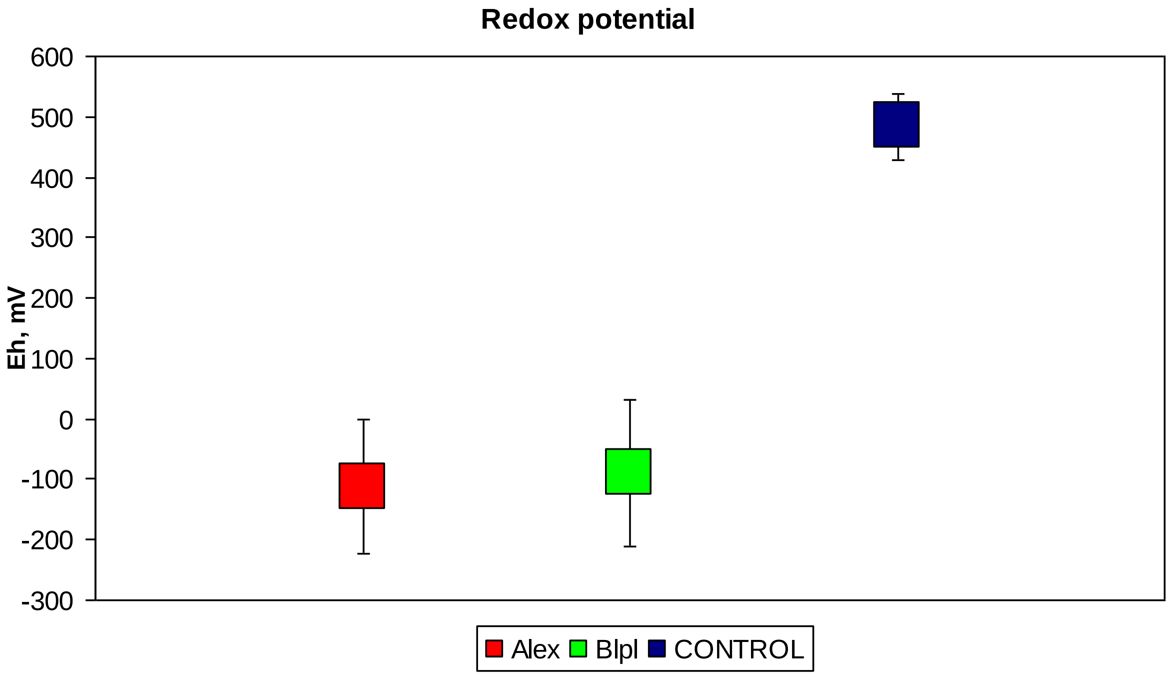

Figure 13: Redox potential in the biosolids and the control (soil).

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