REGENERATION OF KAOLIN MINED LANDS TO MAXIMIZE LOBLOLLY PINE GROWTH AND WILDLIFE HABITIAT[1]

by

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Compliance with the Surface Mining Control and Reclamation Act of 1977 and Georgia Surface Mining Act of 1968 requires that land equal in area to each year's disturbance be reclaimed and a vegetative cover established. Approximately 60% of kaolin mined areas are reclaimed to pine forest. Current methods of reclamation after grading involve fertilization, seeding with a cover crop of grass and legumes, followed by planting of tree seedlings. Restrictive soil physical conditions, a lack of organic matter and nutrients, and competition by cover crop species can reduce survival and growth of loblolly pine seedlings. Also, current cover crop species have only marginal value for wildlife. In this research, we evaluated alternative methods of reforestation that 1) control erosion while providing greater benefits for wildlife and reduced competition with loblolly pine seedlings, 2) ameliorate adverse soil physical conditions through deeper tillage (subsoiling vs. disk harrowing), and 3) improve spoil fertility and structure by application of a composted paper mill by-product. Results from field trials indicate control of erosion by wildlife grasses is comparable to seed mixtures currently used in the industry. Subsoiling and disking both had ameliorative effects on soil physical properties with seedling survival at 92% and 88% respectively, compared to 45% of the surrounding area. Composted paper mill by-product served as an additional source of organic matter, nutrients, and protective mulch, thereby enhancing seedling growth as well as ameliorating pine seedling chlorosis on site. Results from the first year growing season show stem volume of seedlings mulched with the paper mill compost was greater than twice the size of seedlings grown under current reclamation practices.

Additional Key Words: kaolin mine reclamation, reforestation, revegetation, tillage, compost, paper mill by-product

Introduction

In Georgia, mining of kaolin, a white commercial clay, occurs along the geological transition from the Piedmont to the Upper Coastal Plain (the "fall line"). The Surface Mining Control and Reclamation Act of 1977 and the Georgia Surface Mining Act of 1968 both require that land equal in area to each year's disturbance be reclaimed and a vegetative cover established.

Mining creates conditions that make it difficult to establish vegetation. After minerals are extracted, soil removed for mining ("spoil") is back-filled into the disturbed areas. This newly created soil is a heterogeneous mixture of various earth strata that lacks soil development. Due to the depth of mining (up to 200 feet), this spoil material is low in organic matter content and several essential plant nutrients, and may have physical characteristics that restrict root growth.

As land is reclaimed, cover is often established as pasture or forest. Approximately 60% of kaolin mined areas are reclaimed to pine forest (Haddock 1997). Early attempts at reforesting mined areas resulted in poor tree seedling survival (J. May, pers. comm.). May (1978) stated that rooting medium and climate are the most limiting factors in the fall line

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area. These factors can inhibit plant growth, thereby increasing erosion on site. Typical fall line climate includes severe rains in the spring followed by periods of excessive drought in the summer and autumn. Sheet erosion and surface crusting are results of these climatic patterns. Due to these problems, immediate establishment of a cover crop is critical following land disturbance.

Current methods of reclamation after soil grading involve fertilization with N, P, K; seeding with a cover crop of grass and legumes (fall mixture usually abruzzi rye, bermuda, and *Sericea lespedeza*); and planting of tree seedlings the following winter. This procedure is generally successful for controlling erosion; however, previous research and observations from members of the Georgia China Clay Producers Association indicate reclamation procedures do not always lead to successful tree establishment. In particular, competition from the cover crop can be severe, leading to high rates of tree seedling mortality during the first growing season following planting. When this occurs, the cost of reclamation, which is approximately $1,900 per acre (CCPA 1996), is increased due to the added cost of reseeding and replanting.

This research is evaluating methods for improving loblolly pine (*Pinus taeda*) growth and survival on reclaimed kaolin mines and reducing establishment costs. Three specific objectives are being addressed. The first objective is to compare the effects of subsoiling vs. disk harrowing on seedling growth and survival. We predict that subsoiling will increase growth and survival of seedlings over that of disk harrowing, due to the greater volume of soil the roots will be able to exploit for water and available nutrients. The second objective is to evaluate cover crops that control erosion while providing greater benefits for wildlife and reducing competition with loblolly pine seedlings. Several grasses that are beneficial for wildlife and that we expect will control erosion are being tested in comparison with current grass mixtures used by industry. The third objective is to measure how mulching with composted paper mill by-product affects pine seedling growth, both through field trials and greenhouse experiments. We expect that the composted paper mill by-product will increase tree growth by acting as a slow release source of nutrients and retaining soil moisture.

Literature Review

Effects of tillage on loblolly pine seedling growth and survival

Soil productivity is strongly influenced by soil physical conditions. Spoil back-filled into the mined site is composed of various strata of marine deposits, thereby creating extremely variable growing conditions. In addition to variable and often high clay content of the newly replaced soil, surface and subsoil layers may become compacted through site preparation processes, such as grading and back filling. This decreases soil pore space and increases soil bulk density. Bulk densities in mined areas are usually higher than adjacent undisturbed sites of similar texture.

During the critical first years of reclamation, soil tillage practices such as subsoiling and disking can potentially improve adverse soil physical conditions. Subsoiling ameliorates root restrictive soil physical conditions. On compacted surface mined land with subsoil textures ranging from silt loam to clay loam, Dunker et al. (1995) found that as depth of tillage increased, soil strength decreased, net water extraction increased, rooting depth increased, and crop yields for corn and soybean increased. Further research indicates that the implementation of tilling can reduce soil strength, which is a function of bulk density, water content, and soil type (Hooks et al. 1987, Campbell et al. 1974). Rooting density and root extension rates decrease as soil strength increases (Thompson et al. 1987, Taylor and Burnett 1964, Taylor and Garner 1963). Therefore, decreasing the soil strength through subsoiling enhances root proliferation throughout the fractured soil volume (Dunker et al.1995).

Subsoiling increases availability of subsoil moisture, thereby increasing plant growth (Kamprath et al. 1979). In Paleudults of the southeastern Coastal Plain with restrictive subsoil conditions, Campbell et al. (1974) found that during drought conditions, a 38% to 81% increase in crop yields was associated with subsoiling. Water stresses were decreased due to the deeper soil depths and greater volume of soil available for root exploitation. Subsoiling also increased infiltration rates and precipitation retention. Campbell et al. (1974) suggested that deep tillage of certain soils can have ameliorative benefits if irrigation is lacking. This increase in available soil moisture is critical during summer drought conditions in the Upper Coastal Plain. In highly compacted areas in the southeastern United States, an increase in plant growth has been attributed to the implementation of subsoiling (Chancy and Kamprath 1982, Box and Langdale 1984, Busscher et al. 1988).

Cover Crop Treatments - Erosion control

Vegetation establishment on barren sites is critical for controlling erosion after mining. Poor physical and chemical properties of some kaolin-mined land can inhibit successful establishment of a vegetative cover. Rushatakul (1971) evaluated the effects and reasons for possible failure of a seeding operation on kaolin mine spoil. Species tested in seeding trials were fescuegrass, bahiagrass, *Sericea lespedeza*, birdsfoot trefoil, and loblolly pine seed. Rushatakul found that these field trials on kaolin spoil had quite variable results, rangiug from very successful to complete failure.

Cover crop species currently used by industry for land reclamation such as *Sericea lespedeza,* a legume, and bermuda grass, are effective in controlling erosion on severely eroded sites. However, these cover crops have only marginal value for wildlife and create competition for water and nutrients that can reduce the survival and growth of loblolly pine seedlings (Erosion Control and Wildlife Planting technical committee, unknown). Where erosion is moderate, other cover crops are available that control erosion as well as benefit wildlife. An advisory committee of individuals from the Natural Resources Conservation Service, Georgia Department of Natural Resources, as well as seed and timber industries, developed the Erosion Control and Wildlife Planting for Forestry Operations guide which recommends mixtures with any of the following: white clover, red clover, ryegrass, rye, wheat, and oats as providing good ground cover as well as forage and habitat for wildlife.

Composted paper mill by-product used as soil amendment and added nutrient source

Paper mill by-product, primarily composed of wood cellulose, is a large source of biomass. Approximately 40,000 dry tons of organic wastes (primary clarifier sludge, secondary sludge, and yard wastes) can be generated by a single mill in a year. In the United States, over 50 % of this recyclable organic waste is disposed of in landfills by the pulp and paper industry (Unwin 1997). Composted paper mill by-product can be used safely and productively to enhance agriculture and forestry (Smyser 1982, Hatch and Pepin 1985, Zibilske 1987, Valente et al. 1987, Pridham and Cline 1988, Shimek et al. 1988, Campbell et al. 1991, 1995; Tripepi et al. 1996.).

Composting enhances the quality of paper mill by-product for use as a soil amendment by decreasing its weight, volume, and carbon to nitrogen (C:N) ratio. These factors are considered problems associated with pulp and paper primary sludge (Campbell et al. 1991). In the original form, primary sludge can have an extremely high C:N ratio (e.g. 270:1), but is potentially reduced through composting (Campbell et al. 1991). Supplementing the composted matter with an N source, such as chicken litter, can further offset the C:N ratio.

Composted paper mill by-product has been found to enhance the chemical and physical properties of soil. In preliminary studies on five sludge treatments in a sandy soil in Wisconsin, Einsphar et al. (1984) found a greater improvement in physical soil properties in treated than untreated soil. Composted kraft mill sludge increased the cation exchange capacity (CEC) and available soil moisture 2 to 3 times relative to the control after 2 years of weathering.

Revegetation and land reclamation projects have benefited from the use of a composted paper mill by-product. G.N. Richardson and Associates used composted paper mill sludge as "topsoil" rather than imported topsoil to establish vegetative cover on a landfill closure site (Garret 1998). Within weeks of seeding on the composted material, a healthy vegetative cover was established. The Glatfelter Company, a pulp and paper mill, has incorporated composting of their primary and secondary sludge into a beneficial soil amendment. Preliminary research conducted on this material finds it to be a counterpart to peat moss application (Carter, 1983). The addition of paper mill by-product as an organic matter source for kaolin mined areas, which are basically void of such material, can be critical for the development of soil conditions favorable to plant growth.

If incorporated into the "top soil", compost can enhance soil conditions and plant growth by increasing soil aeration, improving water-holding capacity, promoting water infiltration, reducing bulk density, and minimizing surface crusting (Campbell et al. 1991). An alternate method of application, the use of composted material as a mulch, can decrease surface soil temperatures, increase water content, and function as an additional nutrient source if mixed with a high N- containing waste such as chicken litter. Campbell et al. (1995) concluded that there was no difference in incorporation of compost or using it as mulch in the growth response of poplar plants. Further research conducted by Tripepi et al. (1996) indicated that compost used as mulch on cottonwood plants is associated with an increase in height over plants growing in compost incorporated soil. Use of the compost as a mulch is also probably more economically feasible due to less handling of the material. However, due to the nature of kaolin spoil, incorporation of the compost might prove beneficial in amending physical soil properties.

Campbell et al. (1991) expressed the need for further field trials to demonstrate the value of compost and to prove its market potential. Thus far, research conducted in this area is still limited.

Materials and Methods

Site description

This study is conducted on Engelhard Corporation land that was previously mined for kaolin. The site is located on Highway 24, approximately one mile east of Tuttle Barksdale's General Mercantile, between Sandersville and Millegeville, Georgia. This site was chosen because of its accessibility, availability at time of study initialization, slope, and available area. The site is composed of heterogeneous spoil from a kaolin mining operation that was graded to a 5-7% slope. Area of the site from the top slope to base, including buffer areas, is approximately 1.06 acres.

Engelhard Corporation prepared the site according to company reclamation procedures. The land was graded, fertilized with 60 lbs. N, 120 lbs. P, and 120 lbs. K per acre and limed, and disk harrowed to incorporate the fertilizer and lime.

The study design is a factorial design composed of 2 tillage treatments and 4 cover crop treatments, replicated in 2 complete blocks. The site consists of 32, 20 ft x 39.5 ft plots, with 8 plots on each of 4 rows. The tillage treatments consist of subsoiling, which is a deep till to approximately 18 inches; and conventional tillage, harrowing to approximately 8 inches.

Starting from the top slope of the field site, the tillage practices alternate between conventional practices and subsoiling. The 4 cover crop treatments are applied in random order on each row. The 4 cover treatments include wildlife I (abruzzi rye, wheat, ladino clover, and crimson clover), wildlife II (abruzzi rye and wheat - no legumes), a current grass mixture used by the kaolin industry (the control: abruzzi rye, *S. lespedeza*, and common hulled bermuda), and composted paper mill primary sludge mulch/soil amendment treatments. The cover crop treatments are fall seed mixtures. The wildlife mixtures are rated by individuals from the Natural Resources Conservation Service (NRCS) and industry as being very good for deer, rabbits, and turkeys in areas with moderate potential for erosion.

Erosion Measurements

In September 1997, sediment fences were installed, according to proper protocols for installation (John McEvoy, NRCS comm.), at the base of each test plot (20 ft in length). The fence continues up the side of the rectangular plots for approximately 1.64 ft to ensure collection of sediment. Yard edging placed around the circumference of each plot, approximately 1 and one half inches deep, confines sediment movement and restricts lateral and vertical water flow between individual plots.

Erosion measurement and data collection

To measure sediment movement and soil movement down slope, a series of pin flags were placed at a known depth throughout the bottom quarter of each plot after seeding. Each plot contains four rows of pin flags with five flags in each column. Deposition of sediment is measured on each flag approximately once per quarter.

Cover Establishment

With the completion of plot establishment, seed mixtures were spread with a hand operated broadcaster in October 1997. Legume seeds were inoculated with rhizobium bacteria before spreading. The composted paper mill sludge was distributed among assigned plots with a front-end loader and was spread manually with shovels. Application rates for each material are as follows:

<u>Wildlife I.</u> Abruzzi Rye 1.0 lb/1000 ft^2, Saluda Wheat 1.0 lb/1000ft^2, Ladino Clover 0.023 lb/1000ft^2 * (bacteria inoculant required), Crimson Clover 0.13 lb/1000ft^2*

<u>Wildlife II.</u> Abruzzi Rye 2.0 lb/1000ft^2, Saluda Wheat 4.1 lb/1000ft^2

<u>Current.</u> Abruzzi Rye 1.3 lb/1000ft^2, *S. Lespedeza* 0.57 lb/1000ft^2*, Common Bermuda 0.07 lb/1000ft^2

Composted paper mill sludge. 57 dry tons/acre, approximately 4 inch thick layer

Seedling Establishment

In February, 1998, loblolly pine seedlings were manually planted with a dibble bar on each plot along the slope contour and in the rips of the subsoiled plots where applicable. Each plot has 7 rows with 7 trees in each row 3.3 ft apart with 6.5 ft spacing between rows. Due to rodent predation in spring 1998, plastic guards were placed around surviving seedlings to prevent further losses.

Growth Assessment

Seedling growth is assessed by measuring tree height and ground line diameter approximately once a quarter. In Spring, 1998, biomass harvest of grasses were collected from 2 randomly chosen 3.28 ft x 0.82 ft areas in 3 cover treatments (wildlife I, wildlife II, current) from each row. Samples were oven dried and weighed.

Analysis of variance of loblolly pine seedling growth response among treatments after the first growing season was conducted using GLM procedures of SAS (SAS Institute Inc., 1985). Differences among means were tested with the Duncan multiple range test with a probability level of 0.05. Variance of erosion among cover treatments and between tillage practices and also analyzed using GLM and Duncan's procedures.

Results

Loblolly pine seedling (*Pinus taeda*) growth response to 4 cover treatments and tillage treatments is presented in tables 1 and 2, respectively. Due to predation in spring 1998, some seedlings will not be included in growth response analysis. Predation did not effect the paper-mill-amended sites.

Erosion trial. Results from field trials indicate control of erosion by wildlife grasses is comparable to seed mixtures currently used by the industry (Figure 1).

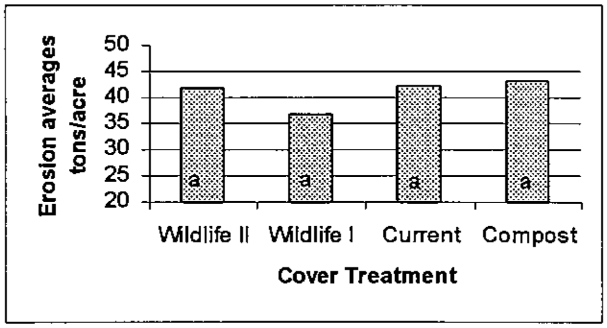

Figure 1. Erosion during six months following establishment of reclaimed kaolin mines using different establishment procedures. (Treatments with the same letter were not significantly different (Duncan's,a=0.05)

Table 1. Loblolly pine seedling growth response to cover treatment for seedling measured at the end of the first growing season.

Cover Treatment	Height (cm)	Diameter (cm)	Stem Volume (cm^3)	Survival Rate (%)
Current	43.05	0.83	32.84	90.56
Wildlife I	42.14	0.85	37.77	86.73
Wildlife II	43.17	0.83	34.03	91.33
Amendment	43.15	1.2	78.16	87.5

Table 2. Loblolly pine seedling growth response to tillage treatment at the end of the first growing season.

Tillage Treatment	Height (cm)	Diameter (cm)	Stem Volume (cm^3)	Survival Rate (%)
Subsoiled	42.4	0.92	43.7	91.45
Disk Harrowed	43.31	0.95	47.71	86.61

Cover treatment. Growth response, as measured by stem volume, did not vary among Current, Wildlife I, and Wildlife II cover treatments (Table 1). However, stem volume of loblolly pine seedlings mulched with the composted paper mill by-product is significantly different from other treatment and is greater than twice the size of seedlings grown with current reclamation practices (Figure 2). Survival rate did not vary among cover treatments and ranged between 86.7% and 91.3%.

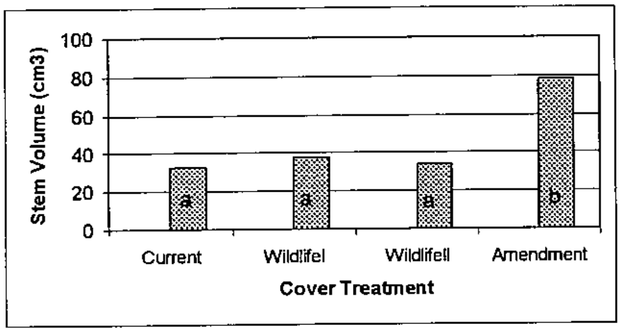

Figure 2. Loblolly pine seedling stem volume following the first growing season on kaolin mined land reclaimed using four cover management strategies. (Treatments with the same letter were not significantly different (Duncan's, a=0.05)

Tillage treatment. There was no significant difference between the two tillage treatments. Stem volume for subsoiling was 36.8 cm^3 compared to plots disk harrowed which was 39.4 cm^3. Survival rates for tillage treatments were 86.4% for disk harrowed and 91.4% for subsoiled. Although it was a very difficult year to establish plantations (preliminary observations reported of seedling survival in the surrounding area from late summer were variable ranging from 35-60%) survival for this study site was good.

Discussion

Cover crop. Competition for water and nutrients is a major factor when establishing seedlings in a site already stabilized with a cover crop. Survival rates among the cover crop treatments did not differ. Thus, this field trial indicates that seed mixtures beneficial for wildlife could be a comparable replacement for the mixture industry is currently using. Using grasses beneficial for wildlife provide forage and habitat, thereby forwarding reclamation to natural states by wildlife seed dispersal.

Composted paper by-product. Previous research has shown composted paper mill by-product enhances the chemical and physical properties of soil. The dramatic increases in stem volume on the composted paper mill amended sites results from a number of factors. The amendment serves as a mulch, which decreases surface soil temperatures and increases water retention. With the drought conditions experienced the summer of 1998, these factors might have played a critical role in productivity and survival. This material also serves as an immediate organic horizon, lacking in kaolin spoil, which is beneficial for initiating biological processes on site. More importantly, the compost adds essential plant nutrients to the nutrient deficient soils. Use of this material not only increases loblolly pine seedling growth, but is a viable means of reducing waste that would otherwise end up in landfills.

Estimated cost of application is similar to that of other forest-applied organic products. Application cost is approximately \$3.60/ton and hauling for up to 50 miles is an additional \$7.00/ton (Bush et al. 1999). However, cost will depend on material accessibility, distance of transport, as well as machinery availability.

Tillage treatment. After the first growing season, differences in stem volume and survival between tillage treatments were minimal. Several more growing seasons may be necessary to evaluate the potential benefits of deep tillage. The additional rooting volume created by subsoiling could prove beneficial as seedlings grow and roots must exploit a greater soil volume. However, a possible over-ridding factor of tillage treatments is the variable characteristics of the soil on site. Haddock (1997) found that in a comparison between high and low productive sites on reclaimed mine land, more highly productive sites have redder surface soils and sandier soil textures compared to less productive sites. Haddock further suggested that these soils should be favored when replacing overburden. Field observations in this study find the red, sandy-textured soils described by Haddock are at the top and bottom rows of this site, and whiter, clayey-textured soils are found in the middle two rows. If seedling growth response data is analyzed on an area basis rather than treatment, the top row of the site has considerably greater stem volume than the 2 middle rows (Figure 2.). As a result of this potential confounding, we believe it is premature to reject subsoiling as a beneficial soil tillage treatment on these sites.

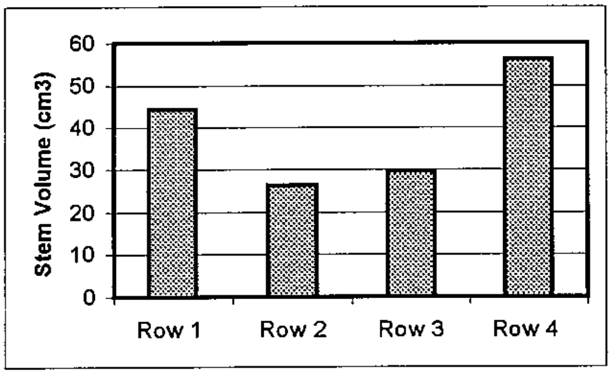

Figure 2. Seedling growth response on an area basis at the end of the first growing season.
*Row 1 – base of slope, Row 4 – top of slope

Summary

Data from the first-year-growing season support the following conclusions:

1. Seed mixtures beneficial for wildlife are comparable to grass mixtures currently used by the kaolin industry in controlling erosion.
2. There was no significant difference between tillage practices. However, additional growing season data is necessary to determine the impact of tillage.
3. The use of composted paper mill by-product as a soil amendment in mine reclamation was significantly correlated with an increase in stem volume. Stem volume of seedlings mulched with the compost material more than doubled compared to seedlings treated with current reclamation practices.

Greenhouse trials began in January 1999 testing various application methods and rates to determine optimal usage of composted paper mill sludge for improving seedling growth in spoil high in kaolin content. This study compares loblolly pine seedling growth response between incorporation of the material and applying it as mulch at both high (57 dry tons/acre) and low (28 dry tons/acre) rates. These results are being compared to a treatment fertilized with N, P, and K. Soil physical and chemical characteristics as well as foliar nutrient concentrations are being analyzed for both the greenhouse study and field trials. This data will be used to evaluate the effects of the cover treatments on plant nutrient availability and nutrient uptake.

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Literature Cited

Box, J.E. and Langdale, G.W. 1984. The effects of in-row subsoil tillage and soil water on corn yields in the southeastern coastal plain of the United States. *Soil & Tillage Research.* 4: 67-78.
https://doi.org/10.1016/0167-1987(84)90017-5

Bush, P.B., Merka, W.C, Morris, L.A., and Torrance, R. 1999. Chicken litter as a nutrient source for slash pine establishment in the Georgia coastal plain. *Proceeding of the Tenth Biennial Southern Silvicultural Research Conference*, February 16-18, 1999, Shreveport, LA.

Busscher, W.J., Karlen, D.L., Sojka, R.E., and Burnham, K.P. 1988. Soil and plant response to three subsoil implements. *Soil Science Society of America Journal.* 52: 804-809.
https://doi.org/10.2136/sssaj1988.03615995005200030037x

Campbell, A.G., Engebretson, R.R., and Tripepi, R.R. 1991. Composting a combined RMP/CMP pulp and paper sludge. *Tappi Journal.* September: 183-191.

Campbell, A.G., Zhang, X., and Tripepi, R.R. 1995. Composting and evaluating a pulp and paper sludge for use as a soil amendment/mulch.. *Compost Science & Utilization.* Winter. 84-95.
https://doi.org/10.1080/1065657X.1995.10701773

Campbell, R.B., Reicosky, D.C., and Doty, C.W. 1974. Physical properties and tillage of Paleudults in the southeastern Coastal Plains. *Journal of Soil and Water Conservation.* Sept.-Oct. 220-224.

Carter, C.N. 1983. Composting disposes of sludge, yields byproduct at Glatfelter. *Pulp & Paper.* March: 102-104.

Chancey, H.F. and Kampreth, E.J. 1982. Effect of deep tillage on N response by corn on a sandy Coastal Plain soil. *Agronomy Journal.* 74: 657-662.
https://doi.org/10.2134/agronj1982.00021962007400040016x

Dunker, R.E., Hooks, C.L., Vance, S.L., and Darmody, R.G. 1995. Deep tillage effects on compacted

surface-mined land. *Soil Science Society of America Journal*. 59: 192-199.
https://doi.org/10.2136/sssaj1995.03615995005900010029x

Erosion Control and Wildlife Planting technical committee. *Erosion Control and Wildlife Plantings for Forestry Operations.* Alabama chapter of the Soil and Water Conservation Society.

Einsphar, D., Fiscus, M.H., and Gargan, K. 1984. Paper mill sludge as a soil amendment. *TAPPI Proceedings: Environmental Conference.*

Garrett, P.G. G.N. Richardson & Associates. 1998. The beneficial use of composted paper mill sludge and animal waste for an industrial landfill closure. *Proceedings of the 1998 Conference: Composting in the Southeast.* Athens, GA.

Georgia China Clay Producers Association. 1997 <http://kaolin.com/>

Georgia Soil and Water Conservation Commission. 1994. *A Georgia Guide to Controlling Erosion with Vegetation.*

Haddock, R.B. 1997. Soil Chemical and Physical Factors Influencing the Productivity of Loblolly Pine Stands Growing on the Reclaimed Kaolin Minesoils of Georgia. M.S. Thesis Submitted to the Graduate Faculty of the University of Georgia, Athens.

Hatch, C.J. and Pepin, R.G. 1985. Recycling mill wastes for agricultural use. *Tappi Journal.* October 70-73.

Hooks, C.L., Jansen, I.J., and Holloway, R.W. 1987. Deep tillage effects on mine soils and row crop yields. *Proceeding, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation*, University of Kentucky, Lexington, Kentucky. December.

Kamprath, E.J., Cassel D.K., Gross, H.D., and Dibb, D.W. 1979. Tillage effects on biomass production and moisture utilization by soybeans on Coastal Plain soils. *Agronomy Journal.* 71: 1001-1005.
https://doi.org/10.2134/agronj1979.00021962007100060024x

May, J.T. 1978. China (Kaolin) Clays: Mining and reclamation. *Environmental Management of Mineral Wastes.* Sijthoff & Noordhoff. The Netherlands.

Pridham, N.F. and Cline, R.A. 1988. Paper mill sludge disposal: completing the ecological cycle. *Pulp & Paper Canada* 89:2. 73-75.

Rushatakul, B. 1971. Results of a Seeding Operation on Kaolin Clay Mining Spoil. A Special Problem Submitted to UGA.

SAS. 1985. SAS User's Guide, version 5 edition. Cary, NC: SAS Institute Inc.

Shimek, S., Nessman, M., Charles, T., and Ulrich, D. 1988. Paper sludge land application studies for three Wisconsin mills. *Tappi Journal.* September 101.

Smyser, S. 1982. Compost paying its way for paper producer. *Biocycle.* May/June pp. 25-26.

Taylor, H.M., and Burnett, E. 1964. Influence of soil strength on the root-growth habits of plants. *Soil Science* 98: 174-180.
https://doi.org/10.1097/00010694-196409000-00006

Taylor. H.M. and Gardner, H.R. 1963. Penetration of cotton seedling taproots as influenced by bulk density, moisture content, and strength of soil. *Soil Science.* 96: 153-156.
https://doi.org/10.1097/00010694-196309000-00001

Thompson, P.J., Jansen I.J., and Hooks, C.L. 1987. Penetrometer resistance and bulk density for predicting root system performance in mine soils. *Soil Science Society of America Journal.* 51: 1288-1293.
https://doi.org/10.2136/sssaj1987.03615995005100050035x

Tripepi, R.R., Zhang, X., and Campbell, A.G. 1996. Use of raw and composted paper sludge as a soil additive or mulch for cottonwood plants. *Compost Science & Utilization.* Spring 26-36.
https://doi.org/10.1080/1065657X.1996.10701827

Unwin, J.P. 1997. Results of NCASI's 1995 Wastewater and Solid Waste Survey. In Abstracts and Presentation Material, NCASI 1997 Southern Regional Meeting and Workshop. June 23-27. Asheville, N.C.

Valente, C.A., Vaz, A.R., and de Carvalho. 1987. Composting pulp mill sludge. *Biocycle.* July 46-49.

Zibilske, L.M. 1987. Dynamics of nitrogen and carbon in topsoil during paper mill sludge decomposition. *Soil Science*. January 26-33.
https://doi.org/10.1097/00010694-198701000-00004