THE BENEFICIAL USE OF BIOSOLIDS FROM THE CITY OF GRAND RAPIDS: A PRELIMINARY ASSESSMENT OF ITS IMPACT ON SHALLOW SOIL WATER

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INTRODUCTION

This report is part of a project sponsored by the City of Grand Rapids at the North Central Experiment Station (NCES). The project was coordinated by the NCES with technical assistance provided by the Natural Resources Research Institute (NRRI) to evaluate the impact of applying biosolids and wood ash to forest land on shallow soil water in the unsaturated zone. The overall purpose of the project is to determine if biosolids can be used in a beneficial manner, alone, or in combination with wood ash, as part of managing the reforestation of timber land in northern Minnesota.

Biosolids from the City of Grand Rapids were applied by NCES staff on research plots planted with tree seedlings in the summer of 1995. The biosolids were applied at two rates, 15 and 30 ton/acre, with and without wood ash applied at a rate of 10 ton/acre. This report presents the first year results for soil water monitoring during the summer-fall of 1995.

METHODS

The research site is located near the North Central Experiment Station. The site was previously clear-cut and woody debris was removed prior to the application of biosolids and wood ash, the planting of tree seedlings, and the installation of piezometers and lysimeters.

Eighteen suction-cup lysimeters were installed in July 1995 to monitor subsurface water quality. The lysimeters were fabricated at NRRI using porous ceramic cups, Schedule 20 PVC pipe, stoppers, tubing, and clamps. The lysimeters were installed on July 5, 1995 on the six plots located in Replication 2, as shown in Figure 1. Three lysimeters were installed, at the same depth, on each plot.

The lysimeters were installed in boreholes using a 3 1/4-inch auger which terminated at a depth of 24 inches. A schematic of the lysimeters are shown in Figure 2. Approximately 4 inches of a silica flour slurry was placed in the bottom of each borehole, and the porous ceramic cup was embedded into the slurry. The borehole was backfilled with native soil, in lifts of 4-6 inches, and compacted using a small diameter rod. Each lysimeter terminated at a depth of 6 inches below the soil surface.

Two piezometers were installed on plots 3 and 5, in replication 2, as shown in Figure 1. Piezometers were used to determine depth to the water table when lysimeters were sampled during 1995. A 3 1/4-inch borehole was drilled using a hand-held bucket auger. Both piezometers were fabricated in the field to fit the proper depth of each borehole. Piezometers were constructed using 2-inch diameter Schedule 40 PVC pipe and #10 slotted PVC screen.

Each piezometer was placed into the borehole and clean sand was poured into the annular space around the screened section of pipe. A bentonite seal of approximately 12 inches was placed on top of the clean sand to prevent the movement of near surface water along the solid pipe and into the piezometer. The borehole was backfilled with native soil, in lifts of approximately 6 inches, from the top of the bentonite to the ground surface. A solid riser pipe for each piezometer extended above the surface and a removable cap was placed on top of each piezometer.

Piezometer 1 (P-1) was installed in a borehole 90 inches deep. The screened length is 24 inches, as shown in Figure 3. Piezometer 2 (P-2) was installed in a borehole 67 inches deep, with a screened length of 18 inches, as shown in Figure 4.

Water samples were collected from lysimeters during the months of July, August, September, and October 1995 for a total of five sampling events. A hand pump was used to remove water samples from each lysimeter by applying a vacuum of approximately 60 pounds per square inch (psi) the day prior to sample collection. After evacuating water from each lysimeter, the samples were analyzed in the field for temperature and specific conductance. Water samples were kept cool and analyzed at NRRI for pH. The samples were submitted to the University of Minnesota, Research Analytical Laboratory (RAL), for analysis of chloride, nitrogen (NO_3+NO_2), and total concentrations of the following elements: aluminum (Al), boron (B), calcium (Ca), cadmium (Cd), chromium (Cr), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), nickel (Ni), phosphorus (P), lead (Pb), and zinc (Zn) using Inductively Coupled Plasma (ICP) Atomic Emission Spectrometry.

RESULTS & DISCUSSION

PIEZOMETER/GROUNDWATER MEASUREMENTS

The soils at the study site are outwash sand with a seasonal water table in close proximity to the existing surface. The soils are loamy sands to sands with a topsoil layer 2 to 6 inches thick. The coloration of the soil (mottling) indicated that the seasonal high water table is at a depth of approximately 20 to 25 inches below the existing soil surface at the locations evaluated in the study area.

The actual depth to groundwater measured during the months July through October 1995 are shown in Table 1. The lysimeters were 17 to 47 inches above the water table at the time of sample collection. In P-1, groundwater was 57 inches below the surface in July and dropped to 71 inches below the surface on September 21, 1995. The water rose 10 inches in P-1 from September 21 to October 31, 1995 during this period of groundwater recharge. In P-2, groundwater was 41 inches below the surface on July 10, 1995 and dropped to a low of 66 inches below the surface on September 21, 1995. The water rose 15 inches in P-2 to 51 inches below the surface during the interval September 21 to October 31, 1995.

LYSIMETER ANALYSES

The results for specific conductance, chloride, sodium, and nitrate-nitrogen are graphically presented in Figures 5-8. The results (mean values) are displayed for each of the six treatments: 1) the control, 2) biosolids at 15 ton/acre, 3) biosolids at 30 ton/acre, 4) wood ash at 10 ton/acre, 5) biosolids at 15 ton/acre and wood at 10 ton/acre, and 6) biosolids at 30 ton/acre and wood ash at 10 ton/acre. Mean values of specific conductance, chloride, sodium, and nitrate in soil water are shown before the application of biosolids/wood ash (background conditions) and after treatments were applied during the months July, August, September, and October 1995.

Specific conductivity is a measure of the ability of a solution to carry an electrical current and depends upon the concentration of ions in solution (including such ions as calcium, magnesium, sodium, potassium, sulfate) and the temperature of the solution. As shown in Figure 5, slightly higher conductivities were measured in shallow soil water on plots amended with wood ash. Wood ash is composed of inorganic substances, including calcium, potassium, magnesium, sodium, sulfate, aluminum, and chloride. Some ions, including sulfate and chloride, are negatively charged and move from the surface down through the soil to varying depths. Higher conductivities were measured in August, September, and October 1995 on the plot amended with biosolids at 30 ton/acre with wood ash. The application of biosolids alone, at both rates, did not show an increase in conductivity in comparison to the control plot.

The mean chloride levels measured in soil water are shown in Figure 6. The Maximum Contaminant Level (MCL) for chloride in drinking water is 250 mg/l (Minnesota Department of Health, 1991). Background chloride levels (measured in July 1995) for five of the six treatments were higher or comparable to levels measured after the application of treatments (July through October 1995). Slightly higher chloride levels were measured on the plot amended with biosolids at 30 ton/acre and wood ash in August and September 1995, with a mean chloride level of approximately 30 mg/l.

Sodium levels in soil water are shown in Figure 7. Sodium is a cation that is fairly mobile in the soil. Low sodium levels were measured in five of the six treatments. Elevated sodium levels were measured on the plot amended with biosolids at 30 ton/acre and wood ash.

The levels of nitrite + nitrate-nitrogen in soil water are shown in Figure 8. The drinking water standard for nitrate is 10 mg/l. The levels of nitrate for five of the six treatments were comparable, including the control, biosolids at both 15 ton/acre and 30 ton/acre, wood ash alone, and biosolids at 30 ton/acre and wood ash. For all six treatments, including the control, there was an increase in nitrate levels in soil water as the summer progressed from July through September, with a decrease in nitrate levels in October. Higher soil water nitrate levels were measured in August through October on the plot amended with biosolids at 15 ton/acre and wood ash. Natural soil variability can account for higher nitrate levels at different locations within the same field.

The analysis for the remaining parameters measured in the study to determine baseline conditions for total concentrations of aluminum, boron, calcium, cadmium, chromium, copper, iron, potassium, magnesium, manganese, nickel, phosphorus, lead, and zinc in soil water are presented in Tables 2 through 6. The data is presented by month, including background levels measured in July 1995, and after treatments were applied for the months July, August, September, and October 1995. The detection limits, along with the MCL/RAL (Maximum Contaminant Level/Recommended Allowable Limit) for drinking water are presented. When the concentration of an element was reported by the laboratory as less than the detection limit, the value of the detection limit for that element was used in this report.

Background concentrations of aluminum through zinc measured in soil water, prior to the application of biosolids/wood ash in July, are presented in Table 2. Elemental concentrations are typically less than, or close to, the detection limit for pollutants of concern in groundwater, where drinking water standards have been established (ie; boron, cadmium, chromium, copper, iron, manganese, nickel, lead, and zinc). The concentrations of the elements measured were less than the established MCL/RAL, with the exception of iron in one sample. The standard (a secondary standard) for iron is 0.3 mg/l.

The levels of aluminum through zinc, from water samples collected a short time after the application of biosolids/wood ash in July 1995 are presented in Table 3. No obvious changes in soil water quality, in comparison to background conditions, are readily apparent from the data. Where it could be determined (limited by the detection limit), the drinking water standards were meet at the depth of monitoring (24 inches) in the soil.

The results in August 1995 for the elements aluminum through zinc are shown in Table 4. A general increase in elemental concentrations for some of the elements was measured, most notably for the plot amended with biosolids at 30 ton/acre and wood ash at 10 ton/acre. Higher levels of aluminum, calcium, potassium, magnesium, manganese, and zinc were measured in August, in comparison to concentrations measured previously (in July) and to concentrations measured for the other five treatments in August. The MCL/RAL for the parameters identified in Table 4 were not exceeded in August.

In September, there was a general increase in the concentrations of several elements for most treatments, including the elements aluminum, calcium, manganese, and zinc (Table 5). Furthermore, higher levels of aluminum, boron, calcium, iron, potassium, magnesium, manganese, and zinc were measured on the plot amended with biosolids at 30 ton/acre and wood ash. As previously identified, the highest level of specific conductance was also measured on this plot (Figure 5). Higher levels of aluminum, calcium, potassium, and magnesium in soil water may be associated with the application of wood ash, which has a significant level of these minerals. The MCL/RAL for boron, manganese, nickel, and zinc were exceeded in a few instances in September.

In October, the total elemental concentration in soil water was generally lower than the levels measured in September. At this time, higher concentrations of some elements, including aluminum, boron, calcium, potassium, magnesium, manganese, and to a lesser degree zinc, were measured on the plot amended with biosolids at 30 ton/acre and wood ash.

CONCLUSIONS

Biosolids applied alone at 15 ton/acre and at 30 ton/acre did not impact the quality of shallow soil water in July through October 1995, the year biosolids were applied and tree seedlings were planted.

Higher levels of specific conductance, chloride, and sodium were measured in August and September on plots amended with wood ash at 10 ton/acre and biosolids at 30 ton/acre. Elevated levels of aluminum, boron, calcium, potassium, magnesium, and zinc were also measured in soil water on the plot amended with wood ash at 10 ton/acre and biosolids at 30 ton/acre. Wood ash, often used as a liming material and nutrient source, contains significant amounts of these elements. Many of these elements are essential plant nutrients and are used by trees and understory vegetation as the root system develops and grows down through the soil.

Overall, there were no obvious effects on shallow soil water located above the water table the year that biosolids and wood ash were applied.

LITERATURE CITED

Minnesota Department of Health. 1991. In Recommended allowable limits for drinking water contaminants. Release No. 3. p1-19.

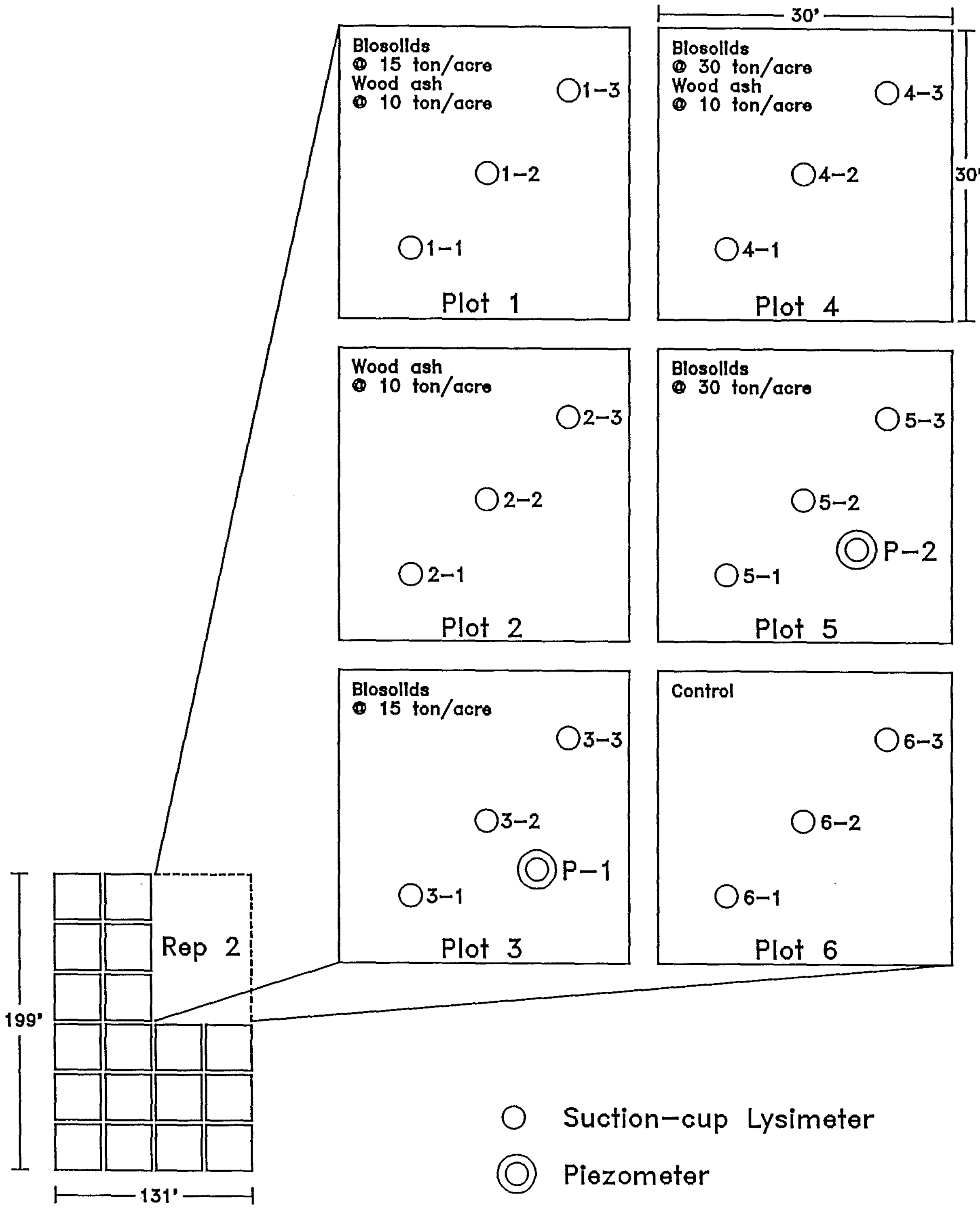


Figure 1. Plot plan for landspreading biosolids and wood ash on forest land.

Suction-cup Lysimeters

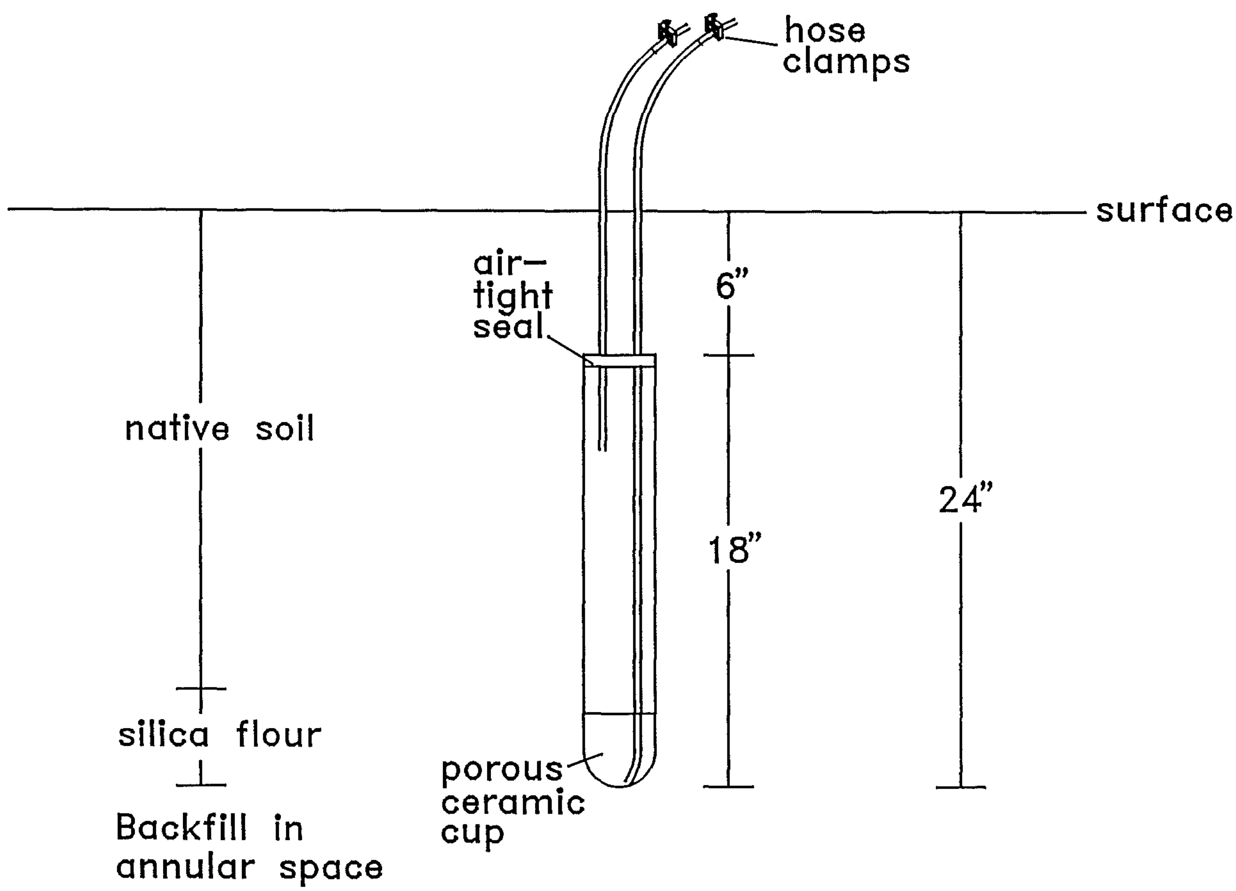
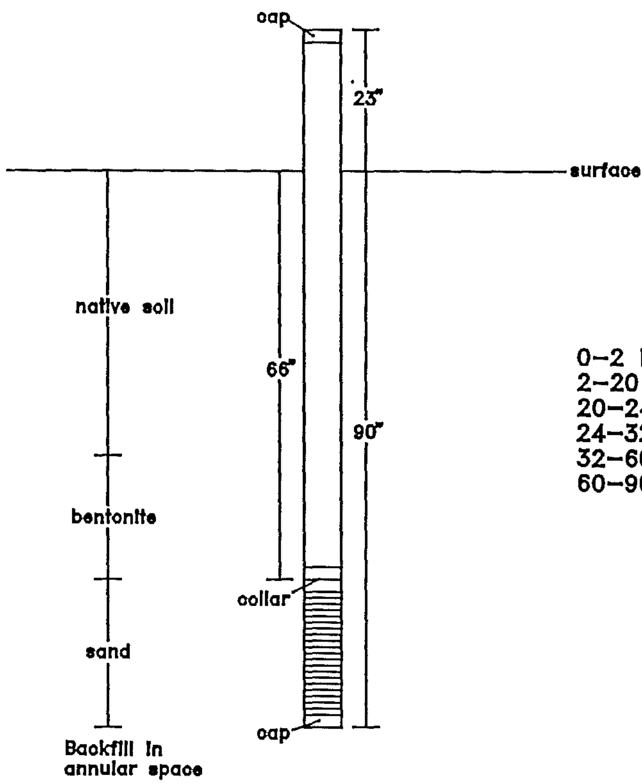
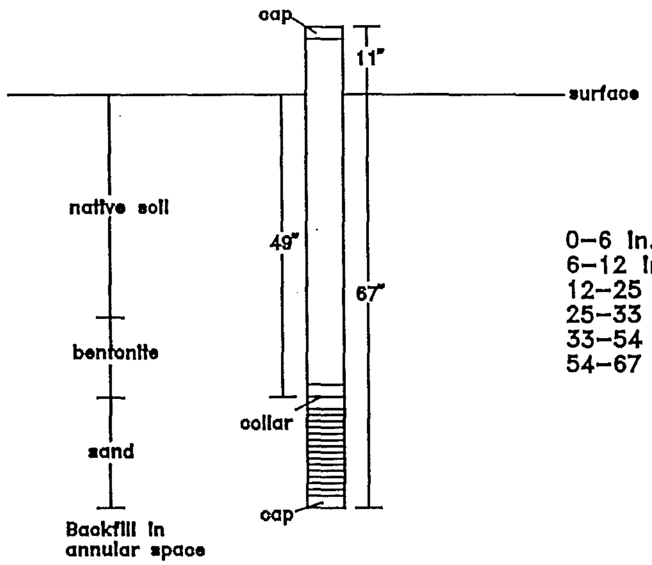


Figure 2. Lysimeter installation detail drawing for the Grand Rapids biosolids research project.



0–2 in.	Topsoil, reddish brown loamy sand
2–20 in.	Medium red sand
20–24 in.	Reddish brown sand with gray mottling
24–32 in.	Gray and red sand
32–60 in.	Gray sand with red mottling
60–90 in.	Dark gray brown sand, visibly moist to wet (water table at 60 inches after boring terminated)

Figure 3. Piezometer 1 (P-1) construction details with associated soils information.



0–6 in.	Topsoil, loamy sand
6–12 in.	Light gray medium sand
12–25 in.	Bright reddish brown medium sand
25–33 in.	Reddish brown sand, trace gray mottles
33–54 in.	Medium sand, gray and red layering
54–67 in.	Red and gray sand, visibly moist to wet (water table at 54 inches after boring terminated)

Figure 4. Piezometer 2 (P-2) construction details with associated soils information.

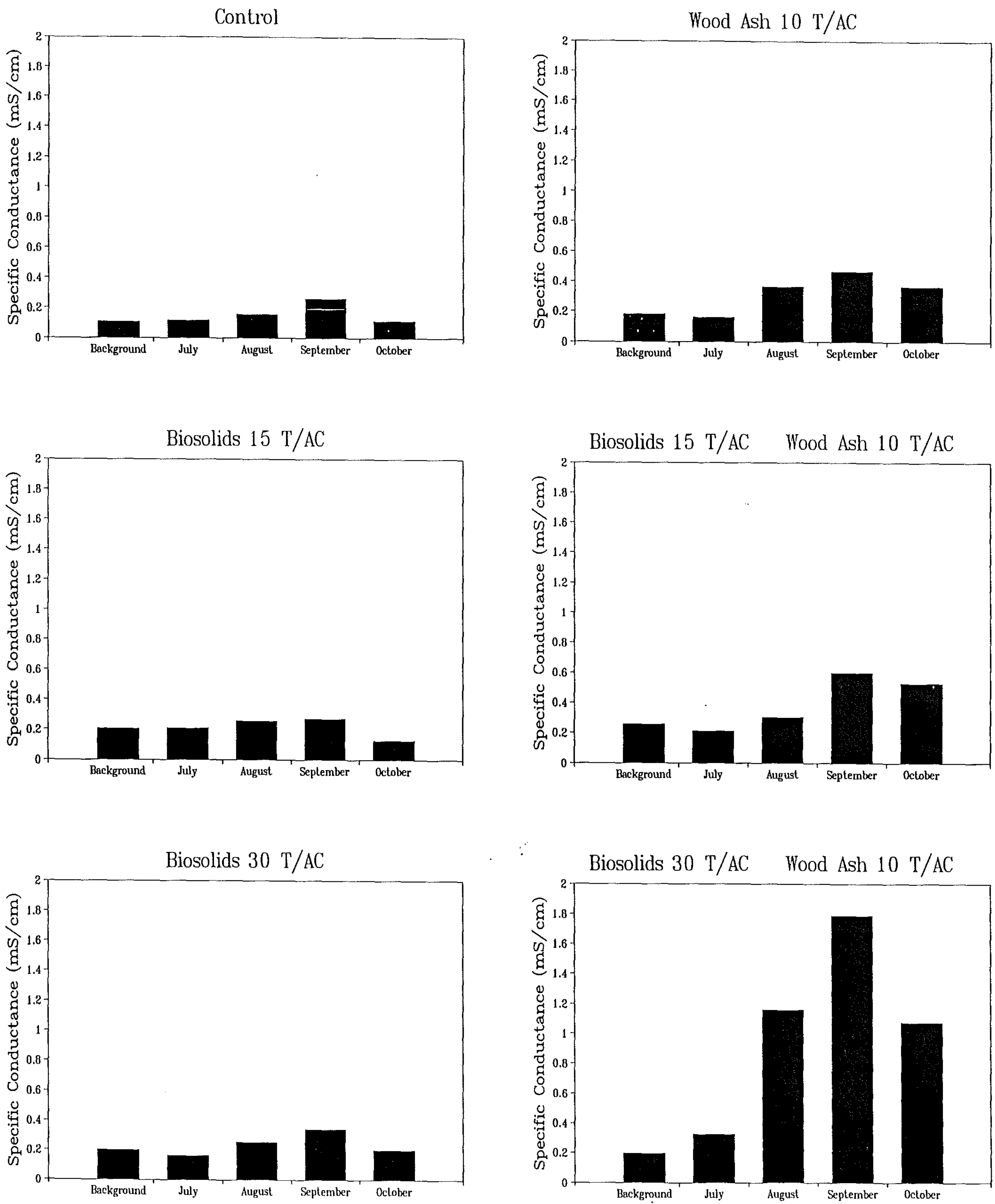


Figure 5. Mean specific conductance for treatments applied at the Grand Rapids biosolids/wood ash forestry project.

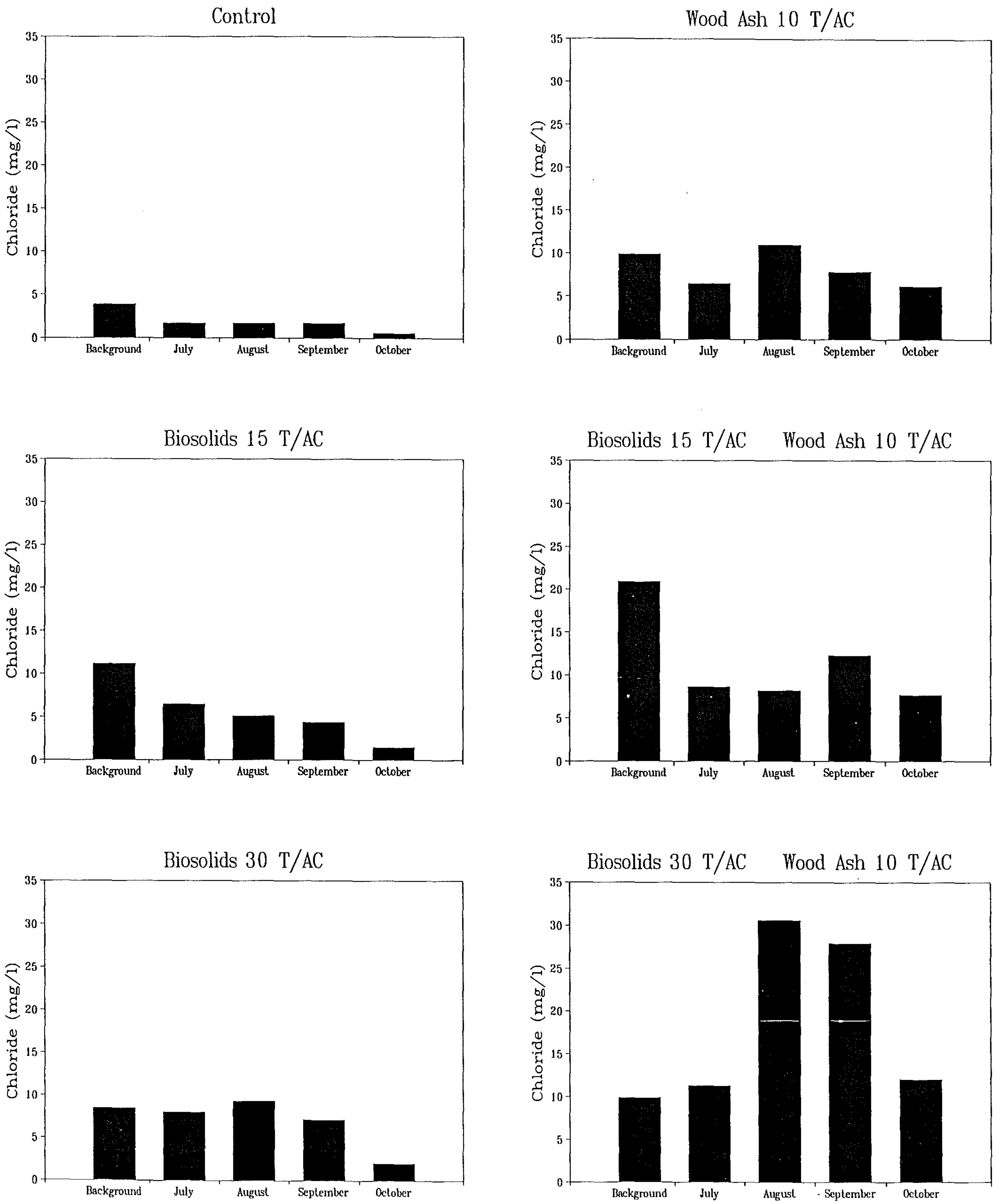


Figure 6. Mean chloride for treatments applied at the Grand Rapids biosolids/wood ash forestry project. The maximum contaminant level (MCL) for chloride in drinking water is 250 mg/l.

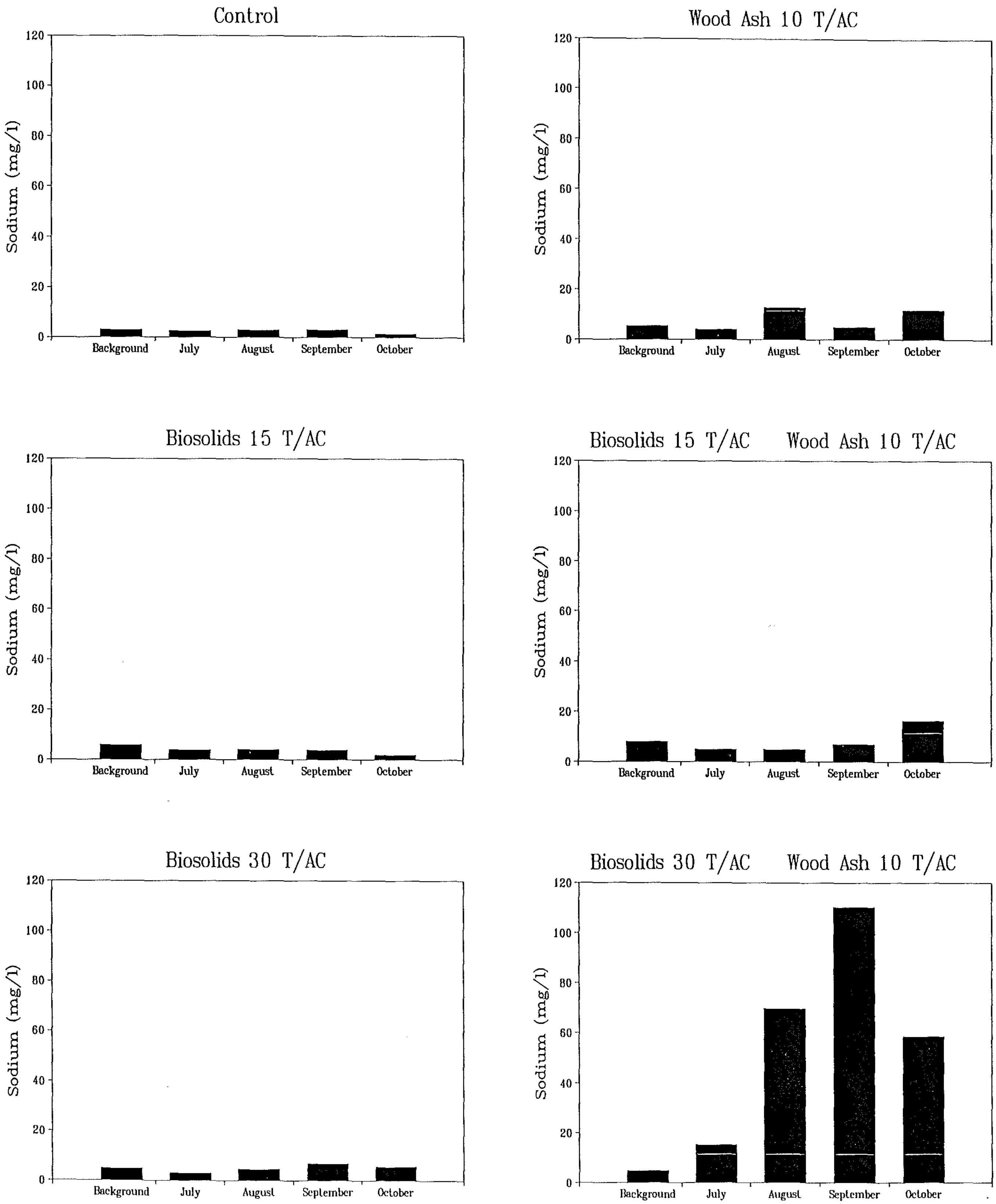


Figure 7. Mean sodium for treatments applied at the Grand Rapids biosolids/wood ash forestry project.

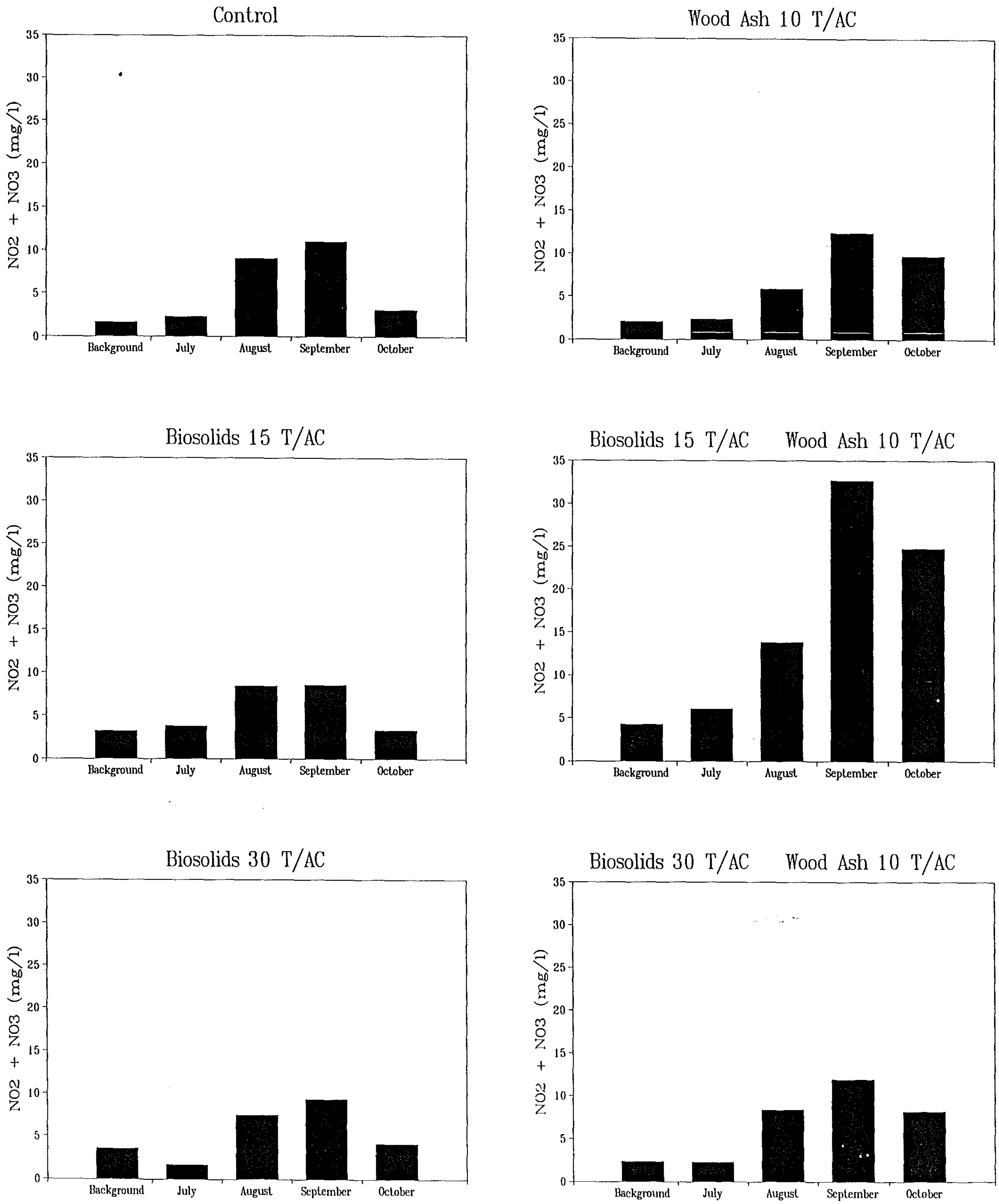


Figure 8. Mean NO_2 + NO_3 for treatments applied at the Grand Rapids biosolids/wood ash forestry project. The maximum contaminant level (MCL) for nitrate is 10 mg/l.

Table 1. Depth of groundwater from July through October 1995 in piezometers P-1 and P-2.

Date	Piezometer P-1	Piezometer P-2
July 10, 1995	57"	41"
July 19, 1995	57"	43"
August 21, 1995	64"	54"
September 21, 1995	71"	66"
October 31, 1995	61"	51"

Table 2. Mean background lysimeter analyses from July at the Grand Rapids biosolids/wood ash forestry project[1].

Treatment	Al	B	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Ni	P	Pb	Zn
	mg/l													
Control	0.182 ±0.01	0.027 ±0.0	10.6 ±3.9	0.006 ±0.0	0.014 ±0.0	0.043 ±0.03	0.035 ±0.0	1.8 ±0.1	2.7 ±0.6	0.032 ±0.0	0.022 ±0.0	0.049 ±0.0	0.084 ±0.0	0.047 ±0.02
Wood Ash 10 T/AC	0.191 ±0.02	0.049 ±0.0	19.4 ±3.5	0.006 ±0.0	0.014 ±0.0	0.066 ±0.03	0.027 ±0.0	3.7 ±1.4	4.3 ±0.5	0.049 ±0.0	0.022 ±0.0	0.072 ±0.0	0.084 ±0.0	0.070 ±0.02
Biosolids 15 T/AC	0.214 ±0.06	0.054 ±0.0	22.4 ±3.6	0.006 ±0.0	0.014 ±0.0	0.069 ±0.04	0.084 ±0.0	4.1 ±0.5	4.8 ±0.5	0.070 ±0.0	0.026 ±0.0	0.148 ±0.0	0.084 ±0.0	0.061 ±0.03
Biosolids 15 T/AC + Wood Ash 10 T/AC	0.179 ±0.00	0.055 ±0.0	26.7 ±15.	0.006 ±0.0	0.016 ±0.0	0.134 ±0.16	0.039 ±0.0	7.4 ±3.9	6.0 ±3.3	0.070 ±0.0	0.028 ±0.0	0.092 ±0.0	0.084 ±0.0	0.098 ±0.07
Biosolids 30 T/AC	0.179 ±0.00	0.051 ±0.0	21.3 ±1.3	0.006 ±0.0	0.014 ±0.0	0.050 ±0.02	0.354 ±0.4	2.5 ±0.6	5.5 ±0.3	0.205 ±0.1	0.036 ±0.0	0.074 ±0.0	0.084 ±0.0	0.141 ±0.03
Biosolids 30 T/AC + Wood Ash 10 T/AC	0.193 ±0.02	0.052 ±0.0	21.1 ±1.6	0.006 ±0.0	0.014 ±0.0	0.060 ±0.02	0.045 ±0.0	4.0 ±0.5	5.4 ±0.5	0.088 ±0.0	0.023 ±0.0	0.097 ±0.0	0.084 ±0.0	0.134 ±0.08
Detection Limit (ICP)[2]	0.179	0.023	0.041	0.006	0.014	0.026	0.017	0.707	0.190	0.003	0.022	0.035	0.084	0.007
MCL[3]/RAL[4]		0.3		0.004	0.10	1.0	0.3			0.3	0.07		0.02	0.7

[1]Mean values ± S.D. N=3
[2]Inductively Coupled Plasma
[3]Maximum Contaminant Level
[4]Recommended Allowable Limit

Table 3. Mean lysimeter analyses from July at the Grand Rapids biosolids/wood ash forestry project[1].

Treatment	Al	B	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Ni	P	Pb	Zn
	mg/l													
Control	0.179 ±0.00	0.023 ±0.00	9.3 ±3.6	0.006 ±0.00	0.014 ±0.00	0.026 ±0.00	0.038 ±0.02	1.2 ±0.1	2.4 ±0.8	0.045 ±0.04	0.022 ±0.00	0.035 ±0.00	0.084 ±0.00	0.060 ±0.02
Wood Ash 10 T/AC	0.197 ±0.03	0.048 ±0.01	16.7 ±4.6	0.006 ±0.00	0.014 ±0.00	0.041 ±0.02	0.023 ±0.01	3.0 ±0.7	4.2 ±1.0	0.030 ±0.01	0.022 ±0.00	0.055 ±0.02	0.084 ±0.00	0.068 ±0.01
Biosolids 15 T/AC	0.237 ±0.05	0.064 ±0.01	19.6 ±6.9	0.006 ±0.00	0.014 ±0.00	0.059 ±0.02	0.056 ±0.03	4.2 ±1.0	5.9 ±2.3	0.061 ±0.04	0.044 ±0.02	0.073 ±0.01	0.084 ±0.00	0.205 ±0.14
Biosolids 15 T/AC + Wood Ash 10 T/AC	0.225 ±0.04	0.049 ±0.01	19.8 ±8.2	0.006 ±0.00	0.014 ±0.00	0.502 ±0.82	0.059 ±0.02	4.7 ±1.8	5.6 ±2.1	0.034 ±0.01	0.027 ±0.00	0.067 ±0.02	0.085 ±0.00	0.322 ±0.42
Biosolids 30 T/AC	0.179 ±0.00	0.035 ±0.01	16.9 ±1.0	0.006 ±0.00	0.014 ±0.00	0.036 ±0.02	0.211 ±0.30	2.9 ±0.9	5.3 ±0.3	0.172 ±0.16	0.023 ±0.00	0.039 ±0.01	0.084 ±0.00	0.153 ±0.02
Biosolids 30 T/AC + Wood Ash 10 T/AC	0.184 ±0.01	0.047 ±0.00	29.5 ±24.6	0.006 ±0.00	0.014 ±0.00	0.031 ±0.01	0.032 ±0.01	5.6 ±3.7	8.7 ±7.0	0.072 ±0.05	0.025 ±0.00	0.040 ±0.01	0.084 ±0.00	0.164 ±0.06
Detection Limit (ICP)[2]	0.179	0.023	0.041	0.006	0.014	0.026	0.017	0.707	0.190	0.003	0.022	0.035	0.084	0.007
MCL[3]/RAL[4]		0.3		0.004	0.10	1.0	0.3			0.3	0.07		0.02	0.7

[1]Mean values ± S.D. N=3
[2]Inductively Coupled Plasma
[3]Maximum Contaminant Level
[4]Recommended Allowable Limit

Table 4. Mean lysimeter analyses from August at the Grand Rapids biosolids/wood ash forestry project[1].

Treatment	Al	B	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Ni	P	Pb	Zn
	mg/l													
Control	0.179	0.029	14.7	0.006	0.014	0.026	0.061	1.6	3.5	0.067	0.023	0.035	0.084	0.111
	±0.00	±0.00	±2.7	±0.00	±0.00	±0.00	±0.02	±0.0	±0.2	±0.04	±0.00	±0.00	±0.00	±0.10
Wood Ash 10 T/AC	0.196	0.064	33.9	0.006	0.014	0.051	0.037	4.7	8.2	0.109	0.047	0.048	0.084	0.375
	±0.03	±0.00	±3.5	±0.00	±0.00	±0.02	±0.02	±0.8	±0.7	±0.02	±0.01	±0.02	±0.00	±0.11
Biosolids 15 T/AC	0.261	0.063	24.9	0.006	0.014	0.061	0.101	4.5	6.5	0.101	0.044	0.072	0.084	0.349
	±0.13	±0.01	±8.1	±0.00	±0.00	±0.04	±0.02	±1.2	±2.3	±0.06	±0.03	±0.04	±0.00	±0.24
Biosolids 15 T/AC +	0.291	0.053	35.9	0.006	0.014	0.192	0.044	7.5	8.9	0.073	0.041	0.035	0.084	0.427
Wood Ash 10 T/AC	±0.19	±0.00	±11.0	±0.00	±0.00	±0.26	±0.04	±4.8	±2.4	±0.04	±0.01	±0.00	±0.00	±0.19
Biosolids 30 T/AC	0.179	0.048	23.3	0.006	0.014	0.038	0.037	3.3	6.6	0.223	0.047	0.045	0.084	0.303
	±0.00	±0.00	±2.2	±0.00	±0.00	±0.02	±0.02	±1.2	±0.6	±0.18	±0.00	±0.02	±0.00	±0.08
Biosolids 30 T/AC +	0.434	0.091	97.1	0.006	0.014	0.066	0.097	55.7	27.2	0.204	0.063	0.053	0.084	0.696
Wood Ash 10 T/AC	±0.25	±0.05	±94.1	±0.00	±0.00	±0.02	±0.13	±86.6	±26.2	±0.18	±0.01	±0.03	±0.00	±0.23
Detection Limit (ICP)[2]	0.179	0.023	0.041	0.006	0.014	0.026	0.017	0.707	0.190	0.003	0.022	0.035	0.084	0.007
MCL[3]/RAL[4]		0.3		0.004	0.10	1.0	0.3			0.3	0.07		0.02	0.7

[1]Mean values ± S.D. N=3
[2]Inductively Coupled Plasma
[3]Maximum Contaminant Level
[4]Recommended Allowable Limit

Table 5. Mean lysimeter analyses from September at the Grand Rapids biosolids/wood ash forestry project[1].

Treatment	Al	B	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Ni	P	Pb	Zn
	mg/l													
Control	0.560	0.023	27.6	0.006	0.014	0.061	0.036	2.0	6.3	0.128	0.047	0.035	0.084	0.381
	±0.33	±0.00	±7.2	±0.00	±0.00	±0.03	±0.01	±0.3	±1.9	±0.02	±0.02	±0.00	±0.00	±0.29
Wood Ash 10 T/AC	1.304	0.043	51.6	0.006	0.014	0.087	0.075	5.9	11.8	0.272	0.066	0.035	0.084	0.741
	±0.27	±0.00	±4.5	±0.00	±0.00	±0.01	±0.02	±0.7	±0.2	±0.02	±0.01	±0.00	±0.00	±0.21
Biosolids 15 T/AC	0.573	0.036	27.5	0.006	0.014	0.076	0.114	4.6	7.0	0.153	0.056	0.035	0.084	0.523
	±0.34	±0.00	±6.2	±0.00	±0.00	±0.04	±0.08	±0.8	±1.9	±0.08	±0.03	±0.00	±0.00	±0.14
Biosolids 15 T/AC +	1.373	0.037	65.9	0.006	0.014	0.227	0.074	10.0	15.4	0.233	0.065	0.036	0.084	0.782
Wood Ash 10 T/AC	±0.29	±0.00	±9.1	±0.00	±0.00	±0.24	±0.06	±7.7	±1.3	±0.02	±0.01	±0.00	±0.00	±0.10
Biosolids 30 T/AC	0.578	0.037	34.6	0.006	0.014	0.063	0.025	3.5	9.2	0.355	0.090	0.035	0.084	0.810
	±0.16	±0.01	±2.4	±0.00	±0.00	±0.03	±0.01	±0.7	±1.1	±0.27	±0.02	±0.00	±0.00	±0.27
Biosolids 30 T/AC +	1.663	0.331	130.8	0.006	0.014	0.077	0.120	130.0	34.6	0.368	0.071	0.035	0.084	0.972
Wood Ash 10 T/AC	±0.07	±0.37	±44.8	±0.00	±0.00	±0.03	±0.10	±207.6	±8.6	±0.08	±0.01	±0.00	±0.00	±0.14
Detection Limit (ICP)[2]	0.179	0.023	0.041	0.006	0.014	0.026	0.017	0.707	0.190	0.003	0.022	0.035	0.084	0.007
MCL[3]/RAL[4]		0.3		0.004	0.10	1.0	0.3			0.3	0.07		0.02	0.7

[1]Mean values ± S.D. N=3 Except for plot 2 that received wood ash only at 10 T/AC, in September and October 1995, N=2 because no sample could be withdrawn from lysimeter number 3.
[2]Inductively Coupled Plasma
[3]Maximum Contaminant Level
[4]Recommended Allowable Limit

Table 6. Mean lysimeter analyses from October at the Grand Rapids biosolids/wood ash forestry project[1].

Treatment	Al	B	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Ni	P	Pb	Zn
	mg/l													
Control	0.372	0.023	11.9	0.006	0.014	0.030	0.033	0.9	2.7	0.048	0.022	0.035	0.084	0.148
	±0.11	±0.00	±3.2	±0.00	±0.00	±0.01	±0.03	±0.1	±1.1	±0.01	±0.00	±0.00	±0.00	±0.09
Wood Ash 10 T/AC	1.051	0.038	36.5	0.006	0.014	0.081	0.025	3.8	8.3	0.174	0.041	0.035	0.084	0.497
	±0.65	±0.00	±13.5	±0.00	±0.00	±0.00	±0.00	±0.3	±2.1	±0.04	±0.01	±0.00	±0.00	±0.26
Biosolids 15 T/AC	0.335	0.023	12.1	0.006	0.014	0.056	0.050	2.2	2.9	0.062	0.034	0.035	0.084	0.266
	±0.15	±0.00	±2.1	±0.00	±0.00	±0.03	±0.06	±0.2	±0.5	±0.02	±0.00	±0.00	±0.00	±0.05
Biosolids 15 T/AC +	1.112	0.032	52.1	0.006	0.014	0.389	0.034	7.0	12.4	0.156	0.046	0.035	0.084	0.611
Wood Ash 10 T/AC	±0.51	±0.01	±14.9	±0.00	±0.00	±0.52	±0.02	±4.4	±2.6	±0.08	±0.01	±0.00	±0.00	±0.18
Biosolids 30 T/AC	0.690	0.024	19.3	0.006	0.014	0.339	0.025	2.1	4.9	0.149	0.066	0.035	0.084	0.707
	±0.56	±0.00	±6.8	±0.00	±0.00	±0.46	±0.00	±0.1	±1.4	±0.05	±0.02	±0.00	±0.00	±0.26
Biosolids 30 T/AC +	1.060	0.550	72.2	0.006	0.014	0.061	0.049	79.4	22.9	0.196	0.039	0.035	0.084	0.469
Wood Ash 10 T/AC	±0.99	±0.46	±64.9	±0.00	±0.00	±0.02	±0.02	±65.6	±26.3	±0.17	±0.01	±0.00	±0.00	±0.22
Detection Limit (ICP)[2]	0.179	0.023	0.041	0.006	0.014	0.026	0.017	0.707	0.190	0.003	0.022	0.035	0.084	0.007
MCL[3]/RAL[4]		0.3		0.004	0.10	1.0	0.3			0.3	0.07		0.02	0.7

[1]Mean values ± S.D. N=3 Except for plot 2 that received wood ash only at 10 T/AC, in September and October 1995, N=2 because no sample could be withdrawn from lysimeter number 3.
[2]Inductively Coupled Plasma
[3]Maximum Contaminant Level
[4]Recommended Allowable Limit