SUBSOILS AS TOPSOIL SUBSTITUTES FOR SURFACE COAL MINE RECLAMATION IN MISSISSIPPI: ALLUVIAL FLOODPLAINS[1]

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Abstract: Alluvial soils in the Upper Coastal Plain soil resource area in the state of Mississippi occur in narrow floodplains. Prime farmland soil was collected in 4 foot increments to a depth of 16 ft. Soil collected from Kirkville and Oaklimiter sites was placed in 5 gallon pots in the greenhouse with five replications. Soil fertility (P, K, Ca, Mg and CEC) increased ($P<0.05$) as depth increased indicating that deep alluvial subsoils have a greater productive capacity. Soil pH was acidic (4.5 to 5.2) and tended to be similar with depth from the Oaklimiter site, but decreased curvilinearly to a depth of 12 ft from the Kirkville site. Pearl millet was planted in the summers of 2005 and 2006 followed by annual ryegrass in the winters of 2006 and 2007. Soil was remixed and limed with 2 tons dololmite per acre after year one. Pearl millet growth in 2005 increased linearly ($P < 0.05$) as subsoil depth increased at both sites. Manganese (Mn) levels in pearl millet increased linearly as subsoil depth increased from both soils to greater than 2000 ppm but was apparently not toxic to pearl millet. Ryegrass growth increased curvilinearly to a depth of 12 ft from Oaklimiter subsoils but decreased linearly as depth increased from Kirkville due to elevated Mn levels in ryegrass. Mn levels above 500 ppm were toxic to ryegrass. Liming increased pH to as high as 7.6 in soil from Kirkville and to 7.2 from Oaklimiter and had a neutral impact on pearl millet growth. Ryegrass growth following lime was greater as depth increased from Kirkville subsoils and was similar in Oaklimiter. Mn levels in both pearl millet and ryegrass were reduced to non-toxic levels following lime indicating that lime ameliorated subsoils would be suitable as topsoil.

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Introduction

The Surface Mine Control and Reclamation Act (SMCRA) was enacted in 1977 as Public Law 95-87 (Plass 2000). This required agricultural land to be returned to its original premining usage capability, restoration of approximate original contour, deep burial of toxic and acid forming materials, and salvage and stockpiling of topsoil and subsoil layers. These requirements led to reclamation practices that often resulted in soil compaction and reduced yields due to the usage of scrapers and levelers (Albrecht and Thompson, 1982 cited in Dunker and Barnhisel, 2000; McSweney et al., 1987). Shovels and open-ended dump trucks and bulldozers provide the best operational method of respreading suitable growth material (Hooks et al, 1992 cited in Dunker and Barnhisel, 2000) and is the current method utilized at the Red Hills Lignite Mine (RHM) in Ackerman, MS.

Alluvial floodplains consist of soils that are mixed and non-uniform, characteristic of young soils (Entisols and Inceptisols). Each of the bottomland(*) prime(+) farmland soils within the Red Hills Mine permit area are mixed Fluventic or Fluvaquentic Dystrudepts indicating that they are recently formed water deposited soils (Table 1). Pits dug to a depth of 16 ft in Cascilla and Chenneby mapped areas November, 2005 had un-decomposed wood at a depth of 12 to 16 ft that indicates their formation may be within a few hundred to few thousand years. Their topsoil horizons are shallow to depth of 7 to1 0 inches with little subsoil development except as indicated by gray mottling due to variations in water table levels that range from 0 to 5 ft (McMullen, 1986). These bottomland subsoils consists of reduced depositional topsoil and subsoil layers eroded from nearby sloping uplands (Janak, 2001).

Upland prime farmland soils within the Red Hills Mine permit area are Alflisols that have thin topsoil horizons less than 10” thick. Two of the soils (Bude and Providence) have fragipans indicating that recovery of its subsoil layers would result in destruction of its fragipan and may create favorable conditions that should be desirable for reconstructed reclaimed soil. Acreage of the Tippah soil is small and intermixed with Bude and Sweatman soils, making their recovery operationally difficult. .

Table 1.Taxonomic Classification† of soils within the Red Hills Lignite Mine Permit Area

Ariel*+----------------	Coarse-silty, mixed, active, thermic Fluventic Dystrochrepts
Arkabutla*-----------	Fine-silty, mixed, active, acid, thermic Fluventic Endoaquepts
Bude+-----------------	Fine-silty, mixed, active, thermic Aquic Fragiudalfs
Cascilla*+------------	Fine-silty, mixed, active, thermic Fluventic Dystrudepts
Chenneby*+----------	Fine-silty, mixed, thermic Fluvaquentic Dystrudepts
Guyton*--------------	Fine-silty, siliceous, active, thermic Typic Glossaqualfs
Kirkville*+-----------	Coarse-loamy, siliceous, thermic Fluvaquentic Dystrudepts
Oaklimeter*+--------	Coarse-silty, mixed, active, thermic Fluvaquentic Dystrudepts
Providence+---------	Fine-silty, mixed, active, thermic Oxyaquic Fragiudalfs
Smithdale------------	Fine-loamy, siliceous, thermic Typic Hapludults
Sweatman------------	Clayey, mixed, thermic Typic Hapludults
Tippah+--------------	Fine-silty, mixed, thermic Aquic Paleudalfs

† SoilDataMart.nrcs.usda.gov
* Bottomland
\+ Prime Farmland Soil

Sweatman and Smithdale soils are Ultisols that are considered nonprime farmland soils suitable for forestry. Their oxidized subsoil and topsoil constitute the approved topsoil substitute material for nonprime upland soils. It has been demonstrated to be suitable as an excellent plant growth medium for wheat, bermudagrass and loblolly pines (Lang et al., 2005) that exceeds yield potential of undisturbed soil as per the county soil survey (Table 2).

Table 2. Yield potential† of soils within the Red Hills Mine, Ackerman, MS

Soil	Map Unit	Wheat	Bermudagrass	Loblolly Pine	Land Capability Subclass
		Bu/acre	lbs/acre	Site Index Ht (feet) 50 Yr	
Soil					
*Oaklimiter	Oa	35	9000	90	IIw
*Chenneby	Ce	30	7000	100	IIw
*Kirkville	Kk	30	8000	95	IIw
*Providence	PoB2	30	7000	84	IIe
Smithdale	SmE	—	4500	80	VIe
Sweatman	SwC	25	4000	83	IVe
Smith-Sweat	SS	—	—	81	VIIe

† McMullen, 1986
* Prime Farmland Soil

Reconstruction of alluvial soils may not be best accomplished by careful recovery of topsoil and subsoil layers. Pettry and Wood (1996) disturbed and replaced an Alligator clay (very fine, montmorillonitic, thermic Allic Dystraquerts) prime farmland soil found in the Mississippi floodplain commonly known as the Delta. Soil was excavated to a depth of 11.5 ft with careful recovery of the A and B horizons to a depth of 4 ft. Treatments included (1) An undisturbed control, (2) Replacement of the A and B horizons in the same morphological order to a depth of 4 ft over mixed materials, (3) The A and B horizons were mixed together and replaced to depth of 4 ft over mixed materials, (4) The A and B horizons were removed separately to a depth of 2 ft and replaced in the same morphological position over mixed materials, (5) Loamy materials occurring at a depth of 5 to 11 ft were removed, segregated and replaced to a depth of 4 ft over mixed materials and (6) The entire 11.5 foot lift was randomly mixed and replaced to a depth of 11.5 ft. Soybean (*Glycine max*) yield was statistically similar for all mixed soil treatments and twice that of the undisturbed native soil. Treatment 4 that consisted of using deep subsoil loamy layers at a depth of 5 to 11.5 ft were numerically highest (33.0 bu/Ac) and soil replacement with the A and B horizons in the same morphological order or A and B horizons mixed together had numerically the lowest (30.4 and 30.3 bu/A, respectively), average over three years. Soybean yield on undisturbed soil was 33% less (21.1 bu/A). Disturbed and mixed soil had better soil texture and larger macropores compared with undisturbed plots that served as reference areas (Pettry and Wood, 1996). These data indicate that mixed alluvial soils along the Mississippi River have productive subsoil layers that provide superior plant growth materials compared with native undisturbed soil.

Similar findings have been reported in lignite producing regions of Louisiana and Texas (Feagley and Hossner, 2000). Alluvial clay soils in Texas are similar to the Alligator soil described above by Petty and Wood (1996). Hossner et al. (1992) worked with a Kaufman soil (very fine, montmorillonitic, thermic, Typic Pelludert) that occurs on level to gently sloping floodplains and found that its high clay and claypan were improved by deep mixing rather than replacing A and B horizons. Higher crop productivity and greater tree survival were observed on minesoils compared with native soil and the portion of land classified as prime farmland increased from 38.3% premined to 65.9% postmined (DeMent et al., 1992). However, other studies in Illinois on highly productive soils have shown topsoil provides the best growth compared to subsoil layers (Dancer and Jansen, 1981) though certain subsoils, e.g. claypans, were best ameliorated by mixing of B and C horizon layers for use as subsoil replacement (McSweney et al., 1981).

Characteristics of bottomland soils within the Red Hills Lignite Mine permit area indicate that subsoil layers provide suitable plant growth material that exceeds topsoil's productive capacity in terms greater of P, K, Ca, Mg and cation exchange capacity (CEC) as soil extraction depth increased from 4 to 16 ft (Table 3). Soil pH became more acidic in the Kirkville soil as soil depth increased but was similar at all depths in the Oaklimiter and was moderately to strongly acidic. All layers, including the surface 0 to ft, would require agricultural limestone at a rate of 1 to 3 tons/Ac. Soil texture varied between layers and between soils with high levels of sand in some layers (Table 4), typical of textural variation in many mixed alluvial soils.

The objective of this study was to determine the productivity of subsoil layers collected in 4 foot intervals to a depth of 16 ft from Oaklimiter and Kirkland soil.

Table 3. Soil fertility characteristics of bottomland soil collected at four depths from two soils at the Red Hills Mine, July 2004.

Site	Depth	pH	OM	P	K	Ca	Mg	Zn	Na	Mn†	CEC
	ft		%	------------------ mg/kg --------------------							$cmol^+/kg$
Kirkville	0-4	5.2	0.44	9	25	271	68	1.0	38	65	4.08
	4-8	4.7	0.41	8	22	198	58	2.0	40	62	4.03
	8-12	4.3	0.39	32	52	459	123	6.0	56	242	9.31
	12-16	4.5	0.27	33	65	577	169	6.0	51	145	11.01
Oaklimiter	0-4	4.9	0.58	7	29	414	115	1.0	41	151	6.30
	4-8	4.5	0.64	8	19	221	76	2.0	32	79	5.24
	8-12	4.8	0.30	21	59	745	333	4.0	49	310	11.24
	12-16	5.0	0.21	34	41	630	277	2.0	41	230	8.51

† Mn sampled June, 2006

Table 4. Soil particle size distribution of bottomland soil collected at four depths from two soils at the Red Hills Mine, July 2004.

Soil	Depth	Sand	Silt	Clay	Texture
	Feet	-------------------------------- % ------------------ -----------			
Kirkville	0-4	80	18	2	Loamy Sand
	4-8	76	21	3	Loamy Sand
	8-12	47	49	4	Sandy Loam
	12-16	33	61	6	Silt Loam
Oaklimiter	0-4	45	53	2	Silt Loam
	4-8	74	24	2	Loamy Sand
	8-12	36	56	8	Silt Loam
	12-16	43	50	7	Sandy Loam

Methods

Soil collected from each 4 foot interval was crushed and sieved to pass a 2 mm screen and 10 kg soil was placed in 20 L round plastic pots in a vented but uncooled greenhouse in May 2005 at Starkville, MS. 'Tifleaf III' pearl millet (*Pennisetum glaucum*) was planted at 25 to 30 seed per pot on 1 June 2005 in 5 replications and thinned to 10 plants per pot on 13 June 2005. Pots were fertilized with 1 gm of 15-5-10 fertilizer at planting and with 1 gm of 34-0-0 fertilizer at 2 to 3 week intervals. Pots were drip irrigated for 10 minutes per day at a rate of 4 L per hour. Millet was harvested at 10 cm above the soil on 19 July, 11 August, and 7 October 2005, dried at 60 ^{o}C for 5 days and ground to pass a 1 mm sieve. Minerals were analyzed following digestion by inductively coupled plasma spectroscopy (ICP). Following millet, 'Jumbo' ryegrass was planted at target population of 140 seeds per pot on 20 January, 2006. Pots were fertilized with 100 mls Miracle-Gro at planting and at 2 week intervals. Ryegrass seedlings were counted but not thinned. Plants were cut at 2 cm above the soil on 3 April and 22 May, 2006, dried at 60^{o}C for 5 days, ground to pass a 1 mm sieve and analyzed for minerals as above (N, P, K, S, Ca, Mg, Mn, Fe, Cu and Zn),

Pots were broken following ryegrass harvest in June 2006 and limed with 20 gm dolomite/10 kg soil. Pearl Millet was seeded at 25-30 seeds per pot on 11 July 2006 and thinned to 15 plants on 24 July. Pots were watered and fertilized as above. Millet was harvested at 10 cm above the soil on 30 August and 25 October 2006, dried at 60^{o}C for 5 days, ground to pass a 1 mm sieve and analyzed for minerals. Ryegrass was replanted on 5 February 2007 and harvested on 1 March and 30 April, 2007 and dried, ground and analyzed as above.

Results

Yield of greenhouse grown pearl millet increased with subsoil extraction depth in 2005 with the deepest depths (8 to 12 and 12 to 16 ft) showing the greatest pearl millet yield potential (Table 5 and Fig. 1A). This was due to higher nutrient levels (P, K, Ca, Mg and CEC) in the deeper layers compared with near surface layers (Table 3). Liming had a negative effect on pearl millet in 2006 (Table 5 and Fig. 1B. Soil pH increased by 1 to 2 units from 4.9 to as high as 7.7 (Fig. 4). Pearl millet is highly tolerant of acid pH (as low as 3.5) but is adversely affected by pH greater than 7.5. This makes it a good test species for evaluating the success of loblolly pine on reclaimed land.

Mineral analysis indicated that Mn tissue levels in pearl millet were elevated as soil depth increased (Fig. 2). In 2005 Mn levels approached and exceeded toxic levels (>2000 mg/kg) to wildlife and livestock (Ditsch and Collins, 2000). Liming had a positive effect on reducing pearl millet tissue Mn levels in 2006 (Fig. 3). There was a 50% reduction in Mn in 2006 compared with 2005 indicating that lime at 1 to 2 tons per acre will ameliorate potential Mn toxicity problems.

Table 5. Greenhouse yield of 'Tifleaf III' Pearl Millet and 'Jumbo' annual ryegrass growing in bottomland soil collected from two sites to a depth of 16 feet in 4 foot increments.

		Yield of Pearl Millet[†]		Yield of Annual Ryegrass[‡]	
Soil	Depth	2005	2006	2006	2007
	Feet	------------------------ dry weight gm per pot --------------------------------			
Kirkville	0-4	34.8	42.8	10.4	6.1
	4-8	43.4	42.1	8.3	5.8
	8-12	67.4	27.2	5.9	5.1
	12-16	72.8	31.7	5.2	5.7
Oaklimiter	0-4	53.6	37.0	8.3	7.1
	4-8	49.0	45.4	8.8	6.4
	8-12	60.4	30.3	10.5	6.8
	12-16	75.6	37.1	6.8	5.5
	$LSD_{(0.05)}$	7.4	6.3	2.1	2.4

[†] Replicates = 5; Pots were thinned to 10 plants per pot in 2005 and 15 plants per pot in 2006; Means are the sum of three growth cycles in 2005: July to November and two growth cycles in 2006: August to October.

[‡] Ryegrass was planted at 140 plants per pot and not thinned; means are the sum of two harvests (April and May) in 2006 and 2007. Germination was excellent in 2006 (Mean count = 126 +/- 20.3) but very poor and variable in 2007 (Mean count = 24 +/- 9.4) plants per pot, due to a greenhouse heating failure in February 2007.

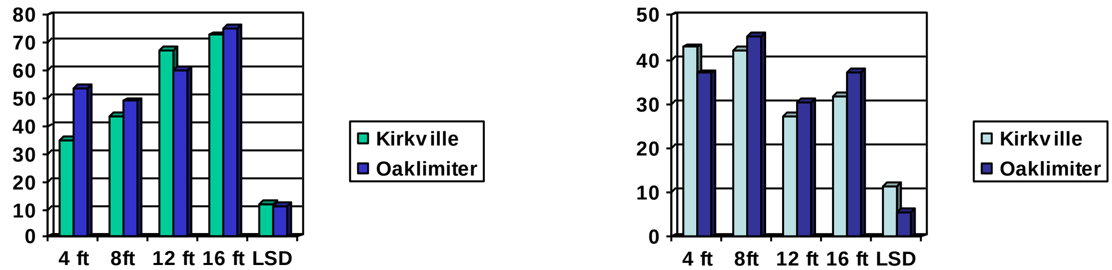


Figure 1A. Yield of Pearl Millet 2005 (gms/pot)   1B. Yield of Pearl Millet in 2006 Following Lime

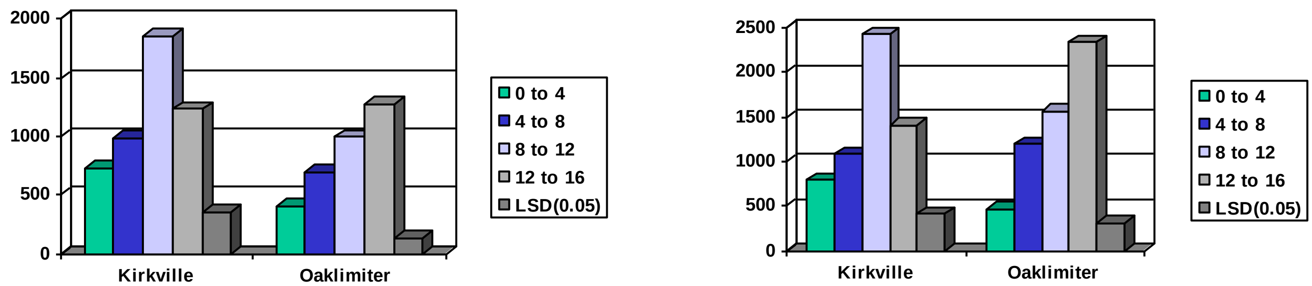


Figure 2A. Manganese levels in millet, October 2005 (mg/kg)   2B. Manganese levels in millet, December 2005

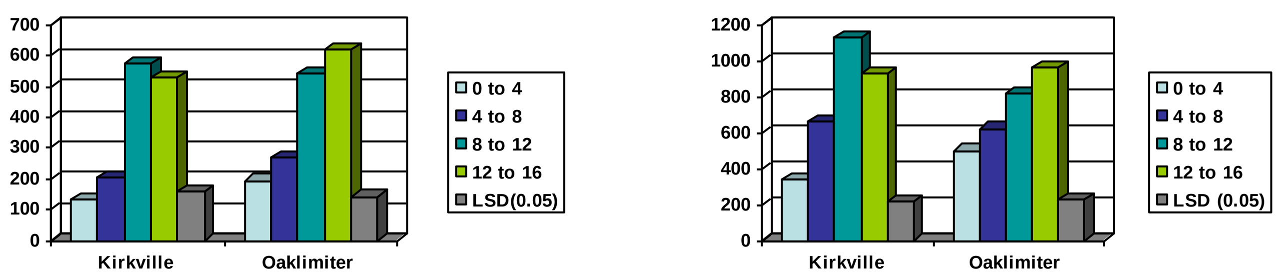


Figure 3A. Manganese Levels in Millet, August 2006   3B. Manganese Levels in Millet, October 2006

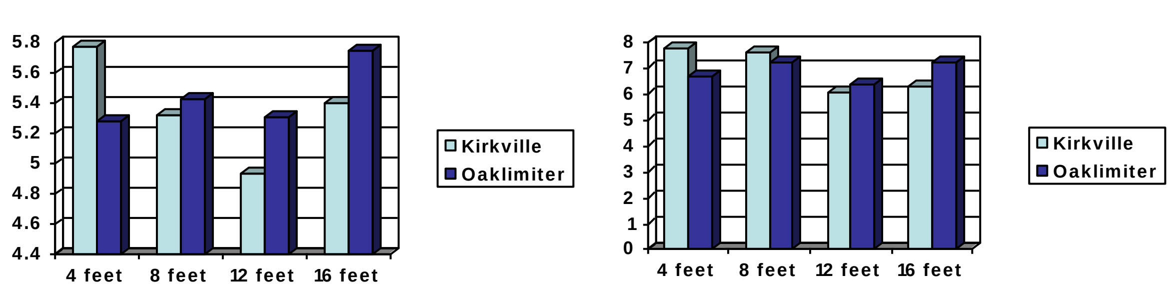
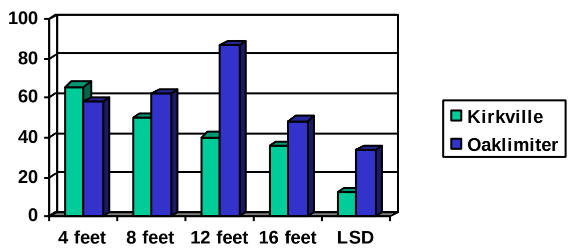


Figure 4. Soil pH in 2006 prior to lime and in 2007 following lime.

Ryegrass growth increased with subsoil depth to 12 ft and was statistically similar with the top 4 ft at a depth of 16 ft from the Oaklimiter site in 2006 (Table 5, Fig. 5A). In contrast, ryegrass growth decreased with soil depth in deep subsoil layers collected below 8 ft from the Kirkville site 2005. This was due to greater toxicity from elevated Mn in the Kirkville soil compared with Oaklimiter (Fig. 6). Ryegrass yield in 2007 responded positively to lime particularly in the Kirkville (Fig. 5B) soil likely due to reduced Mn levels. Plant size was much greater in 2007 than in 2006 due reduced plant populations (126 plants per pot in 2006 and 24 plants per pot in 2007).

mg per plant



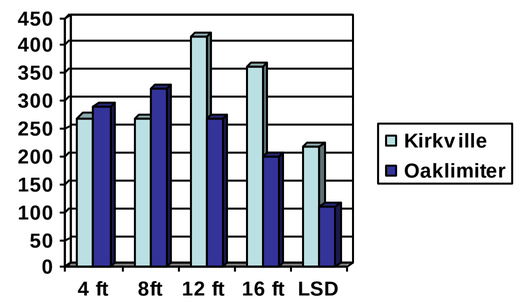
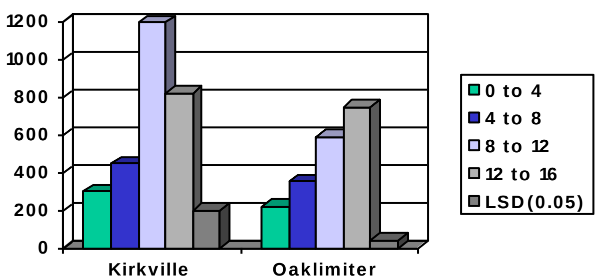


Figure 5A.Yield (mg/plant) of Ryegrass 2006

Figure 5B.Yield (mg/plant) of Ryegrass 2007

mg Mn/kg tissue



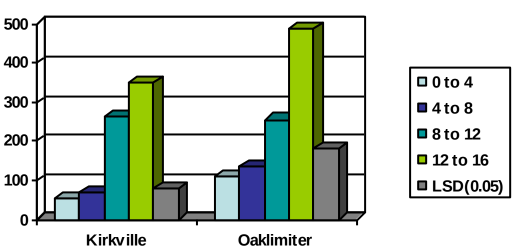


Figure 6A. Manganese levels in Ryegrass, April 2006

6B. Manganese levels, April 2007

Conclusions

Deep subsoil layers extracted to a depth of 16 ft from alluvial floodplains have the potential to provide suitable topsoil replacement material if limed with 1 to 2 tons of lime per acre to ameliorate potential Mn toxicity. Subsoil layers extracted to a depth of 8 ft provide suitable topsoil replacement materials without lime additions provided post mining usage is loblolly pine.

Further research is needed to determine if mixtures of topsoil and subsoil layers extracted to depths of 0 to 16 ft provide suitable topsoil replacement materials.

References:

Dancer, W. S., and I. J. Jansen. 1981. Greenhouse evaluation of solum and substratum materials in the southern Illinois coal field: I. Forage crops. J. Environ. Quaility10:396-40.
https://doi.org/10.2134/jeq1981.00472425001000030031x

DeMent, J. A., S. Cooney, and J. Denman. 1992. Developmemt of a Prime Farmland Minesoil in Selectively Cast Overburden in Northeast Texas. *In*: R.E. Dunker et al. (ed.). Prime Farmland Reclamation. The Surface Mining Control and Reclamation Act: 15 Years of Progress. Dept. of Agron., Univ. of Illinois, Urbana, IL, pp 177-181.

Ditsch, D. C. and M. Collins. 2000. Reclamation Considerations for Pasture and Hay Lands Receiving Sixty-six Centimeters or More Precipitation. *In*: Barnhisel, R.I., R.O. Darmody, and W.L. Daniels. (eds). Reclamation of Drastically Disturbed Lands. American Society of Agronomy Monograph 41:241-271.

Dunker, R. E. and R. I. Barnhisel. 2000. Cropland Reclamation. *IN*: Barnhisel, R. I., R. G. Darmody, and W. L. Daniels. (eds). Reclamation of Drastically Disturbed Lands. American Society of Agronomy Monograph 41:323-369.

Feagley, S. E. and L. R. Hossner. 2000. Reclamation of Lignite Mines. *In*: Barnhisel, R. I., R. G. Darmody, and W. L. Daniels. (eds). Reclamation of Drastically Disturbed Lands. American Society of Agronomy Monograph 41:415-432.

Hossner, L. R., S. G. Tipton, and S. D. Purdy. 1992. Reclamation of Alluvial Valley Floors in Texas Using Mixed Overburden. *In*: R. E. Dunker et al. (ed.). Prime Farmland Reclamation. The Surface Mining Control and Reclamation Act: 15 Years of Progress. Dept. of Agron., Univ. of Illinois, Urbana, IL, pp. 25-30.

Janak, E. 2001. Red Hills Mine Permit Renewal, Responses to Regulations. Volume 5, Chapter 25: Soil Resources, Section 2531.

Lang, D. J., G. Hawkey and B. Chow. 2005, Productivity of Reclaimed Soil at The Red Hills Lignite Mine in Ackerman, MS, Proceedings America Society of Mining and Reclamation, 2005 pp 667-677. http://dx.doi.org/10.21000/JASMR05010667.

McMullen, J. W. 1986. Soil Survey of Choctaw County, Mississippi. United State Department of Agriculture. Soil Conservation Service. 128 pp.

McSweeney, K., I. J. Jansen, and W. S. Dancer. 1981. Subsurface horizon blending: an alternative strategy to B horizon replacement for the construction of post-mine soils. Soil Sci. Soc. Am. J. 45:794-799. http://dx.doi.org/10.2136/sssaj1981.03615995004500040024x.

McSweeney, K., I. J. Jansen, C. W. Boast and R. E. Dunker. 1987. Row Crop Productivity of Eight Constructed Minesoils. Reclamation and Revegetation Research, 6 (1987) 137-144

Pettry, D. E. and C. W. Wood 1996. Productivity in Mississippi Delta Prime Farmlands Drastically Disturbed by Simulated Surface Mining. Mississippi Agricultural & Forestry Experiment Station Bulletin 1054, 10 pp.

Plass, W. T. 2000. History of Surface Mining Reclamation and Associated Legislation. *In*: Barnhisel, R. I., R. G. Darmody, and W. L. Daniels. (eds). Reclamation of Drastically Disturbed Lands. American Society of Agronomy Monograph 41:1-20.

Zarate-Valdez, J. L., R. L. Zasoski and A. E. Lauchli. 2006. Short-term effects of moisture content on soil solution pH and soil Eh. Soil Sci. 171423-431.

Apparently there is an error in the above citation besides the lack of a space between 171 and 423.