Ecosystem Restoration

Plant and Soil Responses to Biosolids Application following Forest Fire

V. F. Meyer, E. F. Redente, K. A. Barbarick,* R. B. Brobst, M. W. Paschke, and A. L. Miller

ABSTRACT

Soil stability and revegetation is a great concern following forest wildfires. Biosolids application might enhance revegetation efforts and enhance soil stability. In May 1997, we applied Metro Wastewater Reclamation District (Denver, CO, USA) composted biosolids at rates of 0, 5, 10, 20, 40, and 80 Mg ha^{-1} to a severely burned, previously forested site near Buffalo Creek, CO to improve soil C and N levels and help establish eight native, seeded grasses. The soils on the site belong to the Sphinx series (sandy-skeletal, mixed, frigid, shallow Typic Ustorthents). Vegetation and soils data were collected for four years following treatment. During the four years following treatment, total plant biomass ranged from approximately 50 to 230 g m^{-2} and generally increased with increasing biosolids application. The percentage of bare ground ranged from 4 to 58% and generally decreased with increasing biosolids rate. Higher rates of biosolids application were associated with increased concentrations of N, P, and Zn in tissue of the dominant plant species, streambank wheatgrass [*Elymus lanceolatus* (Scribn. & J.G. Sm) Gould subsp. *lanceolatus*], relative to the unamended, unfertilized control. At two months following biosolids application (1997), total soil C and N at soil depths of 0 to 7.5, 7.5 to 15, and 15 to 30 cm showed significant ($P < 0.05$) linear increases ($r^2 > 0.88$) as biosolids rate increased. The surface soil layer also showed this effect one year after application (1998). For Years 2 through 4 (1999–2001) following treatment, soil C and N levels declined but did not show consistent trends. The increase in productivity and cover resulting from the use of biosolids can aid in the rehabilitation of wildfire sites and reduce soil erosion in ecosystems similar to the Buffalo Creek area.

With the settlement of the West and subsequent fire suppression starting in the early 1900s, fuels accumulated in forested lands. The accumulation of fuels has resulted in more frequent high-intensity, stand-replacing forest fires than before the early 1900s (Caldwell et al., 2002).

Fire may adversely affect the physical, biological, and chemical aspect of forested systems, depending on the intensity and duration of the heat produced, the degree of biotic destruction, and climatic conditions at the time of fire (Neary et al., 1999). DeBano et al. (1998) have shown that a moderate to severe fire can result in soil surface temperatures greater than 500°C and temperatures greater than 400°C at a 25-mm depth, which can oxidize and volatilize essential plant elements. Soil productivity as well as stream-water quality can thus be adversely affected by fire (Belillas and Feller, 1998).

Soil organic matter has a great capacity for cation adsorption in mineral soils. Fire, especially of high severity or long duration, can result in volatilization of nutrients held on the exchange sites of organic matter. The amount of nutrients lost due to soil heating is dependent on the depth of penetration of volatilizing temperatures. Soil organic matter can begin to be lost at temperatures below 100°C while 85% can be lost at temperatures of 200 to 300°C (DeBano et al., 1998). Nutrients with low volatilization temperatures, notably N and S, can be lost at relatively low temperatures as well. Whereas S can be volatilized at 300°C, N can begin to volatilize at temperatures as low as 200°C (Fisher and Binkley, 2000). Because most soil N is contained in organic matter, the amount of N lost by volatilization is very closely related to the amount of organic matter lost (DeBano et al., 1998). Those nutrients with high volatilization temperatures (i.e., >1000°C), such as Ca, K, and Mg, are usually incorporated into ash (Covington and Sackett, 1984; Fisher and Binkley, 2000). These nutrients may thus show an increase in concentration at or immediately below the soil surface where they are subject to movement by wind and/or water erosion (Wells et al., 1979).

After severe fire, the loss of plant nutrients and destabilization of soils can inhibit plant regeneration resulting in increased runoff and erosion. The greater the soil heating, the slower the recovery of vegetation and organic matter pools, which are essential for reducing erosion potential on bare soil. Detrimental changes in soil characteristics such as water holding capacity, porosity, and infiltration rate can result in decreased ecosystem sustainability (Neary et al., 1999). Surface runoff can increase by as much as 70% when less than 10% of the soil surface is covered with plants and litter. Erosion can be three or more times greater in burned areas (Robichaud et al., 2000). Severe fire can also cause vaporization of organic substances in the upper soil layers. These substances then move downward in the soil and condense in the cooler underlying layers, causing a temporary (one to three years) water-repellent layer at that depth. The more severe the fire, the deeper in the soil the water-repellent layer develops. Coarse soil textures also can result in a deeper water-repellent layer. Once a water-repellent layer is formed, water can only infiltrate the soil to that point (DeBano et al., 1998). Thus, intense and/or prolonged rainstorms can cause signifi-

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Abbreviations: Metro, Metro Wastewater Reclamation District (Denver, CO).

cant runoff, which in turn can lead to extensive erosion. Areas that have experienced substantial erosion due to fire are less productive and become difficult sites for vegetation establishment. Additionally, due to the immediate increase in available N (NH_4–N) and a decrease in soil organic matter, annual plant species may invade the site (Hobbs, 1991). If remediation of these lands is not attempted, the effects of fire and flooding may cause long-term degradation of plant community productivity, soil stability, and water quality.

Rehabilitation of ecosystems using biosolids is common. Research has been conducted on the effects of municipal biosolids application as fertilizer and soil amendment on forest and agricultural lands since the 1970s. Several studies have shown that biosolids significantly increased total forest production (Cole et al., 1986; Harrison et al., 2002; Luxmoore et al., 1999; Binkley, 1986). Biosolids can improve soil structure, increase soil water retention and nutrient levels, and enhance root penetration (Rigueiro-Rodriguez et al., 2000). A study by Jurado and Wester (2001) found that biosolids not only increased forage production, but improved forage quality as well. Accompanying this increase in production would be an increase in total leaf area, which is important in reestablishing pre-fire hydrologic conditions to burned sites (Fisher and Binkley, 2000). Biosolids has been shown to alleviate erosion when applied to land degraded by mining activities (Sort and Alcaniz, 1996). Meyer et al. (2001) found that increased vegetative cover due to biosolids application reduced sediment yield from runoff in the Buffalo Creek wildfire area. Other studies have shown that biosolids can increase biomass production on over-grazed rangelands and semiarid shrublands, as well as on desert areas (Pierce et al., 1998; Harris-Pierce et al., 1993; Jurado and Wester, 2001).

Forest ecosystems are commonly limited by N (Henry and Cole, 1994; Newland and DeLuca, 2000; Caldwell et al., 2002). Biosolids supply N over an extended period, commonly one to two years, through mineralization of the organic nitrogen, depending on the form of the biosolids applied and other environmental factors (Cowley et al., 1999; Gilmour et al., 1996; White et al., 1997; Zebarth et al., 2000).

Past biosolids research has focused on application rates that not only enhance forest productivity, but also supply macro- and micronutrients (Harrison et al., 1996; Aschmann et al., 1990). Greenhouse experiments have shown that biosolids can increase the rate of vegetation recovery of burnt soils (Villar et al., 1998). However, no available research has focused on the application of biosolids for post-fire forest rehabilitation.

Our objective was to determine the effects of a one-time application of up to 80 Mg dry composted biosolids ha^{-1} on ecosystem recovery as measured by changes in plant canopy cover, biomass production, plant tissue and soil concentrations of N, P, and Zn, and total soil C and N contents at the Buffalo Creek wildfire site. We hypothesized that the use of biosolids on this severely burned site would result in accelerated seeded grass growth. We predicted that the addition of biosolids would increase plant biomass production because similar post-fire sites are usually nutrient limited for optimum plant growth. A second prediction was that biosolids would increase plant concentrations of N, P, and Zn and total soil C and N content because biosolids contain substantial amounts of these elements relative to post-fire surface soil horizons.

MATERIALS AND METHODS

The study was conducted at the 1996 Buffalo Creek wildfire site in Pike National Forest approximately 45 km south-southwest of Denver, CO. The site is located at 39°22′4.4″ N, 105°14′26.5″ W at an average elevation of 2235 m. Mean annual precipitation at the site is 520 mm and mean annual temperature is 8°C. Nearly 75% of the annual precipitation occurs in spring or summer, while fall and winter months are drier (Marr, 1967). The Buffalo Creek wildfire of May 1996 was a high-intensity, fast-moving, stand-replacing crown fire that burned approximately 4900 ha of forested land. The predominant tree species in the Buffalo Creek area are ponderosa pine (*Pinus ponderosa* D.&C. Laws. var. *scopulorum* Engelm.), a fire-adapted species, which is associated with Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco.), a non-fire-adapted species, and an understory of fire-adapted species that depend on specific fire regimes for regeneration, disease and pest control, and ecological succession. However, because this was a high-burn-severity fire, as indicated by complete destruction of the litter and duff, all plant cover was destroyed, and a strong water-repellency layer formed, leaving the site susceptible to erosion and further degradation. Two months following the fire, the site received high-intensity rainfall in a short period from a localized thunderstorm. Local news reported subsequent erosion and flooding caused two deaths and more than $5 million in property damage as well as losses of valuable topsoil. Even though fire is a natural part of these ecosystems, unprotected slopes on burned areas can result in catastrophic events.

Soils at the study site are developed from Pike's Peak granite, and are contained in the Sphinx soil series (USDA Forest Service and Soil Conservation Service, 1983). These soils are typically up to 25 cm deep, well drained, have low water holding capacity, gravel content of 15 to 75%, are slightly acidic to neutral pH, and exhibit a low shrink–swell potential. The A horizon is generally at 0 to 10 cm and consists of dark brown, gravelly coarse sandy loam. The AC horizon at 10 to 25 cm is yellowish brown, very gravelly loamy coarse sand. The Cr horizon is from 25 to 150 cm and consists of weathered granite. Typical slopes at the site range from 25 to 50%.

Dominant late successional vegetation of these soils is typically ponderosa pine and Douglas-fir with an understory of kinnikinnick [*Arctostaphylos uva-ursi* (L.) Spreng.], common juniper (*Juniperus communis* L.), Fendler's ceanothus (*Ceanothus fendleri* Gray), and mixed perennial grasses and forbs. Average annual understory production of dried plant biomass ranges from 17 to 34 g m^{-2} (USDA Forest Service and Soil Conservation Service, 1983).

The study site contains a total of 24 treatment plots, each 300 to 500 m long and 3 m wide, with a distance of approximately 15 m between each plot. The experimental design was completely randomized with four replicates of six treatments for a total of 24 plots. Metro Wastewater Reclamation District (Metro) used a Fiatallis (Carol Stream, IL) 21C bulldozer along the contours to prepare the plots so that the biosolids could safely be applied; very little soil disturbance occurred during this phase. Plots either received no biosolids (control) or composted biosolids (5, 10, 20, 40, or 80 dry Mg ha^{-1}) from Metro in May 1997. Metro's compost is a mixture of anaerobically digested centrifuged biosolids, fresh wood products, and recycled compost. Composting occurs in a static aerated pile for greater than 28 d. Metro's compost meets USEPA 40 CFR 503's Table 3 and Class A requirements. The nutrient and trace metal composition of these biosolids is presented in Table 1. Composted biosolids application was accomplished using Metro's calibrated Morlang rear-discharge spreader. Biosolids were incorporated in the soil to a depth of 10 to 20 cm with a 4.0-m-wide Domries (Madera, CA) disc with 0.9-m-diameter discs at 1340 kg m^{-1}. Control plots were also disced to a depth of 10 to 20 cm. Average soil bulk densities (determined in 2000) were 1.4, 1.3, 1.4, 1.3, 1.5, and 1.1 g cm^{-3} for the 0, 5, 10, 20, 40, and 80 Mg biosolids ha^{-1} treatments, respectively.

We hand-seeded each plot with a mixture of native grasses at the rate of 27 kg pure live seed ha^{-1} following biosolids application. The seeded species from "The Buffalo Creek Mix" Lot 34071 included slender wheatgrass [*Elymus trachycaulus* (Link) Gould ex Shinners], 23.41% w/w; thickspike wheatgrass [*Elymus macrourus* (Turcz.) Tzvelev], 23.65% w/w; streambank wheatgrass, 14.05% w/w; green needlegrass [*Nassella viridula* (Trin.) Barkworth], 14.49% w/w; mountain brome (*Bromus marginatus* Nees ex Steud.), 9.87% w/w; Canby bluegrass [*Poa canbyi* (Scribn.) Howell], 5.05% w/w; Idaho fescue (*Festuca idahoensis* Elmer), 3.75% w/w; Arizona fescue (*Festuca arizonica* Vasey), 1.01% w/w; undefined crop, 0.98% w/w; non-noxious weed, 0.21% w/w; and inert, 3.53% w/w. After biosolids application, discing, and seeding, a weighted chain link fence was dragged on the surface of all plots to cover the seed and smooth the soil.

We collected plant biomass, plant cover information, and plant tissue samples in July 1998, 1999, 2000, and 2001. We determined aboveground plant biomass using 15 randomly placed 0.5-m^2 quadrats in each treatment plot. An additional four reference plots located between treatment plots were sampled beginning in 1999. Plant biomass was harvested at ground level in each quadrat, separated by species, and placed in labeled paper bags. Following field collection, harvested plant material was oven-dried at 60°C until constant mass, and then weighed.

Plant canopy cover was determined by species using randomly placed 100-m line transects in each plot and reference area. Plant cover was measured at 1-m intervals (100 points per transect) by the categories; plant species, bare ground, litter, and rock (Bonham, 1989). We collected plant tissue samples of the dominant species, streambank wheatgrass, and analyzed the samples for N content using a LECO (St. Joseph, MI) 1000 CHN auto analyzer (Nelson and Sommers, 1996). Streambank wheatgrass tissue samples were also analyzed for P and Zn using HNO_3 digestion (Ippolito and Barbarick, 2000) followed by analysis by inductively coupled plasma atomic emission spectroscopy (ICP–AES; USEPA, 1986).

Composited (three to five random samples per plot; individual samples were taken at 100-m intervals) soil samples were collected from 0 to 7.5, 7.5 to 15, and 15 to 30 cm in 1997 (two months following biosolids application) through 2001 in each plot and placed in plastic sealable bags. The soil samples were composited by volume, sieved (<2 mm), and air-dried following the sampling event. We determined sieved total soil C and N by using a LECO 1000 CHN auto analyzer (Nelson and Sommers, 1996).

All plant parameters were compared with control plots (no biosolids applied) for all years using standard analysis of variance procedures (SAS Institute, 2001). We analyzed the effects of biosolids on total soil C and N for each sampling and each depth using linear regression analyses.

Table 1. Nutrient and trace metal composition (dry weight basis; USEPA, 1986) of Metro Wastewater Reclamation District composted biosolids applied to the Buffalo Creek wildfire site, May 1997.

Constituent	Value
	g kg^{-1}
Organic N	51.0
NH_4–N	5.22
NO_3–N	0.45
Na	0.90
K	3.6
P	32.0
Al	14.0
Fe	10.0
	mg kg^{-1}
Ag	22.2
As	3.1
Hg	1.6
Se	1.6
Pb	74.5
V	14.3
Cu	386
Zn	490
Ni	63.9
Mo	15.9
Cd	3.9
Cr	134
Sr	211
B	33.5
Ba	338

RESULTS AND DISCUSSION

Plant biomass production increased with increasing application rates of biosolids all four years of the study (Fig. 1). For 1998, highest production was 222 g m^{-2} on plots with the highest application rate of biosolids, in 1999 production in the same plots was 202 g m^{-2}, in 2000 total production was 100 g m^{-2}, and in 2001 production at the highest treatment rate was 76 g m^{-2}. All biomasses for all years and all treatments exceeded the understory biomass production of 17 to 34 g m^{-2} reported by the USDA Forest Service and Soil Conservation Service (1983). Maximum total biomass for all years occurred at the highest treatment rate. Increasing biomass production with increasing biosolids rate is similar to the results reported by Fresquez et al. (1990) on a degraded plant community in New Mexico in which they used biosolids to increase yield and cover of grasses. Navas et al. (1999) reported that productivity increased significantly with increasing biosolids addition on semiarid degraded lands in Spain. Nutrients added to the soil by biosolids application, especially N and P, can favor biomass production. Redente et al. (1984) reported that moderate fertilization rates of N and P improved the production of grasses on a disturbed site in northwestern Colorado.

All treatment plots showed a similar decline in total production that averaged 13% from 1998 to 1999, 49% from 1999 to 2000, and 40% from 2000 to 2001. A portion of the biomass decline over time is probably due to the mineralization of biosolids and the depletion of N and P. Additionally, the study site received below-normal precipitation from late June through mid-July 1999. In 2000, the May, June, and July growing season precipitation was only 58% of normal, while rainfall in July 2001 was 61% of normal (Colorado Climate Center,

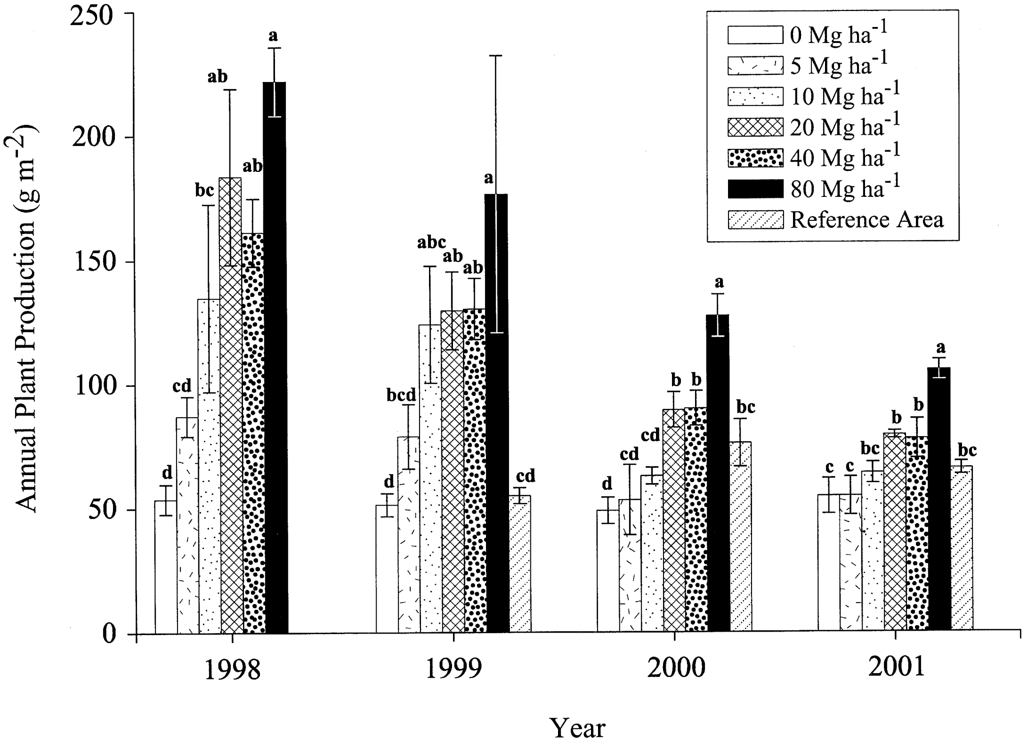

Fig. 1. Mean annual plant production in post-fire study plots at the Buffalo Creek wildfire site amended with biosolids and adjacent intra-plot reference areas. Thin bars represent the standard errors of the means (*n* = 4). Letters above the bars indicate significant differences between treatments within a year as indicated by a Fisher's least significant difference test. Reference areas were not sampled in 1998.

2002; Moody and Martin, 2001). Because sampling took place during the period of peak production, which is late July at this elevation in Colorado, it is likely that the lack of moisture during the growing season contributed to this decline. In their study of drought effects on dry matter production in Africa, Moolman et al. (1996) reported that drought stress induced by 15 d without water resulted in production declines ranging from 35 to 78%. A biosolids study by Benton and Wester (1998) concluded that a decline in production of two grasses was due to below-average rainfall.

Seeded grasses generally accounted for more than 90% of total biomass production during the study (Fig. 2). Streambank wheatgrass was the most responsive species to the application of biosolids. Forb and shrub production were not significantly altered with increased biosolids application rates in the seeded plots during any of the four years. Doerr et al. (1983) reported that lack of response by forbs in fertilized seeded plant communities was a result of increased grass competition resulting from higher N availability.

Despite the elevated nutrient status of the biosolids-amended soils in this study, we did not observe an increase in invasive plant species (Fig. 3); this may have been from several environmental factors including increased competition from seeded grasses. Four years after composted biosolids amendments, there was significantly more invasive species biomass in the control plots relative to the 10, 20, or 80 Mg ha^{-1} biosolids treatments. Total plant cover generally increased with biosolids application rates in three of the four years (Fig. 4). In 2001, plant cover was highest at the application rate of 40 Mg ha^{-1}. Canopy cover of forbs and shrubs showed no change with increasing application rates of biosolids in any year (Meyer, 2000). Biosolids did not significantly influence plant cover in 2000, three years following application. Again, in part due to the significant decrease in late growing season precipitation from 1998 to 2001, plant growth was restricted. Litter accumulated in each of the years (data not shown); consequently, percent bare ground decreased with increasing biosolids rates in all four years (Fig. 5).

Plant tissue N and P concentrations of streambank wheatgrass increased with increasing application rates of biosolids in 1998 (Fig. 6). Because biosolids contain plant-available N and P, this increase in plant-tissue nutrient concentration was expected. Increases in tissue concentrations of nutrients, particularly N and P, can significantly enhance forage quality and improve nutrient cycling. At the higher application rates, biosolids continued to promote elevated tissue N and P concentrations, even after four years (Fig. 6).

Similarly, Zn concentrations of seeded grasses generally increased with increasing biosolids (Fig. 6). According to Kabata-Pendias and Pendias (1984), the deficiency range for tissue Zn is 10 to 20 mg kg^{-1}. In this study, tissue Zn concentrations in unamended control plots were generally within this deficiency range, indicating that the application of Metro biosolids above this rate provided a Zn source that helped correct potential plant Zn deficiency. Tissue Zn concentrations in the biosolids-amended plots were well below the Zn phytotoxicity thresholds for native perennial grasses reported by Paschke et al. (2000).

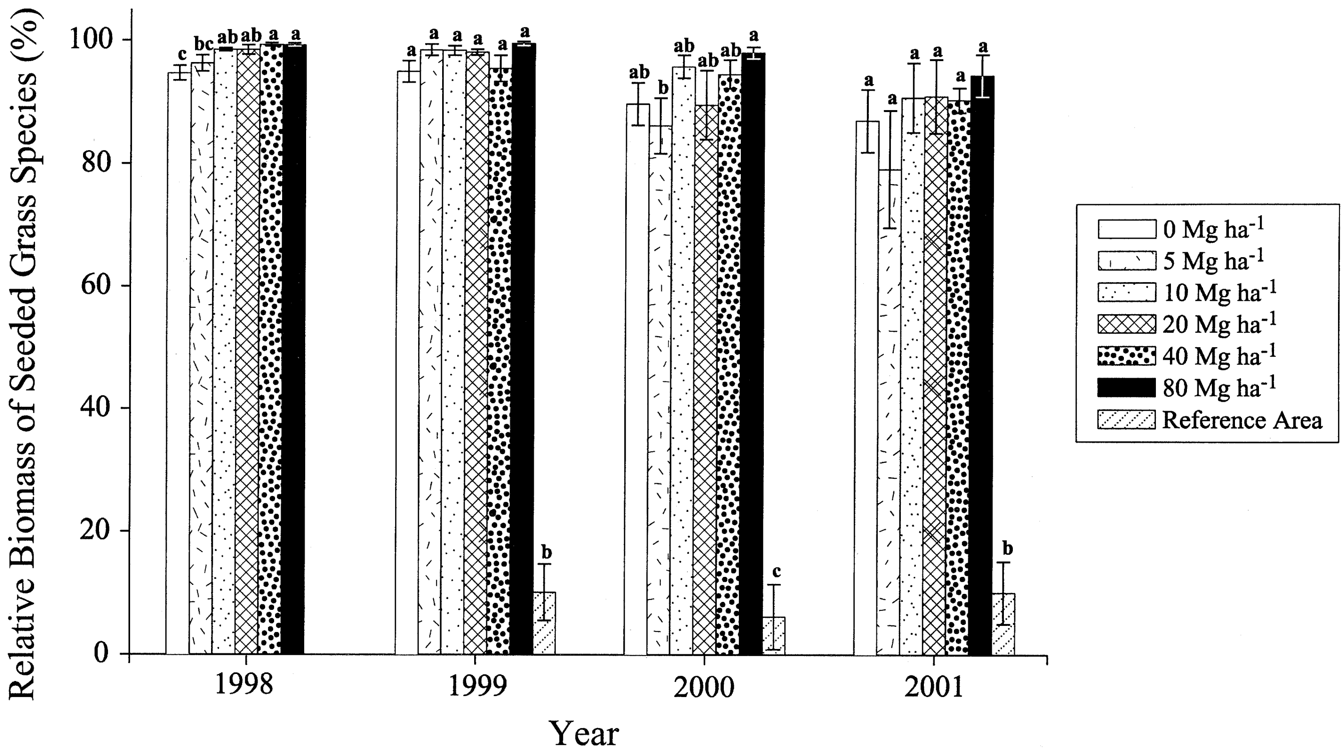

Fig. 2. Mean relative biomass of grass species that were seeded in post-fire study plots at the Buffalo Creek wildfire site amended with biosolids and adjacent unamended (and unseeded) reference areas. Thin bars represent the standard errors of the means (n = 4). Letters above the bars indicate significant differences between treatments within a year as indicated by a Fisher's least significant difference test. Reference areas were not sampled in 1998.

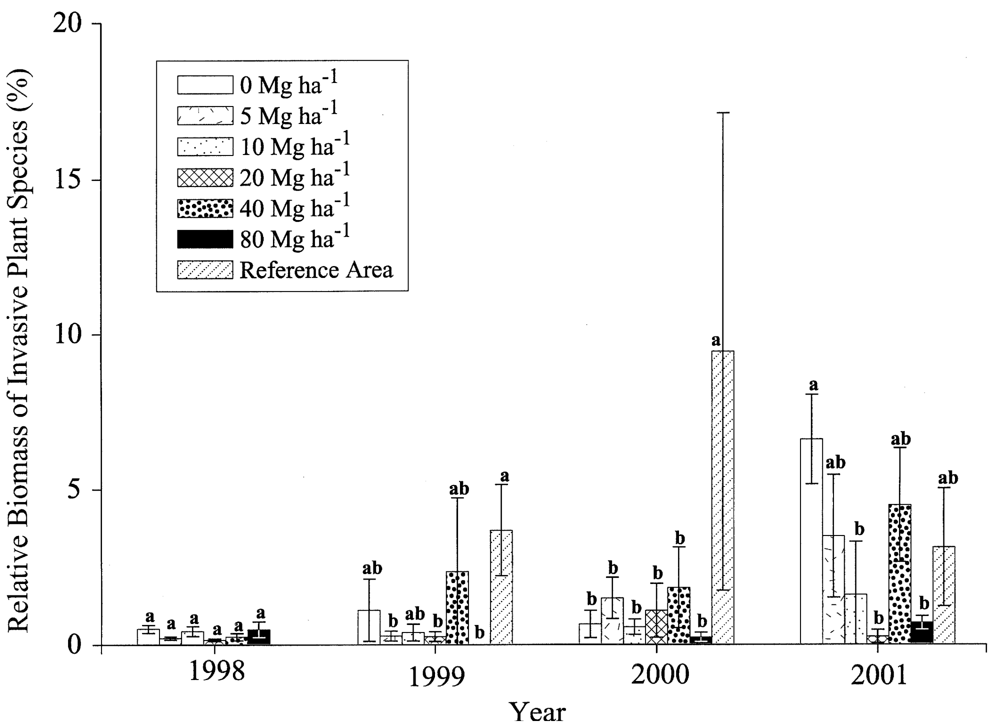

Fig. 3. Mean relative biomass of invasive plant species in post-fire study plots at the Buffalo Creek wildfire site amended with biosolids and adjacent unamended reference areas. Thin bars represent the standard errors of the means (n = 4). Letters above the bars indicate significant differences between treatments within a year as indicated by a Fisher's least significant difference test. Invasive species are those defined as such by USDA Natural Resources Conservation Service (2002). Reference areas were not sampled in 1998.

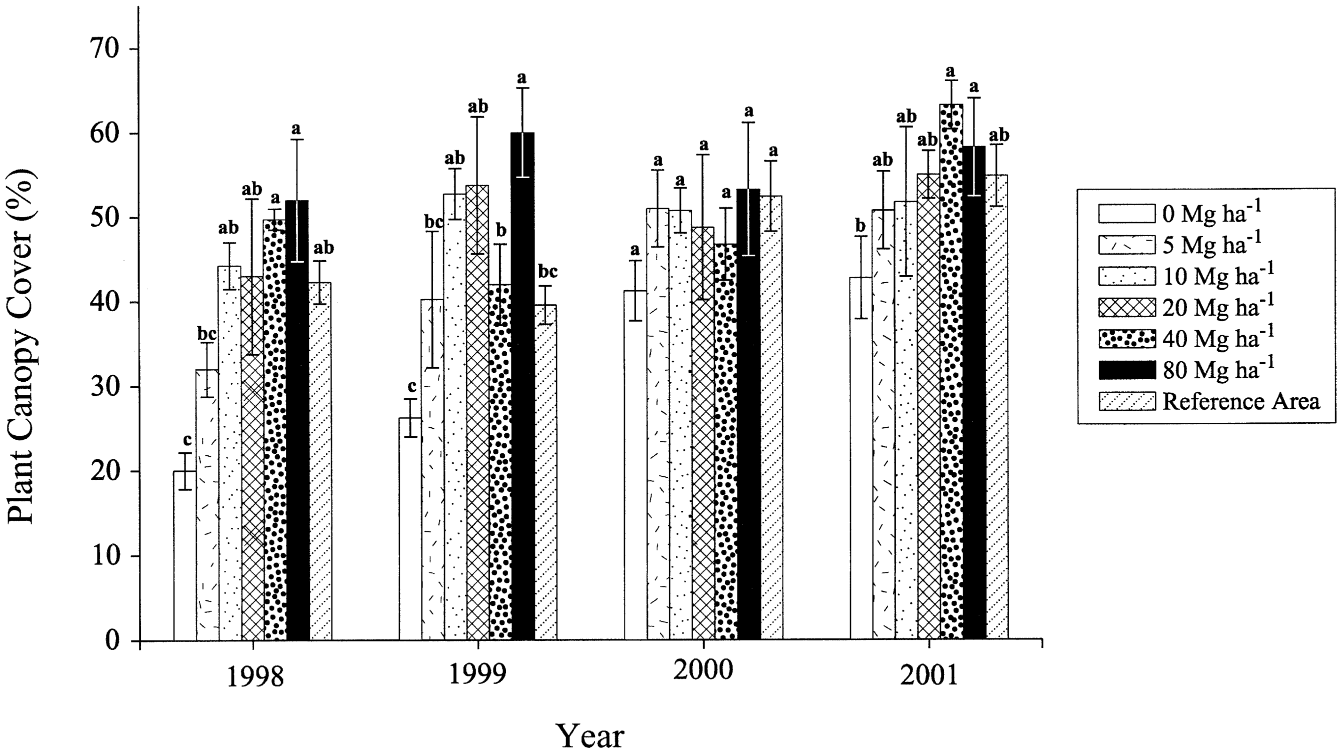

Fig. 4. Mean percentage of plant cover in post-fire study plots at the Buffalo Creek wildfire site amended with biosolids and adjacent unamended reference areas. Thin bars represent the standard errors of the means (n = 4). Letters above the bars indicate significant differences between treatments within a year as indicated by a Fisher's least significant difference test.

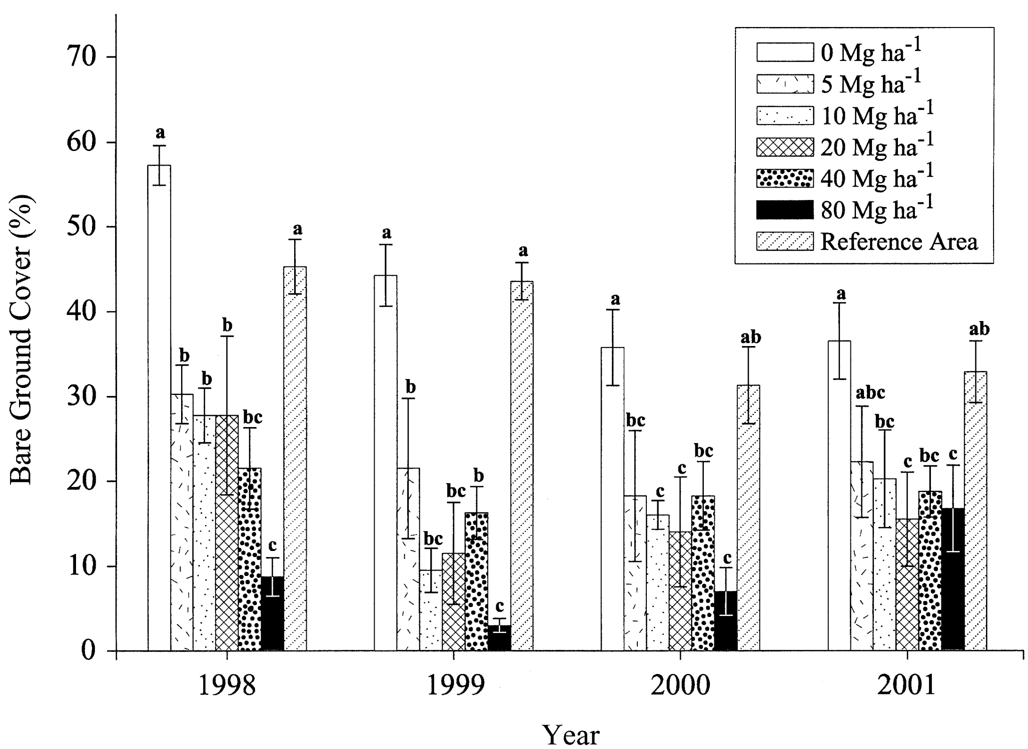

Fig. 5. Mean percentage of bare ground in post-fire study plots at control and biosolids-amended post-fire study plots at the Buffalo Creek wildfire site and adjacent unamended reference areas. Thin bars represent the standard errors of the means (n = 4). Letters above the bars indicate significant differences between treatments within a year as indicated by a Fisher's least significant difference test.

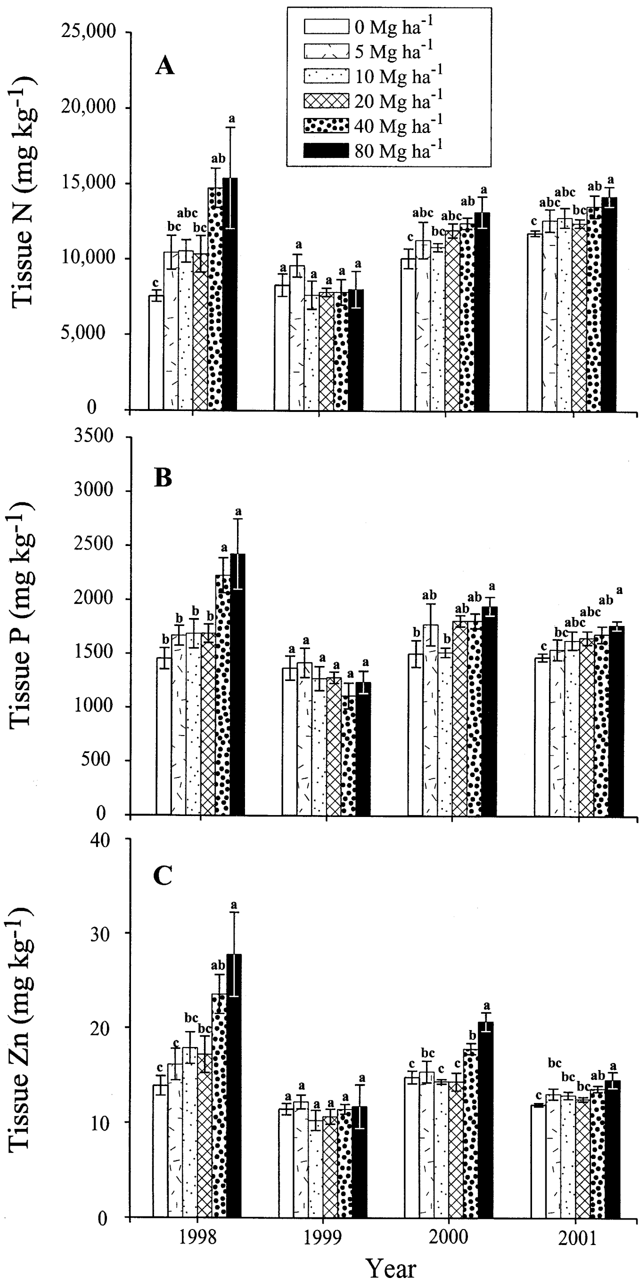

Fig. 6. Mean concentration of (A) nitrogen, (B) phosphorus, and (C) zinc in the aboveground tissue of streambank wheatgrass collected from control and biosolids-amended post-fire study plots at the Buffalo Creek wildfire site. Thin bars represent the standard errors of the means (n = 4). Letters above the bars indicate significant differences between treatments within a year as indicated by a Fisher's least significant difference test.

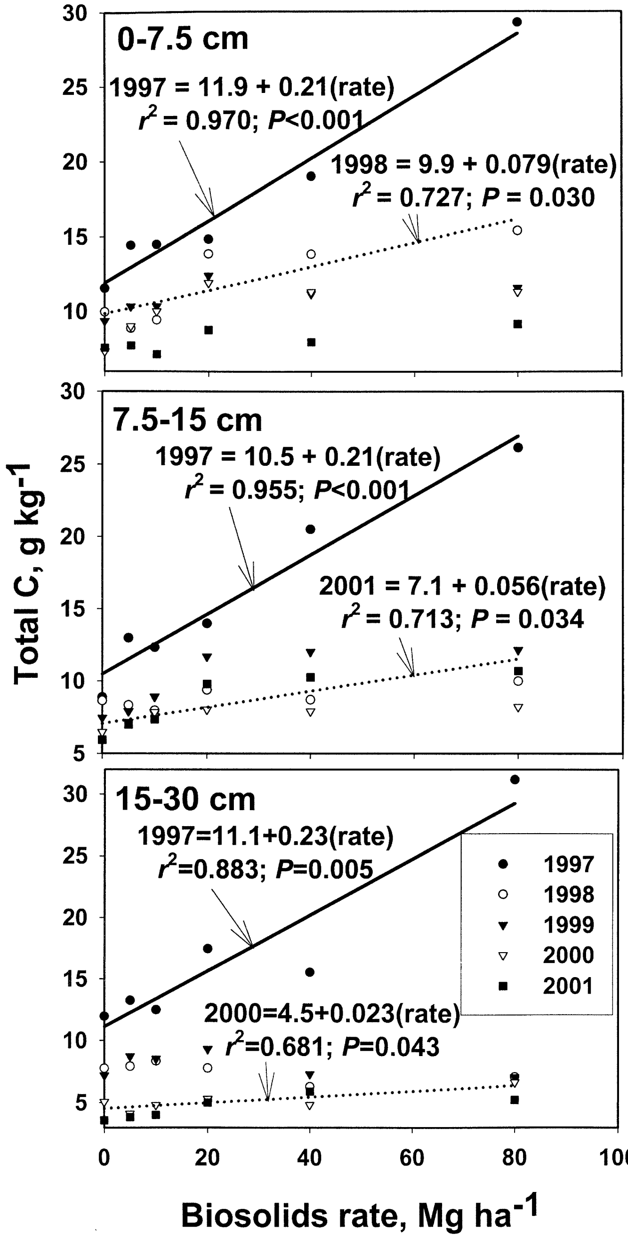

Fig. 7. Total soil C concentration for the 0- to 7.5-, 7.5- to 15-, and 15- to 30-cm depths in control and biosolids-amended post-fire study plots at the Buffalo Creek wildfire site for 1997 through 2001. Significant (P < 0.05) regression curves and equations are illustrated for each depth and year.

As shown in Fig. 7, total C increased significantly ($P < 0.05$) at two months (1997) following treatment in all three sampling depths as biosolids rate increased. The C additions were 0, 1.6, 3.3, 6.5, 13.0, and 26.1 Mg ha^{-1} for the 0, 5, 10, 20, 40, and 80 Mg biosolids ha^{-1} rates, respectively. We did not complete a C mass-balance budget in 1997 because we did not have the associated bulk densities for each plot. We could not follow the mass of C losses over time since bulk density varied within plots and changed each year, and we only had detailed bulk density values for 2000. The 1997 regression analyses, however, indicate a close association between biosolids rate and C content in the top 30 cm of soil. We observed a significant biosolids-rate effect in 1998 at 0 to 7.5 cm, in 2001 at 7.5 to 15 cm, and in 2000 at 15 to 30 cm. After 1997, however, we did not find consistent trends at any depth. Apparently, the biosolids C additions had undergone mineralization.

The total N regression analyses for all depths (Fig. 8) paralleled the total C results (Fig. 7) at two months following treatment. The N additions were 0, 0.095, 0.190, 0.380, 0.760, and 1.52 Mg ha^{-1} for the 0, 5, 10, 20, 40, and 80 Mg biosolids ha^{-1} rates, respectively. We

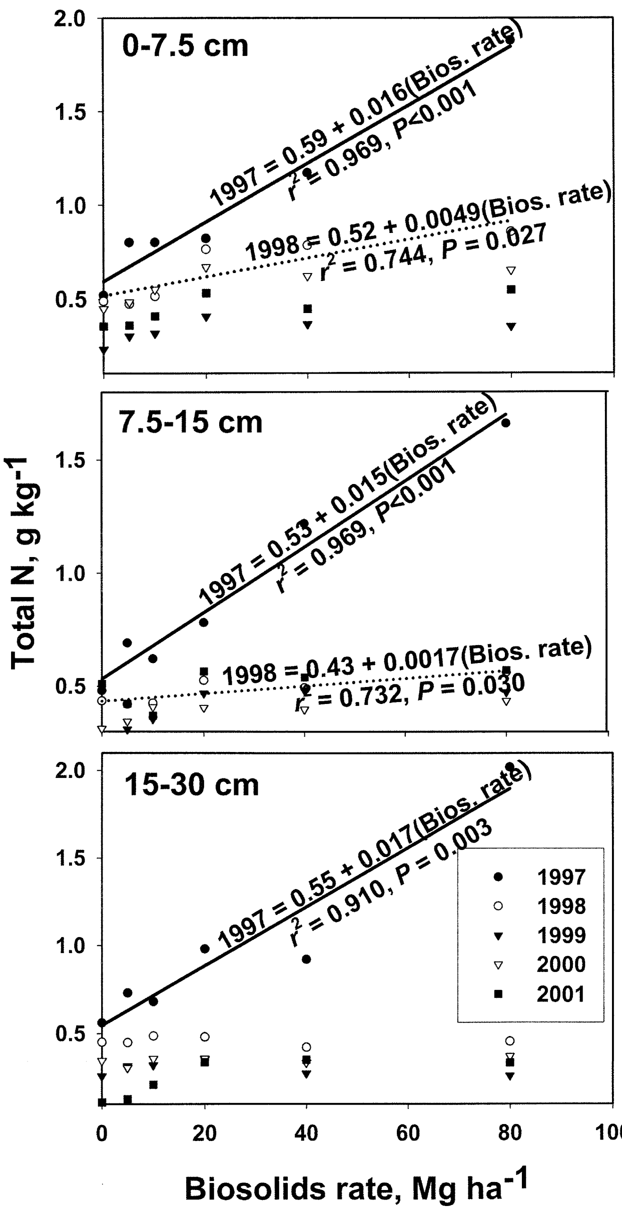

Fig. 8. Total soil N concentration for the 0- to 7.5-, 7.5- to 15-, and 15- to 30-cm depths in control and biosolids-amended post-fire study plots at the Buffalo Creek wildfire site for 1997 through 2001. Significant ($P < 0.05$) regression curves and equations are illustrated for each depth and year.

found significant biosolids effects for the 1998 total N in the top two soil depths. After 1998, biosolids ceased to influence the total N content at any depth. Again, it seems that the N declined because of mineralization. As mentioned for total soil C, we could not complete a N mass-balance budget. The 1997 regression analyses, however, again illustrated a significant relationship between biosolids rate and total N.

CONCLUSIONS

Application of composted biosolids to the Buffalo Creek wildfire study plots in 1997 produced significant increases in plant biomass. The highest biosolids rate (80 Mg ha^{-1}) increased plant biomass production relative to the untreated, unfertilized control (0 Mg ha^{-1}) in all years of the study. Biosolids were also associated with an initial increase in plant cover and longer-term (four-year) decrease in percentage of bare ground. Increases in plant biomass and cover associated with biosolids were attributed largely to responses by the seeded grass species, and most notably in streambank wheatgrass. These changes in the plant community corresponded with increases in soil C and N with increasing biosolids application.

Significant increases in biomass production and reductions in percent bare ground generally occurred with biosolids application rates of 20 to 40 Mg ha^{-1}. To provide effective plant growth and soil cover, we recommend application rates of 20 to 40 Mg biosolids ha^{-1}. The increase in productivity and cover resulting from the use of biosolids can aid in the rehabilitation of wildfire sites and reduce soil erosion in ecosystems similar to the Buffalo Creek area.

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