PRODUCTIVITY OF RECLAIMED SOIL AT THE RED HILLS LIGNITE MINE IN ACKERMAN, MS[1]

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Abstract: The Red Hills Lignite Mine (RHM) is located on the eastern edge of the Wilcox geological formation. The soils within the mine area are generally eroded with an average topsoil depth of 18 cm. In the absence of sufficient topsoil, mining regulations allow that appropriate subsoil or overburden can be used as a topsoil substitute if its soil fertility and vegetative productivity is demonstrated to be equal to or superior to existing soils. This study compared productivity of two native soils (Oaklimiter and Smithdale/Sweatman (SS)) with oxidized (OX) and unoxidized (UNOX) overburden. Oaklimiter is considered prime farmland (PR) by the NRCS and serves as the benchmark for comparison of productivity of potential substitute soils. The PR, SS, and SS soils were placed over oxidized overburden to a depth of 30 cm in 6 x 15 m plots replicated 3 times. UNOX topsoil substitute was placed over 1.2 m of UNOX overburden in similar plots. Soil pH was 5-5.5 for SS, PR, and OX; pH of UNOX was 7.5. Wheat (*Triticum aestivum*) was planted in November 2002 followed by common bermudagrass (*Cynodon dactylon*). Fertilizer was applied to supply 76 kg N/ha for wheat production 67 to 76 kg N/ha after each harvest for bermudagrass production. Wheat grain yield was 1844 kg/ha growing in SS soil, 2333 kg/ha in OX substitute soil, 2301 kg/ha in PR soil, and 2778 kg/ha growing in UNOX overburden. Yield of bermudagrass growing in UNOX was 2656 kg/ha and was considerably less than bermudagrass growing in OX (6434 kg/ha), SS (6478 kg/ha) and PR (8192 kg/ha) in 2003. During 2004, bermudagrass yield was statistically similar for all soils and ranged from 11,480 to 12,768 kg/ha. The UNOX soil substitute was not satisfactory as a potential soil substitute due to its low bermudagrass yield and its high soil pH would be unsuitable for loblolly pine (*Pinus taeda*) growth. The OX soil substitute was 79% as productive as PR soil in 2003 and 110% as productive in 2004. OX soil substitute exceeded the productivity of the native SS soil in terms of wheat grain yield in 2003 and bermudagrass production during both 2003 and 2004.

Additional Key Words: Topsoil substitute, overburden, strip mine

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Introduction

The Red Hills Lignite Mine (RHM) is an open pit mine that opened in 1998 with initial production beginning in 2001 and produces 3.3 million tonnes per year (Fig. 1). Soils within the RHM mine permit area of Choctaw County, MS are part of the eastern edge of the Wilcox (Eocene) geological formation (McMullen, 1986). The area consists of rolling hills that are highly weathered and eroded with a topsoil depth of 7 to 18 cm with an average of about 12 cm. Interspersed are flat creek bottoms with poorly drained soils, some of which are classified as prime farmland. The subsoil of the rolling hills is a red oxidized mixture of sand and clay that is moderately acidic (pH 4.8 to 6) to a depth of 2 to 6 m, some of which contain a fragipan. Gray unoxidized (UNOX) overburden consisting of unconsolidated sand, silt and clay extends to a depth of 6 to 10+ m above the first layer of lignite. This material is less weathered, high in calcium and other plant nutrients, virtually absent of pyritic sulfur and has a pH of 7 to 8. There are eight seams of lignite to a depth of 60+ m layered between 4 to 6+ m of unconsolidated gray unoxidized overburden layers. These are chemically similar to the gray overburden found close to the surface, except that it contains low levels of pyritic sulfur (0.1 to 1%) (Fig. 2). The red oxidized subsoil (OX) is currently permitted as a topsoil substitute.

Figure 1. The open pit lignite mine in Choctaw County, Mississippi.

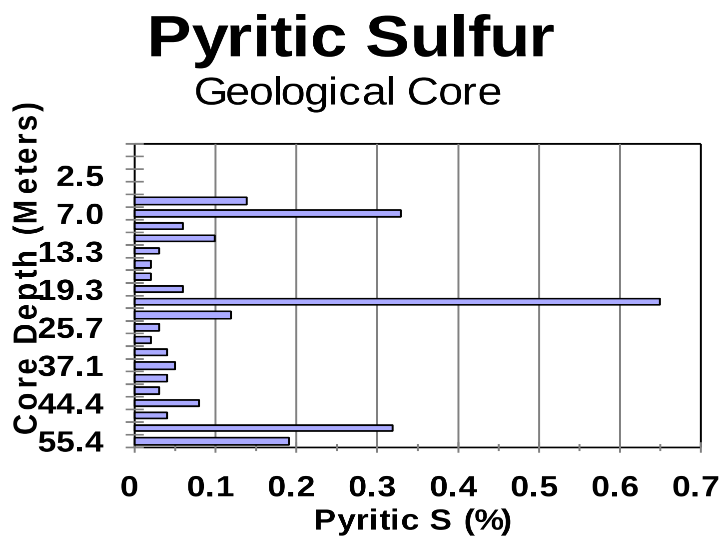

Figure 2. Pyritic sulfur levels at the Red Hills Lignite Mine in Ackerman, MS.

The current revegetation sequence at the RHM includes planting temporary cover crops of wheat (*Triticum aestivum*), crimson clover (*Trifolum incarnatum*), and browntop millet (*Panicum ramosum*) followed by establishment of common bermudagrass (*Cydonon dactylon*). This provides critical erosion control following new placement of reclaimed soil. These fast growing cover crops provide good soil erosion control. Fertilizer and lime were initially added in copious amounts to adequately grow grass cover crops and common bermudagrass to their full yield potential The cropping sequence includes establishment of loblolly pine trees (*Pinus taeda*) following soil stabilization.

Ideal soil pH for grasses is 5 to 6 and for loblolly pine is 4.8 to 5.8 (Marx, 1990). Loblolly pine was not adversely affected by simulated acid rain at a pH of 3.8 (Edwards et al., 1995; Markewitz et al., 1998). Soil pH less than 6 is required to prevent pine seedling loss due to disease (Anderson and Sutherland, 1989). Anticipated rooting depth for bermudagrass is 60 to 120 cm and for loblolly pines the depth of rooting can be as much as 2-3 m (Baker and Langdon, 1990). However, most roots of both species are located within the top 30 cm. The disturbed reconstructed soil has lost some of the negative physical characteristics occurring in the native soil such as fragipans and other restricting factors such as poor drainage. Removal of restriction layers within the new soil profile will likely permit rooting depths greater than in native soil. This can be highly desirable for species such as alfalfa, which are generally not adapted to the native soils within the RHM permit area. The gray unoxidized (UNOX) soil may be suitable for alfalfa. However, the gray unoxidized soil would be unsuitable for loblolly pines due to its high pH.

The native topsoil from the dominant Smithdale (Fine-loamy,siliceous, thermic Typic Paleudults)-Sweatman (Clayey, mixed, thermic Typic Hapludults) (SS) soil association (28 % of the permitted mine area), is thin (< 18 cm) and highly eroded into the red oxidized (OX) 'B horizon' subsoil (McMullen, 1986). The OX soil substitute is essentially the "B" and "C" horizons of the SS soil. The Oaklimiter soil (PR) (Coarse-silty, mixed, thermic Fluvaquentic Dystrochrepts) is what farmers call 'bottomland' and consists of flat fields along creeks. It is frequently flooded and is classified as prime farmland by the Natural Resource Conservation Service (NRCS) (McMullen, 1986). A similar silt loam soil within the RHM mine permit area is Chenneby (Fine-silty, mixed, thermic Fluvaquentic Dystrochrepts), but is wetter with poor drainage and not suited to row crops (McMullen, 1986). Although Oaklimiter and Chenneby are classified as prime farmland they have severe drainage limitations and are not at all similar to good prime farmland found in the Mississippi River alluvial floodplain commonly known as the Delta. The yield potential of these soils constitute the standard by which comparisons with substitute soils can be made (Table 1). The objective of this study was to determine the vegetative productivity of reconstructed substitute soil compared with native soil.

Materials And Methods

A plot area was created during the summer of 2002. Thirty cm of OX, PR, and SS soil were placed over 1.2 m of reclaimed red oxidized soil substitute. Reclaimed soil was dug out to a depth of 1.2 m prior to adding 1.5 m of UNOX overburden. There were three replicates of the four soils in 6 x 15 m plots. Soil samples to a depth of 0-30 cm were collected on 9/26/02 and analyzed for soil texture at A&L Services in Memphis, TN. Soil samples were collected to depth of 0-15 cm on 11/26/02, 06/10/03, 03/24/04, and 08/04/04 and analyzed for extractable nutrients by the Mississippi State University Extension Service soil testing laboratory (Crouse, 2001). Several 0-15 cm soil cores were randomly collected from each plot and mixed together to create a single composite sample from each of the 12 plots. Additional lime was added to PR and SS soil at 4480 kg/ha to adjust soil pH; all plots received 448 kg/ha lbs 17-17-17 in November, 2002.

Table 1. Yield potential† of soils within the Red Hills Mine, Ackerman, MS

Soil	Wheat	Bermudagrass	Loblolly Pine
--------- kg/ha	------------		Site Index
Oaklimiter	2195	10080	90
Chenneby	1880	7840	100
Providence	1880	7840	84
Smithdale	—	5040	80
Sweatman	1880	4480	83
SS	—	--	81

† Soil Survey of Choctaw County, Mississippi

Wheat (*Triticum aestivum* cv. 'Mixed') was planted in December, 2002 and harvested for herbage on 04/11/2002 and for grain on 05/23/2003. Herbage was mechanically harvested at a uniform 5 cm clipping height from two randomly selected strips that were 0.525 m wide by the width of the trimmed plot (5.4 m). Grain was harvested from two randomly selected $1m^2$ quadrants per plot. Bermudagrass (*Cydonon dactylon* cv. 'Common') was seeded at 22 kg/ha with a Brillion cultipack seeder on 05/30/2003. Fertilizer as 15-5-10 was applied at 560 kg/ha on 06/10/2003 and as 34-0-0 at 224 kg/ha on 08/08/2003. Herbage was harvested on 08/08/2003 and 10/20/2003 from two randomly selected strips that were 1.2 m wide by the length of the trimmed plot (14.4 m). All plots received 476 kg/ha 15-5-10 and 336 kg/ha 0-0-60 on 03/24/04. Harvests in 2004 were on 04/27/04, 05/27/04, 07/08/04, 08/10/04, and 09/10/04. Fertilizer as 448 kg/ha 15-5-10 was applied on 03/24/04, 04/27/04, 07/8/04, and 08/10/04 and as 34-0-0 at 224 kg/ha on 05/27/04. Dry matter was determined by drying randomly collected grab samples of fresh herbage at 55°C for 3 days. Data were analyzed by ANOVA procedures with mean separation by LSD at an alpha level of 0.05 for soil comparisons and an alpha level of 0.10 for yield comparisons.

Results And Discussion

The native SS soil found within the RHM is highly eroded and very low in soil P (Table 2), indicating that fertilizer inputs of P will be required for all crops, including loblolly pines. The eroded SS would require greater levels of fertilizer, compared with the OX soil, and is therefore not as suitable as topsoil for re-vegetation purposes. The OX soil currently utilized for the topsoil substitute is chemically equal to or superior to the SS Smithdale-Sweatman soil and PR Oaklimiter soil.

Table 2. Characteristics of native soils and currently used soil substitute within the Red Hills Mine landscape. Soil samples collected to a depth of 0-15 cm on 11/26/2002†.

	OM	pH	P	K	Ca	Mg	Zn	CEC
	- % -	----- extractable mg/kg				-----------		cmole/kg
Unamended Red Oxidized	0.61	4.8	28	80	1124	616	3.2	15.5
Amended Red Oxidized	0.44	7.0	38	67	2435	235	3.0	18.3
Smithdale-Sweatman disturbed	1.33	5.3	3	104	678	275	0.8	11.0
SS undisturbed	3.46	5.6	4	156	1646	540	1.7	18.5
Oaklimiter-undisturbed	1.83	5.7	12	51	931	78	1.8	9.1

† Analyzed by the Mississippi Soil Testing Laboratory (Crouse, 2001)

Soil texture affects soil fertility and water holding capacity. Higher clay content increases the nutrient holding capacity as well as the water holding capacity of the soil. Higher sand levels have lower nutrient and water holding capacities. All soils in the 12 plots were classified as loam soil (Table 3). However, UNOX and OX soils were sandier and would be expected to hold and supply less water than PR or SS soil.

Oaklimiter (PR) soil pH ranged from 5.2 to 5.5; SS soil pH ranged from 5.1 to 5.2 (Tables 2, 4 and 5). Unamended SS soil had a pH of 5.3 to 5.6 (Table 3). Soil pH was statistically similar in OX, SS, and PR plots (Table 4). UNOX was high in pH (7.5) and had an unusually high level of Zn (Table 4). Soil levels of extractable P, K, Mg, and Ca were adequate for good plant growth in the OX, PR, and UNOX soil (Table 4). Soil P levels were deficient in the SS soil (Table 4), but fertilizer P additions were sufficient to alleviate P deficiency (Table 5). Soil K levels remained low in OX and PR soils at the June 2003 sampling (Table 5) following wheat harvest.

Soil fertility levels in 2004 (Tables 6 and 7) remained similar to 2003 levels and were adequate for good bermudagrass growth.

Table 3. Texture analysis† of native and substitute soils in the vegetation plots established in 2002 at the Red Hills Mine, Ackerman, MS

Soil	Sand	Silt	Clay	Texture Class
	---------------------	%	----------------------	
OX	49 +/- 6.1††	31 +/- 3.0	21 +/- 3.1	Loam
PR	32 +/- 4.0	51 +/- 3.0	17 +/- 1.1	Silt Loam
SS	31 +/- 9.9	39 +/- 11.4	29 +/- 2.3	Clay Loam
UNOX	54 +/- 19.1	29 +/- 12.2	17 +/- 7.0	Sandy Loam

† Analyzed by A&L Laboratory, Memphis, TN

†† Sd = Standard deviation

Table 4. Soil organic matter (OM), soil pH, and extractable nutrients† on 11/26/2002.

	OM	pH	P	K	Ca	Mg	Zn	CEC
	-- % --		-----------	extractable	mg/kg	----------		cmole/kg
OX	0.54	5.5	17	90	1168	350	2.7	13.3
PR	0.89	5.2	10	70	713	272	1.7	10.7
SS	0.97	5.1	3	108	609	425	1.1	14.4
UNOX	1.58	7.5	18	114	2594	715	7.2	19.2
LSD $_{P < 0.05}$	0.74	0.36	5	42	455	94	1.1	2.8

† Analyzed by the Mississippi Soil Testing Laboratory (Crouse, 2001)

Table 5. Soil organic matter (OM), soil pH, and extractable nutrients† on 06/10/2003.

	OM	pH	P	K	Ca	Mg	Zn	CEC
	-- % --		-----------	extractable	mg/kg	----------		- cmole/kg -
OX	0.55	5.6	40	60	1112	461	2.3	12.7
PR	0.85	5.5	16	72	806	320	1.5	10.5
SS	1.14	5.2	12	110	953	512	1.2	15.3
UNOX	1.34	7.2	22	97	2409	733	7.0	18.4
LSD $_{P < 0.05}$	0.68	0.4	12	41	320	159	0.9	2.3

† Analyzed by the Mississippi Soil Testing Laboratory (Crouse, 2001)

Table 6. Soil organic matter (OM), soil pH and extractable nutrients[†] on 03/24/2004.

	OM	pH	P	K	Ca	Mg	Zn	CEC
	-- % --		------------- extractable mg/kg ------------					- cmole/kg -
OX	0.57	5.8	21	75	1442	498	1.6	13.8
PR	1.17	5.6	15	63	939	355	0.6	11.4
SS	1.24	5.0	5	114	859	490	0.4	14.1
UNOX	1.46	7.4	26	121	2762	795	5.6	20.8
LSD $_{P < 0.05}$	0.61	0.7	8	38	610	125	0.6	3.6

[†] Analyzed by the Mississippi Soil Testing Laboratory (Crouse, 2001)

Table 7. Soil organic matter (OM), soil pH and extractable nutrients[†] on 08/04/2004.

	OM	pH	P	K	Ca	Mg	Zn	CEC
	-- % --		------------- extractable mg/kg ------------					- cmole/kg -
OX	0.62	5.3	20	66	1364	568	2.9	14.5
PR	1.25	5.3	15	50	1054	369	1.7	11.9
SS	1.34	4.8	6	124	749	457	1.3	14.8
UNOX	1.28	6.8	25	109	2491	729	5.8	18.9
LSD $_{P < 0.05}$	0.33	0.5	10	50	346	87	0.5	1.8

[†] Analyzed by the Mississippi Soil Testing Laboratory (Crouse, 2001)

A soil pH of 5 to 6 is suitable for wheat, bermudagrass, and loblolly pine production. Grass production is suitable over a pH range of 5 to 7.5, loblolly pine growth is reduced at a pH greater than 6. The OX, PR, and SS soils meet the requirements for grass, grain, and pine production, however, the UNOX soil is not suitable for pine growth. The ideal soil pH for loblolly pine growth is 4.8 to 5.8. It is recommended that lime be limited to 2 tons/acre or less on the OX, PR, or SS soil to grow wheat or bermudagrass, if pine seedlings are to be grown subsequently.

Wheat herbage yield was similar for wheat grown in OX, PR, and SS soil (Table 8). The OX soil is currently proposed by the RHM to be soil substitute for SS and PR. Grain yield for wheat growing in OX soil was similar to PR soil and superior to SS soil and was equal to or better than the soils' yield potential (Table 1).

Although wheat growing in UNOX soil had the lowest herbage yield, it had the highest grain yield indicating that wheat growing in UNOX may have matured earlier. This may have been due to high soil Zn levels in UNOX soil (Tables 4, 5, 6, and 7). High soil pH is generally considered detrimental to wheat growth due to tie up of soil P and soil Zn. UNOX overburden has unusual soil chemistry properties which need further evaluation.

Table 8. Wheat herbage and grain yield growing on the soil vegetation plots at the Red Hills Mine, Ackerman, MS 2002-2003

Soil	Herbage 04/11/02			Grain 05/23/03		
	kg/ha		% of Prime	kg/ha		% of Prime
OX	4085	a†	107	2333	b	101
PR	3828	ab	100	2301	b	100
SS	3531	b	92	1844	c	80
UNOX	3666	ab	96	2778	a	121
LSD (0.10)	404			253		

†Means followed by the same letter do not differ statistically (P< 0.10)

Bermudagrass established quickly and achieved 100 % ground cover by mid-July, 2003. Seeded bermudagrass often does not achieve full ground coverage for 2-3 months following seeding. The plots were nearly weed-free. Yield of seeding year bermudagrass is typically 2000 to 6000 lbs/acre (Lang et al., 2002) and can be highly variable. Total herbage yield was statistically similar in OX and PR plots in both August and October (Table 9). Bermudagrass growing in UNOX plots yielded significantly less herbage than the other soils (Tables 9a and 9b). Although bermudagrass growing in PR soil (Oaklimiter) was numerically the highest yield, the relatively low CEC value of the Oaklimiter soil indicates it would require frequent fertilizer applications to remain productive.

Total herbage yield in 2004 was excellent (Table 10a). There was greater occurrence of grasses other than bermudagrass growing in the native SS or PR as well as in OX soil compared with UNOX soil substitute. Occurrence of grasses other than bermudagrass would be expected in topsoil taken from SS or PR and even OX soil due to the seed bank near the surface. The difference between Table 10a and Table 10b is the portion of grasses other than bermudagrass.

Bermudagrass growth in 2004 (Tables 10a and 10ba) exceeded target yield goals established by the NRCS soil survey (Table 1). Bermudagrass growing in OX substitute soil was similar to or greater than bermudagrass growing in PR in May, July and August, but was slightly less in April and September. Total season yield of bermudagrass growing in OX substitute soil was 10 % greater than bermudagrass growing in PR soil. Bermudagrass growing in UNOX substitute soil performed much better in 2004 than in 2003. It followed the same pattern as OX substitute soil relative to its differences to PR soil and total season yield was 9 % greater in UNOX soil than in PR soil. Averaged over two years the OX substitute soil exceeds the 90% requirement compared to PR soil

Table 9a. Yield of total herbage growing in native and substitute soil at the Red Hills Mine, Ackerman, MS 2003.

Soil		08/03/2003		10/20/2003		Total Yield	
	n	Mean	% Prime	Mean	% Prime	Mean	% Prime
		-kg/ha --	-- % --	- -kg/ha --	-- % --	--kg/ha--	---- % ----
OX	3	2615 ab†	73	3819 a	83	6434 a	79
PR	3	3579 a	100	4613 a	100	8192 a	100
SS	3	1945 bc	54	4533 a	98	6478 a	79
UNOX	3	651 c	18	2005 b	43	2656 b	32
	LSD (0.10)	1392		870		1986	

LSD = Least Significant Difference (P < 0.10)

†Means followed by the same letter in the same column do not differ (P< 0.10)

Table 9b. Yield of bermudagrass growing in native and substitute soil at the Red Hills Mine, Ackerman, MS 2003. Bermudagrass yield = total herbage – weed yield.

Soil		08/03/2003		10/20/2003		Total Yield	
	n	Mean	% Prime	Mean	% Prime	Mean	% Prime
		-kg/ha --	-- % --	- -kg/ha --	-- % --	-- kg/ha --	-- % ----
OX	3	2336 ab†	66	3643 a	89	5979 a	78
PR	3	3553 a	100	4083 a	100	7636 a	100
SS	3	1782 bc	50	4219 a	103	6001 a	79
UNOX	3	391 c	11	1991 b	49	2381 b	31
LSD (0.10)		1526		870		2020	

LSD = Least Significant Difference (P < 0.10)

†Means followed by the same letter in the same column do not differ (P< 0.10)

Conclusions

The OX soil substitute achieved 78-79 % of the productivity of PR soil in 2003 and was 98 to 110 % as productive in 2004. Productivity of OX soil substitute exceeded productivity of the native SS soil. The OX soil substitute appears to be a suitable topsoil replacement. The UNOX soil substitute was only 31 to 32 % as productive as PR soil in 2003, but it was 84 to 111 % as productive in 2004. The UNOX soil substitute shows promise as a topsoil substitute for various crops, except loblolly pine. A suitable use for the UNOX soil may be as a mixture with OX soil.

Table 10a. Yield of total herbage bermudagrass growing in native and substitute soils at the Red Hills Lignite Mine, 2004

	---------------------- Harvest Date	---------------------------					% of
Soil	4/27/04	5/27/04	7/8/04	8/10/04	9/10/04	Total	Prime
	--- kg/ha ---						
OX	2087 ab[†]	2349 ab	6280 a	3697 a	2330 b	16742 a	98
PR	3001 a	2395 a	5219 c	3438 a	3089 a	17410 a	100
SS	2111 ab	1684 b	5844 ab	4352 a	3203 a	17193 a	100
UNOX	1022 b	2188 ab	5861 ab	3421 a	1933 b	14425 b	84
LSD $_{(0.10)}$	1364	929	440	1012	497	2204	

[†]Means followed by the same letter within each column were not significantly different, $P < 0.10$.

Table 10b Yield of bermudagrass growing in native and substitute soils at the Red Hills Lignite Mine, 2004. Bermudagrass Yield = Total Herbage – Weed Yield.

	---------------------- Harvest Date	---------------------------					% of
Soil	4/27/04	5/27/04	7/8/04	8/10/04	9/10/04	Total	Prime
	--- lbs/Acre ---						
OX	637 b[†]	1213 ab	5129 a	3495 ab	2214 b	12688 a	110
PR	835 a	1752 a	3328 c	2847 b	2726 a	11488 a	100
SS	429 c	997 b	4309 b	4013 a	3023 a	12771 a	111
UNOX	368 c	1507 ab	5412 a	3355 ab	1920 b	12561 a	109
LSD $_{(0.10)}$	176	633	668	888	450	1455	

[†]Means followed by the same letter within each column were not significantly different, $P < 0.10$.

Literature Cited

Anderson, R.L and J. R. Sutherland. 1989. Soil-Pest Relationships. *In*: U. S. Department of Agriculture, Forest Service, Agriculture Handbook No. 680

Baker, J.B. and O.G. Langdon. *Pinus taeda* L. Loblolly Pine. *In:* Burns, Russell M., and Barbara H. Honkala, tech. coords. 1990. Silvics of North America: 1. Conifers; 2. Hardwoods. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC.

Crouse, K.K. 2001. Soil testing and plant analysis in Mississippi: Procedures used by the Mississippi State University Extension Soil Testing Laboratory. Mississippi State University Extension Publication. 131 pp.

Edwards, G. S., R.E. Sherman, and J.M. Kelly. 1995. Red spruce and loblolly pine nutritional responses to acidic precipitation and ozone. Environmental Pollution. 89: 9-15. http://dx.doi.org/10.1016/0269-7491(94)00049-J.

Lang, D.J, B. Boyd, N.C. Edwards, Jr., R. Elmore, R. Evans, J. Howell, R. Ivy, B. Johnson, B. Macoon, and T. Smith. 2002. Mississippi Forage Crop Variety Trials, 2002. MAFES Info. Bull. 391, 14 pp.

Marx, D.H. Soil pH and nitrogen influence Pisolithus ectomycorrhizal development and growth of loblolly pine seedlings. Forest Science 36 (2):224-245.

Markewitz, D., D.D. Richter, H.L. Allen, and J.B. Urrego. 1998. Three decades of observed soil acidification in the Calhoun Experimental Forest: has acid rain made a difference? Soil Sci. Soc. Am. J. 1998 62: 1428-1439. http://dx.doi.org/10.2136/sssaj1998.03615995006200050040x

McMullen, J.W. 1986. Soil Survey of Choctaw County, Mississippi. United States Department of Agriculture, Soil Conservation Service and Forest Service in cooperation with Mississippi Agricultural and Forestry Experiment Station. 128 pp.