WARM SEASON GRASS ESTABLISHMENT ON LIMESTONE-AMENDED COAL SLURRY[1]

by

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Abstract. Direct seeding of limestone amended areas can be an effective alternative to soil covering. Both wetland and upland plant communities have been established on post law (PL 95-87) slurry areas by the Wildlife Research Laboratory of Southern Illinois University at Carbondale. Terrestrial habitat reclamation has emphasized both cool and warm season grass species, using a 3- year program of limestone amendment (40-50 tons/acre/year) and cover crop (years 1 and 2) and perennial grass (year 3) establishment. Warm season grasses have been included in Midwest slurry reclamation projects since 1984. Vegetation monitoring of three Midwest sites (Illinois and Kentucky), ranging in age from 3 to 12 years since planting, identified current (Fall 1996) ground cover in excess of 100 percent. Warm season grasses accounted for 48 to 73 percent of the ground cover. Switchgrass (*Panicum virgatum*) was the dominant warm season species at all sites, with vegetative cover values ranging from 48 to more than 56 percent. Indiangrass (*Sorghastrum nutans*) accounted for 12 to 16 percent of the ground cover at the two Kentucky sites 3 years after establishment. Vegetative density for all species (forbs and grasses) ranged from 539 to 622 stems/m^2 while above ground biomass values ranged from 404 to over 900 gm/m^2. Warm season grass establishment practices on these direct seeded slurry areas have been successful in providing excellent ground cover and diverse upland wildlife habitat.

Additional Key Words: Tailings, direct seeding, revegetation, reclamation

Introduction

Current coal mining regulations generally require 2 to 4-feet of soil cover or other material for final cover on potentially acid-producing slurry impoundments (PL 95-87). Extensive investigations of geochemical substrate conditions and factors affecting vegetation establishment on coal slurry (coal processing waste $\leq$28 mesh) by the Cooperative Wildlife Research Laboratory (CWRL) of Southern Illinois University at Carbondale (Nawrot 1981) have identified reclamation alternatives that addressed alkaline amendment as an effective method for direct seeding (without soil cover) slurry substrates (Nawrot and Warburton 1987, Nawrot et al. 1991). Direct seeding practices have included the establishment of wetlands as well as cool and warm season grasses and legumes in upland zones (Nawrot and Yaich 1982, Nawrot et al. 1985).

Direct seeding practices have been demonstrated by CWRL on Midwestern slurry areas since 1976. Direct seeding practices of CWRL use an incremental alkaline amendment process that generally includes two to three years of agricultural limestone amendment (@ 40-50 tons/acre/year) and cover crop establishment (winter rye) followed by direct seeding of a perennial grass mix.

Pyrite oxidation and weathering (i.e., depletion of pyrite) does occur in the surface zone (0-18") of unsaturated slurry profiles (Nawrot and Warburton 1987); therefore, limestone amendments are delayed until the initial phase (~1-2 years) of acute pyrite oxidation has occurred. During the acute pyrite oxidation phase, pyritic sulfur values of 2-5% are reduced by as much as 90% to "treatable" levels of 0.5-0.75%. Concurrent with pyrite oxidation is the depletion of naturally-occurring calcareous slurry constituents that are depleted in the process of neutralizing acid salts. Therefore, when naturally-occurring neutralization potential is depleted, acidic (pH $\leq$3.5) conditions will develop. After pyrite has reached treatable levels (0.5-0.75% pyrite) in the oxidized zone, alkalinity is restored through incremental limestone application practices. Agricultural limestone ($\geq$93% C.C.E.) is generally applied during late summer using low-ground pressure broadcast spreaders. The limestone amended slurry surface is disked, seeded, and

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[1]Paper presented at the 1997 National Meeting of the American Society for Surface Mining and Reclamation, May 10-15, 1997, Austin, Texas.

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Proceedings America Society of Mining and Reclamation, 1997 pp 82-89
DOI: 10.21000/JASMR97010082

fertilized to establish a temporary cover crop of winter rye (Table 1). Limestone amendment and cover crop establishment continue for 2 to 3 years to adequately amend the surface zone and ensure that all "hot spots" (0.1-0.5 acre) are adequately treated, and to enhance organic matter prior to permanent seeding. The previous year cover crop is disked under following limestone application and prior to seeding and fertilizing. Permanent seeding can include both cool and warm season grass/legume mixes (Table 1).

Table 1. Agricultural limestone and fertilizer schedules and rates used in the direct seeding of potentially acid-producing coal slurry (upland zones).

LIMESTONE (Agricultural grade ≥93% (CCE)	
	Rate/Acre
Fall Year 1	50 ton
Fall Year 2	50 ton
Summer/Fall Year 3	50 ton
VEGETATION	
Cover Crop (Cereal Rye)	
Fall Year 1	100 lbs
Fall Year 2	100 lbs
Fall Year 3	100 lbs
Permanent - Upland zones	
Spring - Year 2 or 3	
Blackwell Switchgrass	12 lbs
Korean Lespedeza	8 lbs
Red Top	8 lbs
Indiangrass (Cheynne)	8 lbs
Big Bluestem (Kaw)	5 lbs
Little Bluestem (Aldous)	5 lbs
Birdsfoot Trefoil	6 lbs
Fertilizer	
Fall - Year 1, Year 2, Year 3	
18-46-0	400 lbs
0-0-60	200 lbs
46-0-0	150 lbs
Spring - Year 1, Year 2, Year 3	
46-0-0	150 lbs
0-46-0	300 lbs

Direct seeding of warm season grasses on limestone amended coal refuse has been done on a limited basis throughout the Midwest (Nawrot et al. 1986). Switchgrass was successfully established (on a test plot basis) on limestone amended gob in 1971 (Medvick and Grandt 1977) and in 1980 (Warburton et al. 1987). Switchgrass was also direct seeded on southern Illinois slurry in 1975 following limestone amendment (100 tons/acre) (Nawrot et al. 1991).

CWRL successfully established warm season grasses on more than 60 acres of limestone amended slurry in 1984 in Illinois. Warm season grasses were seeded on 40 additional acres of limestone amended slurry in Kentucky in 1992. Additional species trials, initiated in 1993 on direct seeded slurry in Kentucky, evaluated the performance of several varieties of switchgrass, Indiangrass, big and little bluestem, and side oats gramma (Carter et al. 1995).

This paper will review results of vegetation establishment in the upland zones of three direct seeded slurry areas. In addition, this paper will briefly discuss establishment practices for warm season grass establishment.

Methods

Study Sites

Evaluations of warm season grass establishment practices were conducted at three direct seeded upland slurry areas: 1) the Arch of Illinois Captain Mine in southern Illinois, 2) the Peabody Coal Company Gibraltar, and 3) Camp 11 mines in western Kentucky. Direct seeding was initiated in 1982 at the Captain Mine, and 1991 and 1992 at the Camp and Gibraltar mines, respectively. Pre-reclamation geochemical site characterization data, alkaline amendment practices, and direct-seeding information are summarized in Tables 2 and 3. Prior to vegetation monitoring (Fall 1996) the Captain Mine had undergone 13 growing seasons. Camp 11 Cell 1 had undergone 4 growing seasons, and the Gibraltar Mine Cell 2B had undergone 3 growing seasons since initial establishment (Spring) of warm season grasses. All sites had received at least two years of limestone amendment (total/site ≈ 100-150 tons/acre) with a rye cover crop prior to warm season grass establishment (Table 3).

Table 2. Pre-and post-treatment slurry substrate geochemical data. Mean values for surface (0-6") and subsurface (30-36") samples.

Mine Site	Pre-Treatment[1] # Samp.	Depth	Pyritic Sulfur (%)	Neut. Potential (T/1000T)	pH (S.U.)	Pre-Treatment[2] # Samp.	Pyritic Sulfur (%)	Neut. Potential (T/1000T)	pH (S.U.)
Captain	4	0-6	1.3	18.5	6.8	5	0.4	53.0	6.7
	4	30-36	1.1	30.5	7.8	2	1.1	32.0	7.4
Camp 11									
Cell 1	28	0-6	0.5	10.2	5.7	27	0.6	148.8	7.4
	10	30-36	1.9	46.8	6.8	10	2.8	76.6	7.0
Gibraltar									
Cell 2B	24	0-6	1.2	<0.5	2.2	22	0.2	146.4	6.6
	5	30-36	1.5	13.6	5.1	5	2.1	103.7	6.8

[1]Gibraltar 1992, Captain 1981, Camp 1991.
[2]Gibraltar 1995, Captain 1986, Camp 1995.

Vegetation Assessment

Vegetation assessments of the three reclaimed slurry areas were conducted during 6-16 September 1996. Stratified random sampling included 1 m^2 plots established along transects located within direct seeded (limestone amended - no soil cover) upland zones. A total of forty-eight 1 m^2 plots were sampled at the three sites (Camp 11 Cell 1 - eighteen 1 m^2 plots, Gibraltar Cell 2 - fifteen 1 m^2 plots, Captain Mine - fifteen 1 m^2 plots). Vegetation evaluations within each 1 m^2 plot included: vegetative cover (percent), density (stems/m^2), and above ground biomass (gm/m^2). Vegetation cover values within each plot were represented as six cover classes (1-5%, 6-25%, 26-50%, 51-75%, 76-95%, 96-100%) (Environmental Laboratory 1987). Mean cover value of each cover class was used to calculate the mean cover percentage for each species within the sampling area. Total percent cover for each plot and the mean total for the sampling area were also calculated from individual plot values. Stem density values were determined within 1/10 m^2 subplots randomly selected within each of the 1 m^2 plots. Above ground vegetation (current year production) was clipped (mid September 1996) at ground level in each 1/10 m^2 subplot, oven-dried @ 70°C for 48 hours and weighed.

Results and Discussion

Geochemistry

Limestone amendment practices (for 2 to 3 years) and direct seeding of an annual rye grain cover crop had occurred at each site prior to seeding of a permanent cover mix (Table 3). Prior to final cover establishment, pH values of the oxidized zones had been increased from acidic (pH 3.4-4.6) pre-treatment conditions to neutral (pH 6.8-7.6) post-treatment values. The neutralization potential had been enhanced from mean pre-treatment levels of 10-15 tons/1000 tons to values of 140 to 148 tons/1000 tons in the amended surface zones at the Gibraltar and Camp 11 slurry cells (Figure 1). Typical of most pyritic slurry areas, significant pyrite oxidation had occurred in the surface zones prior to the first year of limestone amendment. Following 2 to 3 years of limestone amendment, alkalinity was restored to a favorable acid-base balance needed for long-term vegetation establishment.

Vegetation

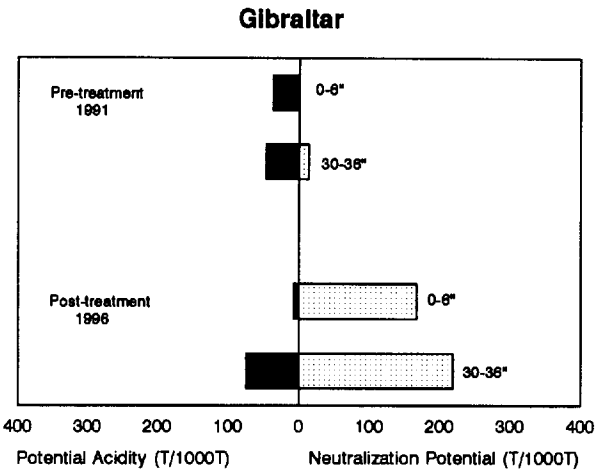
Camp 11-Cell 1. Both warm and cool species had become well- established in the upland direct seeded zone of the Cell 1 slurry area by the fall of 1996. Eighteen species were documented in the upland zone (Table 4).

Table 3. Limestone amendment, fertilizer, seeding rates, and dates of application for direct seeded reclamation areas.

	Limestone		Fertilizer			Permanent Seed Mix[1]		
Mine Site	Year	Rate (tons/ac)	Year		Rate (lbs/ac)	Year		Rate (lbs/ac)
Captain	1983	50	1983	18-46-0	300	1984	Smooth Brome	15
	(July)		(Aug.)	0-0-60	150	(May)	Red Top	5
	1984	60		46-0-0	100		Korean Lespedeza	6
							Indiangrass	3
							Switchgrass	8
							Sweet Clover	8
Camp								
Cell 1	1991	50	1991	18-46-0	400	1993	Blackwell Switchgrass	12
	(July-		(July-	0-0-60	200	(May)	Korean Lespedeza	8
	Aug)		Aug.)	46-0-0	150		Red Top	8
							Indiangrass	8
	1992	40	1992	18-46-0	400		Big Bluestem	8
	(Apr.)			0-0-60	200		Birdsfoot Trefoil	6
				46-0-0	150			
	1993	14	1993	0-46-0	300			
	(Aug.)	Hot Spots	(May)					
	1994	7						
	(June)	Hot Spots						
Gibraltar								
Cell 2B	1992	50	1992	18-46-0	400	1994	Blackwell Switchgrass	20
	(July)		(Oct.)	0-0-60	200	(May)	Kobe Lespedeza	10
				46-0-0	150		Common Bermuda	5
	1993	40	1993	18-46-0	400		Birdsfoot Trefoil	10
	(July)		(Aug.)	0-0-60	200		Indiangrass	15
				46-0-0	100		Little Bluestem	5
							Big Bluestem	5
	1994	50	1994	18-46-0	200		Red Top	5
	(May)		(Feb.)					

[1]Cover crop @ 2 bu/acre rye grain preceded permanent seeding for 1 to 2 years.

Dominant species, in descending order, were switchgrass (*Panicum virgatum* var. Blackwell), Indiangrass (*Sorghastrum nutans* var. Cheyenne), and fleabane (*Erigeron canadensis*). A majority of the plants were warm season grassland, or early successional species. Switchgrass was present in all but two of the plots, and had vegetative cover values ranging from 15% to 97.5%. Indiangrass was recorded in 14 of the 18 plots, and had vegetative cover values ranging from 2.5% to 62.5%. Switchgrass and Indiangrass accounted for an average of 73.4% cover within plots. The upland warm season grass zone supported a mean total cover of 122.2%, and ranged from 62.5% to 172.5%. Stem density values within plots ranged from 256 to 979 stems/m^2. Aboveground dry



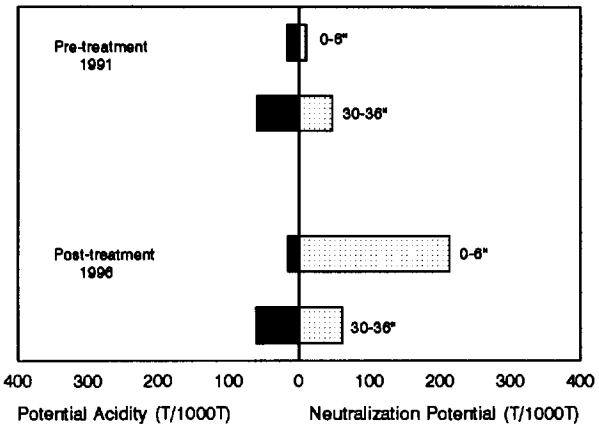


Figure 1. Pre- and post-treatment acid-base balance (mean values) of surface (0-6") and subsurface (30-36") slurry substrates.

weight ranged from 75 to 3000 gm/m^2 with a mean of 906.4 gm/m^2.

Gibraltar-Cell 2B. Similar to the Camp 11-Cell 1 direct seeded slurry area, the Gibraltar 2B slurry area supported a diverse stand of cool and warm season species (Table 4, Figure 2). Twenty species were present within the upland warm season zone. Dominant species, in descending order, were switchgrass, wild-millet (*Echinochloa crus-galli*), and Indiangrass. Vegetation cover was dominated by a mixture of warm season grasses, and early successional upland species (Table 4, Figure 2). Switchgrass was present in all but one of the plots, and had vegetative cover values ranging from 15% to 97.5%. Wild millet was recorded in 10 of the 15 plots, and had vegetative cover values ranging from 2.5% to 85%. Indiangrass was present in only 3 out of 15 plots and had cover values from 37.5% to 85%. Switchgrass and

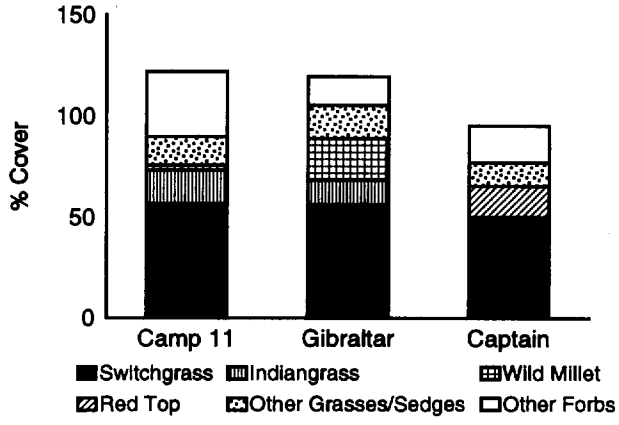


Figure 2. Vegetative cover of dominant (switchgrass and Indiangrass) warm season grasses and other species on three direct-seeded limestone amended slurry areas.

Indiangrass accounted for an average of 64.3% cover within plots. The upland warm season grass zone had a mean total cover of 115.5%, and ranged from 40% to 162.5%. Stem density values within plots ranged from 200 to 900 stems/m^2 with a mean of 612.7 stems/m^2. Aboveground dry weight ranged from 70 to 1000 gm/m^2 ($\bar{x}$ = 443 gm/m^2).

Arch Captain. After 13 full growing seasons since initial establishment, the Arch Captain direct-seeded slurry area supported excellent ground cover and species diversity (Table 4, Figure 2). Twenty-one species, including red top (*Agrostis alba*), switchgrass (var. Cave-In-Rock), and early successional forbs dominated the ground cover. Red top and switchgrass were present throughout most of the upland direct seeded zone. However, switchgrass density was greatest in the drier upslope areas. Wild millet, cattail, reed canary grass (*Phalaris arundinacea*), and smartweeds occurred occasionally in moist depressions in the downslope portion of the direct seeded area.

Species associated with the original seeding accounted for more than 60 percent of the ground cover, with switchgrass density recorded at 48.8%. Establishment of upland old field species has been represented by annual sunflowers (*Helianthus petioloris*), black-eyed susans (*Rudbeckia hirta*), and goldenrod (*Solidago canadensis*). Initial cover at the Captain site included smooth brome and orchardgrass (*Dactylus glomerata*). These cool season species have been decreasing in cover, while the dominant warm season species (switchgrass) has been steadily increasing. Overall, the Captain Mine has demonstrated the value of using warm season grass species for permanent cover in direct seeded slurry areas.

Table 4. Vegetative cover, density, and biomass (mean values) for three direct seeded slurry areas. 6-16 September 1996.

Species Scientific Name	Common Name	Peabody Camp Cell 1	Peabody Gibraltar Cell 2B	Arch of Illinois Captain
		Vegetative Cover (%)		
Ambrosia artemisiifolia	Common Ragweed	5.8	1.2	6.5
Ambrosia bidentata	Ragweed	5.4	6.7	0
Agrostis alba	Red Top	0	0	15.4
Aster simplex	Panicled Aster	7.8	0	0
Bidens aristosa	Tickseed Sunflower	0	0.3	0
Bromus inermis	Smooth Brome	5.7	0	0
Cynodon dactylon	Burmuda Grass	0	2.5	0
Cyperus esculentus	Nutsedge	0	6.3	0.2
Cyperus ovulinus	Round Headed Sedge	0	0	0.2
Echinochloa colona	Jungle Rice	0.3	3.5	2.7
Echinochloa crus-galli	Barnyard Grass	2.5	20.7	1.3
Erigeron canadensis	Fleabane	9	0	0
Eupatorium serotinum	Late Boneset	0.8	0	0
Euphorbia helioscopia	Wart Spurge	0	0.3	0
Helianthus petiolaris	Sunflower	2.1	0	0.2
Juncus biflorus	Rush	0	0	0.2
Krigia dandelion	Dwarf Dandelion	0.1	0	0
Lespedeza stipulaceae	Korean Lespedeza	0.1	3.3	0
Lotus corniculatus	Bird's Foot Treefoil	0	0	6
Panicum capillare	Witch Grass	5.6	0	0.4
Panicum dichotomiflorum	Fall Panicum	0.8	0.2	0
Panicum virgatum	Switchgrass	56.7	56.2	48.8
Phalaris arundinacea	Canary Grass	0	0	3.1
Phragmites australis	Reed Grass	0	2.8	3.1
Plantanus occidentalis	Sycamore	0	0.2	0
Polygonum hydropepperoides	Mild Water Pepper	0	0.2	0.2
Polygonum lapathatolum	Pale Smartweed	1	0	0
Polygonum pennsylvanicum	Common Smartweed	0	1.3	1.5
Populus deltoides	Cottonwood	0	0.2	0
Robinia psuedoacacia	Black Locust	0	0	3.1
Rudbeckia hirta	Black-eyed-Susan	0.1	0.3	0.2
Schizachyrium scoparium	Little Bluestem	0	1	0.2
Setaria glauca	Yellow Foxtail	1.7	0.2	0.4
Solidago canadensis var.scabra	Goldenrod	0	0	12.3
Sorghastrum nutans	Indiangrass	16.7	12.3	0
Typha angustifolia	Cattail	0	0	6.5
	Total # of species	18	20	21
	Mean % Cover/sq. m.	122.2	119.7	112.5
	Mean # Stems/sq. m.	622.2	612.7	539.2
	Mean Dry Weight (g/sq. m.)	906.4	443	404.2

Vegetative Cover Classes: 1=1-5% mean=2.5% 2=6-25% mean=15% 3=25-50% mean=37.5% 4=51-75% mean=62.5% 5=76-95% mean=85% 6=96-100% mean=97.5%.

areas. When direct seeding slurry, pay attention to details, inspect the area frequently for nutrient needs, and correct for nutrient and neutralization deficiencies.

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