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Establishment of Grasses on Sewage Sludge-Amended Strip Mine Spoils

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Abstract. Usefulness of native prairie and domesticated grasses in revegetating strip mine spoil and producing biomass was examined on 30-year old, recontoured spoil banks located near Canton, Illinois. Grasses were planted in the spring and fall on strip mine spoil and spoil amended with 333 MT/ha of dry sewage sludge. By the end of the second growing season, indiangrass [*Sorghastrum nutans* (L.) Nash] produced more biomass than the other warm-season grasses, switchgrass (*Panicum virgatum* L.) and little bluestem [*Schizachyrium scoparium* (Michx.) Nash], on the unamended plots, and no warm-season grasses survived on the sludge amended plots. Warm-season grasses were able to compete with weedy species on unamended sites, but two cool-season grasses, reed canarygrass (*Phalaris arundinacea* L.) and Kentucky 31 tall fescue (*Festuca arundinacea* Schreb.), produced more biomass on amended sites than on unamended sites.

Key Words. strip mine spoils, prairie, sewage, sludge, grasses, biomass, Illinois

INTRODUCTION

Strip mining removes topsoil, subsoil, and bedrock material overlying coal seams. Mine spoils, produced prior to the Federal Surface Mining Control and Reclamation Act of 1977, were usually an uneven mixture of consolidated (bedrock) and unconsolidated (till and loess) overburden with no definite soil profile (Ashby *et al.* 1979). Thus, the resulting spoil surface was low in organic matter and essential nutrients, such as nitrogen, potassium, and phosphorous (Richardson and Evans 1986). Major problems associated with revegetating strip mined soils are 1) substrate pH that was often either excessively high (> 10.0) or low (< 4.0) for vegetation establishment (McGuire et al . 1983, Shuman 1986); 2) high soil temperature and low soil moisture during germination and seedling growth (Bell and Ungar 1981, Jastrow *et al.* 1984); and 3) high concentration of soluble salts in the spoil that inhibited revegetation (Jastrow *et al.* 1984, Stark and Redente 1985, Smith *et al.* 1986).

Sewage sludge has been shown to improve many physical and chemical properties of mine spoils. Sludge added essential nutrients for plant growth, increased the humus content and water holding capacity (Epstein 1975, Joost *et al.* 1987), improved the pH of spoils (Epstein 1975, McGuire *et al.* 1983), and generally enhanced plant growth (Anderson and Birkenholz 1983, Joost *et al.* 1987). However, sludge often contained heavy metals (Zn, Cu, Cr, Ni, Pb, and Cd) which could accumulate in soil or plant tissues (Pietz *et al.* 1983).

Native prairie grasses may be excellent plants for spoil reclamation, but their potential use in mine spoil reclamation has been analyzed by relatively few workers (Schramm and Kalvin 1978, Master and Taylor 1979, Anderson and Birkenholz 1983, Kuenstler *et al.* 1983, Jastrow *et al.* 1984, Bonfert *et al.* 1986). Roots of some prairie grasses penetrate the soil to a depth of 200 cm or more and increase soil friability (Hole and Nielsen 1970). Two-thirds of the prairie biomass is below ground (Risser *et al.* 1981), and as roots and other underground organs decay *in situ* they increase the organic matter content of the soil (Hole and Nielsen 1970). The aboveground parts of the plants also form a protective cover that retard runoff and conserve soil moisture, and they have the potential to yield large quantities of biomass (Old 1969, Risser *et al.* 1981, Anderson 1985).

Prairie grasses are usually planted in spring or early summer so the soil can be worked late in the spring to control cool-season weeds (Schramm 1970). Also, prairie grasses do not have vigorous growth until later in the growing season (Wilson 1970). Strip mine spoils often become dry by early summer making grass establishment difficult. Schramm and Kalvin (1978) and Anderson and Birkenholz (1983) suggested that seeds be planted in the late fall or early spring rather than late spring or early summer to avoid the severe summer drought effects which occur on strip mined land.

METHODS

Description of Study Site

Study plots were established on a strip mine spoil site (6,289 hectares) owned by the Metropolitan Sanitary District of Greater Chicago near Canton in west-central Illinois. The spoil banks were about 30-years old but were recontoured before the experimental work was started. Mean annual precipitation was about 96.5 cm. Dry sewage sludge was applied at a rate of about 333 MT/ha and worked into the top 15 cm of spoil by use of a disk on one-half of the research plots during the year (1979) before the fall planting. The seed beds were prepared by disking prior to planting.

Plant and Sampling of Biomass

Four planting treatments were established: unamended-fall, amended-fall, unamended-spring, and amended-spring. Five grass species: three native prairie, warm-season grasses, switchgrass (*Panicum virgatum* L.), little bluestem [*Schizachyrium scoparium* (Michx.) Nash], and indiangrass [*Sorghastrum nutans* (L.) Nash]; and two cool-season, domestic grasses, reed canarygrass (*Phalaris arundinacea* L.) and Kentucky 31 tall fescue (*Festuca arundinacea* Schreb.), and a mix of the three prairie grasses were planted in separate subplots (13.5 x 30 m) within each treatment plot. There were four replicates of each treatment. Fall and spring planting occurred on 1 November 1980, and 1 and 2 June 1981, respectively. Seed, purchased from a commercial grower in Nebraska, was hand broadcasted at a rate of about 495 live seeds/m^2 (Table 1).

Table 1. Seeding rates (kg/ha) for the grass species in monoculture and mixed plantings of field study.

seeding rate	*Monoculture seeding rate*	*Mixed*
	kg/ha	
Kentucky 31 fescue	8.9	—
Reed canarygrass	7.1	—
Switchgrass	7.1	2.4
Indiangrass	11.2	3.7
Little bluestem	15.4	5.1

During the first growing season, planting success was monitored by counting seedlings of weeds and prairie grasses in 30 quadrats (25 x 25 cm) that were randomly located in each subplot. Aboveground biomass production was estimated using 5 clip quadrats (25 x 25 cm) harvested from each subplot once a month during the first (1981) and second (1982) growing seasons. Tissue samples were oven dried at 70-80 C for 48 hours and then sorted into planted grasses and weeds and weighed. During the first growing season, plots were mowed after each month's sampling to simulate biomass harvest and to also control weeds. During the second growing season, the plots were mowed only after the June sampling period, except one-half of the amended plots were not mowed at all during the second growing season. Only data from mowed plots are presented.

Soil Analyses

pH, organic matter, available P, K, Ca, and Mg, and total N.

At the end of each growing season (fall 1981 and 1982) and at the time of fall planting (1980), soil samples were obtained at two depths (0-15 cm and 15-30 cm) from each plot. Each treatment sample was a composite of two to three soil cores randomly collected from each subplot. Samples were air dried, ground, and analyzed by the Soil and Plant Analysis Laboratory of the University of Wisconsin for pH, organic matter, available P (Bray No. 1), K, Ca, and Mg, and total N (Liegel and Schulte 1977). Soil texture was determined by using the Bouyoucos Hydrometer Method (Bouyoucos 1951).

Electrical conductivity.

Soil samples were collected randomly at two depths (0-15 cm and 15-30 cm) from each plot for determination of electrical conductivity. Electrical conductance of soil solution extracts was measured according to the procedure for analyzing mine soils used by the U.S. Environmental Protection Agency (Sobek *et al.* 1978). The amount of dissolved salts in the extract was approximately proportional to the amount of electrical current conducted through the extract.

RESULTS

First Growing Season

A three-way ANOVA was used to compare seedling counts by season (spring *vs.* fall planting time), substrate (strip mine spoil *vs.* amended spoil), and species. The only significant difference in seedling counts was due to substrates. Significantly ($p < 0.05$) more seedlings were counted in the unamended strip mine spoil (mean ± s.d. for all species and seasons = 56.5 ± 33.4) than in the amended spoil (mean ± s.d. = 17.0 ± 13.5).

Biomass was sampled once a month during the first growing season (June through September 1981), but only the results from the end of the growing season (September) were used to illustrate these data. A three-way ANOVA by season, substrate, and species was performed on the planted species biomass data from the end of the first growing season. Significant effects on biomass production were attributable to species, but no other main effects, substrate or season, were significant. Significant two-way interactions occurred between season (planting time) and species. All other two-way interactions and the three-way interactions were not significant.

No significant differences occurred in mean biomass across substrate and season (mean ± s.d.) among the three warm-season grasses (indiangrass, 19.34 ± 32.19; switchgrass, 32.16 ± 55.47; and little bluestem, 23.85 ± 36.53), and the mixed plantings of these three species (45.61 ± 59.07). No significant differences occurred between the two cool-season species (fescue, 118.24 ± 94.08; and reed canarygrass, 80.21 ± 52.68), or between reed canarygrass and the mixed planting of warm-season grasses. However, mean biomass of fescue was significantly greater than that of the warm-season species and the mixed plantings of these species (Rodgers 1987).

A two-way ANOVA (planting season, substrate) was performed on the total biomass (planted species plus weedy species) at the end of the first growing season (September, 1981). There were significant main effects due to substrates, but not season. The two-way interactions were not significant. The treatments having strip mine spoil amended with sludge produced a significantly greater amount of total biomass than the unamended strip mine spoil (416.29 ± 254.28 *vs.* 210.32 ± 147.40 mean ± s.d.). However, on the amended sites a larger proportion of the total biomass (88%) was comprised of weeds than on the unamended sites (73%).

Second Growing Season

Planted species biomass (June).

Three-way ANOVA (season, substrate, species) indicated sig-

Table 2. Average biomass (mean ± s.d., g/m²) (of planted species and weedy species) at the beginning of the second growing season (June 1982) by species and treatment.

	Unamended				*Amended*			
	Spring		*Fall*		*Spring*		*Fall*	
Species	*Planted*	*Weeds*	*Planted*	*Weeds*	*Planted*	*Weeds*	*Planted*	*Weeds*
	gm/m² (s.d.)							
Indiangrass	71.36ab[1] (60.07)	61.44ABC (96.97)	72.48ab (92.28)	130.64CDEF (69.72)	0.48a (2.15)	190.56F (208.90)	2.08a (7.63)	171.84EF (85.26)
Switchgrass	107.09abc (112.96)	76.59ABCDE (143.08)	58.40a (45.04)	129.92CDEF (102.70)	10.16a (17.66)	155.04DEF (74.82)	3.44a (6.28)	204.88G (179.94)
Little bluestem	120.00abc (129.42)	59.20ABC (87.44)	72.72ab (64.17)	69.44ABCD (66.22)	7.68a (15.57)	182.80F (106.23)	5.36a (12.45)	195.52F (227.30)
Mixture	132.48abc (97.43)	68.08ABCD (131.72)	40.96a (39.14)	148.32CDEF (117.08)	25.44a (66.19)	174.88F (76.51)	6.16a (13.82)	213.76G (99.65)
Reed canary	252.91cd (92.74)	4.05A (15.70)	222.80bcd (247.58)	82.32ABCDE (135.63)	962.72e (455.18)	14.24A (34.89)	1660.56f (1008.11)	105.44BCDEF (463.66)
Fescue	313.12d (149.75)	20.96AB (34.81)	222.40bcd (139.76)	18.80AB (34.55)	624.80e (361.23)	28.56AB (68.90)	612.96e (245.57)	29.68AB (47.01)

[1]Values followed by the same letter are not significantly ($p < 0.05$) different for all means presented. This comparison was made separately for planted species and weeds as indicated by different case letters.

nificant differences in biomass production of planted species at the beginning of the second growing season (June 1982) due to the main effects of substrate and species, but not season. There was no significant difference in the biomass produced between spring and fall planted plots. All two-way interactions and the three-way interactions were significant.

Cool-season grasses produced significantly more biomass than the warm-season grasses and the mixture for fall-amended and spring-amended treatments. No significant differences occurred in biomass production for any treatment among the warm-season grasses, including the mixture. Reed canarygrass produced significantly more biomass than fescue on the fall-amended plots, but not on the spring-amended or unamended plots (Table 2).

When procedures were used to separate all means (Table 2), there were no significant differences in biomass production among warm-season grass species. This apparently occurs because of the wide range of biomass values (0.48 to 1660.56 g/m²) that results when warm-season and cool-season grasses are considered together. Therefore, the warm-season grass species were compared separately. The unamended-spring treatments of the mixture, little bluestem, and switchgrass produced significantly more biomass than all other warm-season grass species regardless of treatment. Although the spring-amended treatment of indiangrass produced the smallest amount of biomass, it was not significantly different from all other amended treatments. Also, for little bluestem, switchgrass, and the mixture, spring unamended plantings produced significantly more biomass than fall unamended plantings.

Weed biomass (June).

A three-way ANOVA (season, substrate, species) of weedy species biomass in June 1982, revealed that there were significant effects due to substrate, season, and planted grass species with which the weeds were growing. There were no significant two-way or three-way interactions. There was significantly greater weed biomass produced on plots amended with sludge (mean ± s.d. for all species plots and seasons = 138.9 ± 190.2 g/m²) than unamended plots (73.9 ± 102.6 g/m²), and there was also significantly more weed biomass produced in plots planted in the fall (125.0 ± 183.1 g/m²) than in the spring (88.4 ± 121.6 g/m²).

No significant differences occurred in weed biomass production among warm-season grass plots for any of the unamended treatments. On amended plots, cool-season grass plots had significantly less weed biomass than the warm-season grass plots, except for the weed biomass on reed canarygrass fall-amended plots, which was not significantly different from the weed production on indiangrass or little bluestem fall-amended plots. On spring-unamended plots, however, there were no significant differences among species plots (Table 2).

Planted species biomass (September).

Three-way ANOVA (season of planting, substrate, and species) performed on the biomass data of the planted species from the end of the second growing season (September 1982) indicated that there were significant differences among treatments due to the main effects of substrate and species. There was no significant difference in the biomass produced on plots planted in spring or fall. Significant two-way interactions occurred between substrate and species. Three-way interactions were also significant.

No biomass was produced by warm-season grasses on amended plots (Table 3). When the biomass of each species was compared across treatments, two warm-season grasses, indiangrass and little bluestem, produced significantly more biomass on spring-unamended plots than on fall-unamended plots. Switchgrass produced more biomass on the fall-unamended plots than the spring-unamended plots and there was no difference between fall- and spring-unamended plots for the mixture of warm-season grasses. Spring plantings of indiangrass on unamended plots and reed canarygrass on fall-amended plots produced significantly more biomass than all other species plantings on amended and unamended plots.

Cool-season grasses produced more biomass on amended plots than unamended plots. Reed canarygrass fall-amended treatment plots produced significantly more biomass than the other plots of cool-season grasses. For fescue, no differences occurred between fall and spring plantings, but amended plots produced significantly more biomass than unamended plots.

Weed biomass (September).

Three-way ANOVA of the September 1982, data for the biomass of the weedy species growing in the species plots indicated there were significant effects on weed biomass production due to substrate, season, and species with which the weeds were growing. There were significant two-way interactions between substrate and season, substrate and species, and season and species, and significant three-way interactions.

Table 3. Average biomass (mean ± s.d., g/m²) (of planted species and weedy species) at the end of the second growing season (September 1982) by species and treatment.

	Unamended				*Amended*			
	Spring		*Fall*		*Spring*		*Fall*	
Species	*Planted*	*Weeds*	*Planted*	*Weeds*	*Planted*	*Weeds*	*Planted*	*Weeds*
	gm/m² (s.d.)							
Indiangrass	378.48h[1]	109.36AB	268.64g	89.68A	0.0a	950.96G	0.0a	652.24F
	(142.18)	(102.70)	(189.84)	(71.57)	(0.0)	(374.13)	(0.0)	(250.79)
Switchgrass	142.19bcd	39.79A	185.92de	46.48A	0.0a	505.20E	0.0a	905.92G
	(58.52)	(27.86)	(108.90)	(39.38)	(0.0)	(219.94)	(0.0)	(376.67)
Little bluestem	156.50cd	91.76A	83.76b	70.32A	0.0a	484.96E	0.0a	953.44G
	(108.82)	(102.90)	(62.71)	(73.99)	(0.0)	(155.71)	(0.0)	(523.68)
Mixture	94.80bc	76.88A	111.36bc	51.84A	0.0a	905.60G	0.0a	668.40F
	(79.32)	(89.88)	(61.15)	(52.32)	(0.0)	(339.12)	(0.0)	(192.59)
Reed canary	250.40efg	19.84A	192.96def	31.68A	254.24fg	135.12ABC	345.20h	252.40CD
	(122.58)	(40.76)	(102.46)	(46.08)	(147.21)	(80.94)	(185.02)	(216.89)
Fescue	82.24b	54.61A	129.68bcd	48.32A	253.76fg	228.72BCD	230.32efg	319.92D
	(57.97)	(105.31)	(66.34)	(86.39)	(192.03)	(186.24)	(229.32)	(163.75)

[1]Values followed by the same letter are not significantly ($p < 0.05$) different for all means presented. This comparison was made separately for planted species and weeds as indicated by different case letters.

For the spring-unamended and fall-unamended plots, no significant differences occurred in weedy biomass production among species plots, but for the amended treatments there were significant differences between species plots in weedy biomass production (Table 3). For the amended treatments, there was no significant difference in weedy biomass between fescue and reed canary plots, but there was significantly less weedy biomass on these plots than on the warm-season grass plots.

Soils

The strip mine spoils were composed of 16.0% sand, 28.6% silt, and 55.4% clay and are in the clay textural class. Addition of sewage sludge to the strip mine spoil decreased soil pH, and increased organic matter, total nitrogen, and available P, K, Ca, and Mg. Electrical conductivity of soil solution extracts was higher on amended sites at the 0-15 cm depth for two years following sludge amendment, however, it was about the same on amended and unamended sites during the third year (Rodgers 1987). Electrical conductivity was measured for only two years (1981 and 1982) at the 15-30 cm depth. Electrical conductivity was higher on the amended than the unamended site for the first year that measurements were taken at this depth but not the second. The electrical conductivities did not indicate that the field soils had excessively high levels of soluble salts. All of the soluble salt concentrations, except the 1980, amended, 0-15 cm sample and the 1981, amended, 15-30 cm sample, were less than 2 millimhos/cm. Salinity effects of soluble salt concentrations in this range were considered to be mostly negligible (Allison *et al.* 1969). The other two samples were in the 2-4 millimhos/cm range, which only affects yields of sensitive crops.

DISCUSSION

Comparison of Fall and Spring Plantings of Prairie Grasses

It was initially hypothesized that fall plantings of native prairie grass would be more successful than the late spring plantings on strip mine spoil. Fall plantings would become established in the early spring when soil moisture would be in good supply and before moisture supplies were reduced during summer, whereas spring plantings could be subjected to low moisture availability before they were well established. During the first growing season, seedling counts were used as a measure of establishment, but no significant differences occurred in seedling counts between fall and spring plantings. Similarly, analysis of biomass data obtained at the end of the first growing season showed no significant difference between plots planted at different times. The only significant difference between fall and spring planting times was for the weedy biomass produced during the second growing season which was greater on fall-planted plots than on spring-planted plots.

For the planted species, overall there was no significant effect on biomass production due to season of planting, but there were significant three-way interactions between species, planting times, and substrates. However, there was no consistent pattern between planting time (fall or spring) and success of the plantings. The two years of this study were unusually rainy and there was above normal summer precipitation. Based on data collected at Macomb, Illinois, 44 km to the west of the site, precipitation for 1981 was 133 cm (31 cm above normal), and for 1982 the precipitation was 122 cm, which was 20 cm above normal (National Oceanic and Atmospheric Administration 1981 and 1982). For the major portion of the growing season (May through September), precipitation was 21 cm above normal in 1981 and 15 cm above normal in 1982. Therefore, due to lack of normal summer precipitation, this study was not able to adequately test this hypothesis.

Comparison of Mixed and Single Species Plots on Strip Mine Spoils

After the first growing season, the mixture of warm-season grasses had a greater number of seedlings established than the single species plantings. Biomass production on mixed species plots was also greater than single species plots at the end of the first growing season and in June of the second growing season, but these differences were not significant. Strip mine spoils are composed of varied substrate conditions and are a heterogeneous mixture of environments. Therefore, the soil heterogeneity may have maintained species diversity allowing the different species to exploit different soil microhabitats (Fitter 1982) and increase seedling establishment on the mixed plots.

However, by September of the second growing season, some of the single species plots produced significantly more biomass than the mixed plots. This decrease in biomass production may have been caused by competition between the three plant species in the mixture (Harper 1977, Fitter 1982). By September, the warm-season grasses reached their peak in growth and production. Since these grasses attained different heights at maturity, there could be marked competition for light. The taller species may have shaded and thus reduced production of the shorter species (i.e. little bluestem), consequently, decreasing the total production of the mixed plantings.

Production of Planted Grass Species on Amended Sites *vs.* Unamended Sites

After the first growing season, substrate had no significant effect on biomass production of planted species. Amended treatments produced more total biomass than the unamended treatments, but a greater proportion of the total biomass produced on the amended sites was comprised of weeds than on the unamended sites. In contrast, for plant species harvested in June of the second growing season, there were significant differences between substrates. Amended plots produced more biomass than unamended plots when all planted species are considered. Examination of the data, however, shows that the majority of biomass in all treatments is being produced by the two cool-season species. These cool-season grasses produce more biomass on the amended plots than on the unamended plots. If the warm-season grasses are considered separately, more warm-season grass biomass is produced on the unamended plots than the amended plots. Also, more weed biomass was produced on the amended warm-season grass plots than on the unamended plots for the same species.

In September of the second growing season, unamended plots produced more planted species biomass than the plots amended with sewage sludge. This was largely the result of the absence of warm-season grass species on the amended plots. The weed biomass had increased on these plots and the warm-season grasses were unable to compete on the amended plots.

The results indicate that the warm-season, native prairie grasses were competitive with annual weeds on unamended sites. However, on amended sites, the abundance of inorganic nutrients encouraged weedy species such as giant ragweed (*Ambrosia trifida* L.), barnyard grass (*Echinochloa* sp. Beauv.), horseweed (*Erigeron canadensis* L.), common smartweed (*Polygonum pensylvanicum* L.) adapted to rich nutrient sites. They out-compete the native grasses. These same weed species are not as successful in competing with the cool-season grasses. The cool-season grasses maximized their growth earlier in the growing season than did the weeds. This apparently reduced the production of the weedy species on these plots compared to weed production on plots planted to warm-season grasses.

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