Slash Mulching and Incorporation as Mechanical Site Preparation for Pine Plantation Establishment and Subsequent Effects on Soil Moisture and Site Hydrology

William A. Lakel, III

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Approved:

W. Michael Aust, Chair

Shepard M. Zedaker

Richard G. Oderwald

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(ABSTRACT)

Over one million hectares of pocosins and wet flats in the southeastern coastal plain are intensively managed for the production of loblolly pine (*Pinus taeda*) plantations. These management activities may have adverse effects on soil physical properties, site hydrology, and overall site productivity. Substantial quantities of wood residues are often left on these sites by timber harvesting operations, and it was hypothesized that the incorporation of this slash into the soil could improve the soil physical properties and site hydrology. One organic pocosin site and one mineral wet flat site were chosen post-harvest for treatment. The wet flat study was organized as an incomplete block design having four blocks and six treatments: (i) conventional bedding, (ii) strip surface mulching with bedding, (iii) strip surface mulching with tillage and bedding, (iv) broadcast mulch without bedding, (v) broadcast mulch with bedding, and (vi) flat planted control. The pocosin study was organized as a randomized complete block design with four blocks and four treatments. The treatments are identical to those of the wet flat site without the broadcast mulch treatments (iv and v). Soil physical property data was analyzed pre- and post-treatment, while post-treatment site hydrology and soil water chemistry data was analyzed periodically for one year. Seedling survival and height data were analyzed after one growing season.

The treatments had little effect on soil physical properties, site hydrology, soil water nutrients, or seedling survival on the wet flat study site. Bedding in general significantly increased tree height growth, but mulching had no significant effects. The treatments had little effect on soil physical properties on the pocosin study site except for soil macroporosity, which was significantly increased by bedding. Site hydrology and soil water nutrients were not significantly affected by the treatments, but seedling survival and height growth were significantly increased by bedding. Mulching had no significant effects on any of the parameters studied.

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INTRODUCTION

Forest products companies and non-industrial private landowners in the eastern Carolinas and Virginia manage 5.3 million acres (2.1 million ha) of wetland forests. Loblolly pine (*Pinus taeda* L.) occurs on about 32% of this acreage, while lowland hardwoods occupy about 55%. Approximately one-half of all pine acreage is intensively managed as plantations, and intensive management typically includes short-rotation harvests, site preparation, competition control, fertilization, and thinning. The majority of these wetlands are classified as mineral wet flats or organic pocosins (Brown, 1997). Forest products companies have acquired these lands for management activities because vast acreages of undeveloped timberland were available at low costs, the climate is suitable for highly productive forests, and wetlands are not generally suitable for urban development or agriculture.

In 1972, the federal government strengthened the Federal Water Pollution Control Act and required that a permit be issued to any landowner who wishes to discharge dredge and fill materials into navigable waters and associated wetlands. Normal farming and forestry activities were exempted from the permit process by section 404 of the 1977 Clean Water Act, provided that: (1) the activity is not a conversion of a wetland to an upland; (2) the activity is part of an ongoing operation; (3) the activity has not lain idle so long that hydrologic operations are necessary; (4) the activity does not contain any toxic pollutants; and (5) the activity uses normal silvicultural operations that comply with certain BMP's (Aust, 1994). The Environmental Protection Agency (EPA) created the Office of Wetland Protection in 1986 to implement a policy that would guarantee no net loss of the nation's wetlands in the future (Andrews, 1993; Siegal and Haines, 1990).

The intensive management required to maximize wood production on these lands often includes extensive ditching and mechanical and chemical site preparation to establish plantations. Clearcutting with ground-based systems is commonly used to harvest timber. Due to the wet conditions that occur on these sites for much of the year, ground- based rubber-tired equipment operations can have significant impacts on residual soil and site quality. Soil compaction and rutting, combined with site organic matter disturbances, can lead to long- and short-term reductions in site productivity (Aust et al., 1993; Kozlowski, 1986; Miwa, 1999). Soil compaction and rutting decreases gas and water movement in the soil profile, which decreases root growth and survival. Organic matter disturbance under sufficiently oxygenated conditions may lead to increased decomposition rates and subsequent losses of associated soil nutrients to leaching and volatilization (Aust, 1994; Burger, 1990; Kozlowski, 1986). Subsequent incorporation of slash residue on these wet (lesser oxygenated) sites might decrease decomposition rates by reducing aerated conditions within the soil profile while simultaneously enhancing the organic matter and soil physical characteristics of compacted and rutted soils.

Conventional timber harvests can leave behind significant amounts of slash that usually are left in place, burned, or moved mechanically from the site. The goals of this study are to determine if post-harvest slash residue can be mulched and incorporated onto or into the soil profile by various treatment methods to ameliorate the previously discussed negative soil/site impacts following wet weather harvesting operations. This type of organic matter management could replace or augment current methods and subsequently reduce management impacts and costs. The incorporation of mulched slash onto or into the soil profile might also enhance inherent soil and site quality.

This study was a collective effort by the USDA Forest Service, Weyerhaeuser Company, and Virginia Polytechnic Institute and State University. Weyerhaeuser provided land and basic treatment installation, while the Forest Service provided funding and augmented treatment installations. The Forest Service concentrated on the evaluation of site carbon balance and soil physics issues, while Weyerhaeuser Company was responsible for quantifying timber growth and yield. Treatments were installed on two wetland sites, one organic pocosin and one mineral wet flat belonging to Weyerhaeuser Company near Washington, North Carolina.

Virginia Tech personnel evaluated the effects of slash incorporation on site hydrology, soil water characteristics, and associated soil physical properties. Major concerns included the effects of mulching treatments on soil water movement, water table levels, soil redox potentials, soil moisture quantity, soil moisture nutrient concentrations, and first-year seedling survival and growth. The general null hypotheses tested were:

- Organic matter incorporation did not affect site hydrology.
- Organic matter incorporation did not affect soil water characteristics.
- Organic matter incorporation did not affect associated soil physical properties.

LITERATURE REVIEW

Forested Wetlands Suitable for Pine Plantations: Wet Flats and Pocosins

Total palustrine wetland acreage in North Carolina was approximately 4.7 million acres in 1992 (USDA National Resources Inventory Data), and approximately 4.5 million acres (96%) were forested (Shepard et al., 1998). Mineral wet flats (2.6 million acres or 1.1 million ha) and organic pocosins (1.6 million acres or 0.6 million ha) are the two major forested wetland types in eastern North Carolina (Cubbage and Flather, 1993).

Mineral wet flats occur in broad interstream terraces and are classified by the USDI Fish and Wildlife Service National Wetland Inventory* as:

System: Palustrine wetlands
Subsystem: None
Class: Forested Wetlands
Subclasses: needle-leaved evergreen and broad-leaved deciduous
Water regime: saturated, semi-permanently, intermittently, or seasonally flooded
Water chemistry: fresh, acidic
Soils: mineral

*Adapted from Harms et al., (1998).

The mineral soils were formed from marine and alluvial deposits of the Quaternary, Tertiary, and Cretaceous periods, and resulting soil orders include alfisols, entisols, inceptisols, spodosols, and ultisols. In most cases the soil orders are aquults, which characteristically have a clay subsurface (argillic) horizon with a low (less than 50%) base saturation. Other soil suborders commonly encountered are aquents, aquepts, and aquods (Allen and Campbell, 1988). These sites are generally somewhat poorly to very poorly drained and are relatively fertile compared to organic soils of this region. Wet flats are often saturated or inundated for brief periods during and after heavy rainfall events because of the perching effect of the argillic horizon, combined with very slight relief. Wet flats receive no alluvial inputs of nutrients and water. Precipitation is the major water input, while stream and surface runoff combined with evapotranspiration are the main outputs (Harms et al., 1998).

Wet pine flats (mineral soils) are less often saturated than pocosins and have more frequent natural fires, therefore they are usually dominated by loblolly pine, with associated pond pine (*P. serotina*) and longleaf pine (*P. palustris*), while wet hardwood flats are dominated by swamp laurel oak (*Quercus laurifolia*), water oak (*Q. nigra*), willow oak (*Q. phellos*), sweetgum (*Liquidambar styraciflua*), and red maple (*Acer rubrum*). In many cases, mineral wet flats exhibit forest species compositions including pines and hardwoods. Wet flats are generally slightly drier than pocosins due to their slightly more elevated land type and are more productive due to superior soil nutrient status (Harms et al., 1998).

Organic pocosins, which are ombrotrophic bogs, are located in broad interstream terraces with little or no natural drainage and are classified by the National Wetland Inventory as:

System: Palustrine wetlands
Class: Forested Wetlands
Subclasses: needle-leaved evergreen and broad-leaved decidous,
Water regime: saturated, semi-permanently, intermittently, or seasonally flooded
Water Chemistry: fresh, acidic
Soils: organic

Pocosins developed after the Wisconsian ice age as a result of rising sea levels and sediment deposition on broad flats that created large inland areas of shallow water. Vegetation growth and deposition of resultant organic material in these flooded areas for approximately 10,000 years have formed organic soils called peats (fibrists) or mucks (saprists), depending on the type of vegetative parent material and the degree of decomposition. In most cases, undisturbed pocosin soils are classified as medisaprists. In some cases, the soils are mineral with a shallow organic layer at the surface. These soils are often poorly to very poorly drained and are generally nutrient-deficient and acidic. Common soil series include Dare (Typic Medisaprists) and Ponzer (Terric Medisaprists). Precipitation is the main water input, while evapotranspiration accounts for nearly all water output during the dry growing season. Stream outflow accounts for a small amount of water output during winters and very wet periods in summer (Sharitz and Gresham, 1998).

Native pocosin vegetation varies with peat depth to mineral soil. Pocosins with deep peat layers (3 to 16 feet) are called low or short pocosins because the vegetation community is dominated by short shrubby species such as fetterbush (*Lyonia lucida*), titi (*Cyrilla racemiflora*), greenbriar (*Smilax* spp.) and several species of bay (*Magnolia* or *Persea* spp.). The saturated deep peat layers often prohibit plant roots from reaching mineral soil and associated nutrients and prohibit the establishment of tree communities. Pocosins with shallower layers of peat (< 5 feet) allow some tree roots to reach mineral soil during periods of drought. This allows some tree species such as pond pine and several species of bay that are adapted to saturated condition, low nutrient status, and occasional intense fires to survive. The shrub species mentioned for the low pocosin dominate the high pocosin as well (Sharitz and Gresham, 1998).

Limiting Factors for Pine Management

Flatwoods sites, including pocosins and wet flats, generally have anaerobic conditions for at least a portion of the growing season. The lack of topographic relief, low elevations and/or depressional topography, and poor internal drainage can cause poor soil aeration, nutritional limitations, and reduced productivity for desirable species such as loblolly pine (Harms et al., 1998; Miwa et al., 1998). Industrial activities on southern wetlands are further restricted during the winter months, when tree dormancy and cool temperatures greatly reduce evapotranspiration water losses from sites (Mitsch and Gosselink, 1993). Heavy equipment traffic is greatly hampered on most wetlands by high water tables and wet soils.

High water tables also affect the species and productivity of wetland sites. Many wet flats and pocosins must be drained extensively to make crop production possible. Pine seedling survival on wetlands in eastern North Carolina is greatly dependent upon artificial site drainage and bedding prior to planting. Low natural soil fertility and intense competition from weed herbaceous and tree species are also impediments to crop tree growth on many southern wetland sites (Allen and Campbell, 1988). Due to the problems associated with poor drainage, a variety of silvicultural operations have been modified to enhance the survival and growth of desirable species.

Silvicultural Manipulations of Wet Sites -- Drainage

Forested wetland sites in eastern North Carolina, owned by industrial and nonindustrial private landowners, are often managed according to the limitations that affect pine plantation establishment and growth. The major limitation for pine management is the generally high water table and resulting wet soil conditions. Therefore, many sites are artificially drained through an extensive network of ditches. These ditches are usually constructed with a mechanized tracked excavator, and fill from the ditches is used to construct forest access roads. Primary and secondary ditches are located along the system of roads, while tertiary ditches are located across the sites at parallel intervals of approximately 5 chains (101 m).

Ditching

Ditching is intended to lower the overall site water table level, thereby increasing soil gas exchange, effective rooting volume, and organic matter decomposition and subsequent nutrient mineralization (Wells and Crutchfield, 1974). Andrews (1993) noted that research generally has shown that ditching increases long-term growth of southern pine species on wet sites. (Maki, 1955, 1968, 1971; Miller and Maki, 1957; Pruitt, 1947). Walker et al. (1961) found that increases in water table depth of 10 to 20 cm produced significant results (Andrews, 1993). Terry and Hughes (1975) noted tree growth increases from 80 to 1300 percent on drained sites versus adjacent undrained sites (Andrews, 1993). Kelting (1999) found that approximately 45 cm of aerated soil is necessary for optimal early survival and growth of loblolly pine grown on wet flats.

Bedding

Bedding may be used alone or in conjunction with ditching to elevate tree seedlings' early rooting environment above the ground surface. This creates a favorable rooting environment for pine seedlings that is drained and aerated sufficiently to promote early seedling survival (Allen and Campbell, 1988). "Bedding has been the most widely used site preparation method in poorly drained areas of the southeast (Haines and Haines, 1978; McKee and Shoulders, 1974; Shoulders and Terry, 1978; Terry and Hughes, 1975)" (Andrews, 1993). Drainage alone can be responsible for up to a 25-foot (7.6-meter) increase in tree height after 50 years (Klawitter and Young, 1965), while bedding following drainage can be responsible for an additional 1-meter (3.3-foot) growth advantage in the first five years (Allen and Campbell, 1988), possibly leading to shortened rotations. Andrews (1993) noted that bedding increases survival and growth on wet sites, but that individual tree growth advantage over non-bedded sites decreases with time (Haines et al., 1975; Lennartz and McMinn, 1973), and overall, bedding may not increase tree height at the end of rotation. However, the enhanced early survival caused by bedding has been shown to increase volume yields by 33% even though individual tree growth differences may not be significant (Andrews, 1993).

Fertilization

A very low level of available phosphorus is a common limitation for tree growth on wet soils in the lower coastal plain. Phosphorus fertilization (diammonium phosphate) is the most common operational solution, and the fertilizer is generally applied to the beds just prior to seedling planting. Pritchett and Comerford (1982) found that "the effects of phosphorus fertilization on loblolly pine growth on poorly drained soils are large and long-term" (Allen and Campbell, 1988). Phosphorus fertilization can increase site index by more than 4 meters (13.1 ft) at age 25 (Allen and Campbell, 1988).

Tippett (1992) noted the research results of MacCarthy and Davey (1976) and Pritchett and Comeford (1982), which showed increased growth of loblolly pine plantations on fertilized wet sites of eastern North Carolina. Stand growth increases (diameter, basal area, and height) were measured from year 1 to year 20 in several studies. Phosphorus fertilization increased tree growth on wet sites and offered some potential as a replacement for bedding on some sites. Long-term growth responses to phosphorus fertilization were more apparent on wet sites and less pronounced on well-drained sites (Tippet, 1992).

Chemical Weed Control

Herbicides are generally applied to recently planted sites during the first few growing seasons to control herbaceous species that compete with planted seedlings for light, moisture, and nutrients. Control of herbaceous weeds can increase seedling survival by as much as 30% and volume growth by as much as 100% (USDA, 1997a). Oust® (sulfometuron methyl, E.I. Dupont de Nemours & Co., Inc., Wilmington, Delaware), Velpar L® (hexazinone, E.I. Dupont de Nemours & Co., Inc., Wilmington, Delaware), Accord® (glyphosate, Monsanto Company, St. Louis, Missouri), Poast® (sethoxydim, BASF Corp., Chemicals Division, Parsippany, New Jersey), and Fusilade® (fluazifop-p-butyl, ICI Americas Inc., Wilmington, Delaware) are all common chemicals used for herbaceous control. Herbaceous release chemicals are often applied in bands with backpack sprayers so as to control the placement of chemical and avoid inadvertent exposure of the crop trees to herbicides. Herbicides are also used to control hardwood competition after planting as well as just prior to stand closure. These are most often aerially applied by helicopters or skidders to ensure adequate and even application of chemical.

Release application timing and frequency are based on the type and amount of competing vegetation. Accord®, Velpar®, Weedone® (2-4-DP, Rhone-Poulenc Ag. Company, Research Triangle Park, North Carolina), Garlon® (Triclopyr-amine, Dow Agricultural Chemicals, Midland Michigan), and Arsenal® are all commonly used hardwood release chemicals. Application methods depend greatly on stand characteristics, but aerial spraying and backpack spraying are the most common application methods.

Thinning

Depending on landowner objectives, southern pine plantations may be commercially thinned prior to age 20 to remove less vigorous trees from the stand. These thinned stems are removed from the stand and marketed as pulpwood or chip-n-saw products (USDA, 1997a). Thinning encourages growth of the higher-quality trees that are left behind and captures volume that would otherwise be lost to competition-induced mortality (Smith, 1986). Stands are usually thinned to a basal area of about 70 ft^2/acre (2.6 m^2/ha). The pine stands are generally harvested at the end of the rotation at approximately 30-35 years (Smith, 1986; USDA, 1997a).

Forest Harvesting Systems

Several ground-based timber harvesting systems are currently used on wet sites in the southeastern coastal plain. The most conventional harvesting system in the southeast for almost all types of forest land in the piedmont or coastal plain involves a rubber-tired feller-buncher and grapple skidders to fell and transport timber out of the woods. This system is used for thinnings as well as final harvests at the end of rotation. This system is very cost-effective compared to other harvesting systems, and production can be adjusted with equipment additions and removals from the system. A system of one feller-buncher and two grapple skidders can produce 700 to 900 tons of wood per week. The relatively low cost of operation and versatility of this system make it the most widely utilized system in the southeast for timber harvesting (Shaffer, 1994).

Cut-to-length systems involving mechanical harvesters and forwarders are used infrequently. This sophisticated and expensive system was recently introduced into the southern United States as an environmentally friendly alternative to more conventional systems due to significantly less stand and forest floor disturbance. This system involves a mechanized rubber-tired harvester and forwarder to transport wood to the deck. The harvester processes harvested stems in the woods and deposits severed limbs in front of the forwarder, which then travels over them. This mat of limbs reduces the impact of the equipment traffic on the soil and tree roots. This system is currently being used on a very limited scale for first and second thinnings in pine plantations. This type of system is able to produce 400 to 600 tons per week of pulpwood per set of equipment (one harvester and forwarder) (Shaffer, 1994).

Wetland harvesting has historically been difficult due to the inability of loggers to operate the heavy equipment required on very wet sites. Concerns about the environmental impacts of wetland logging on residual stands have also increased the difficulty of wetland logging. The rubber-tired skidder is the most utilized piece of heavy equipment for wetland logging in the southeast (Aust, 1994). In many cases, dual tires or extra-wide high flotation tires are used to minimize soil and water impacts on very wet sites. An excavator-based shovel logger is often used to move felled timber from the stump to the logging deck on very wet sites in order to minimize ground disturbance (Stokes and Schilling, 1997).

Helicopter and cable logging systems are also utilized on a very limited scale to remove high-quality timber from very wet sites with low site impact potential. Both of these systems are based on the transportation of felled logs to the log deck with minimal ground contact. The helicopter system involves tethering logs to a hovering helicopter that transports the logs aerially to the deck. The cable system involves the use of an erected tower, power winch, pulleys, and cables to move logs across the site to the deck while minimizing contact with the ground (Aust, 1994; Stokes and Schilling, 1997).

Harvesting Impacts on Site Quality

Soil Physical Properties

Ground-based forest harvesting systems require repeated passes by heavy tracked or rubber-tired machinery. The heavy machinery can have significant impacts on soil physical and chemical characteristics (Aust, 1994). Equipment traffic disturbance severity is largely controlled by soil volumetric moisture percentage at the time of traffic. Traffic impacts on dry soils are usually minimal, while impacts on moist to wet soils are often significant (Greacean and Sands, 1980). Scheerer (1994) reviewed studies of conventional harvesting operations and found that they trafficked 17 to 48 percent of wet flat sites (Aust et al., 1993; Dickerson, 1976; Hatchell et al., 1970; Willis, 1971).

Moist soils (at or above the plastic limit) are wet enough to display plastic properties when under an applied force. Therefore, moist soils can be molded and compacted by heavy equipment traffic as the soil actually flows (Greacen and Sands, 1980). Compaction increases soil bulk density and often decreases soil macroporosity. Soils that are wet (at or above the liquid limit) will often display liquid properties and will be rutted and churned by heavy equipment traffic (Greacen and Sands, 1980; Bodman and Rubin, 1948). Equipment tires or tracks sink into the ground as a result of static forces, and tires or tracks spin when shearing forces exceed soil strength. Soil displaced from under tires or tracks moves upward and forms a rut. Heavily rutted and churned soils are referred to as puddled soils (Burger et al., 1988). Rutting and puddling of soils in skid trails have been found to alter lateral subsurface water flow across harvested sites, thereby impeding soil drainage (Aust, 1994; Miwa et al. 1998).

Compaction decreases macroporosity (Childs et al. 1989); therefore, compaction causes decreased air and water movement, infiltration, and percolation expressed as hydraulic conductivity into the soil profile (Burger, 1990). Decreased rainfall infiltration may lead to increased surface runoff and increased erosion of soil and soil nutrients (Brady, 1990). Decreased soil aeration may cause reducing conditions within the soil profile that can cause a pH change toward neutrality and can affect soil nutrient availability (Aust, 1994; Ponnamperuma, 1972). Compaction may also cause later increases in soil strength under dry soil conditions and decrease soil strength under wet conditions (Burger, 1990; Burger et al., 199; Gracean and Sands, 1980). These effects on soil strength have serious implications for tree root growth.

Overall, soil compaction can have very significant effects on the ability of tree roots to grow, respire, and collect nutrients from the soil profile. Tree root growth is restricted primarily by excessive soil strength resulting from soil compaction. Compacted soils become too strong for roots to penetrate at higher water contents, and aeration in compacted soils is limiting at lower soil moistures, restricting the soil water content range at which roots can grow (Figure 1).

This root growth window is "bounded by soil conditions of inadequate aeration and excessive soil strength. The range of water contents acceptable for root growth decreases as compaction and bulk density increases" (Childs et al., 1989) (Figure 1). From an operational perspective, this implies that excessively rutted sites have reduced periods when they are wet enough to allow root growth, and they have increased periods where excessive water hinders operations such as site preparation.

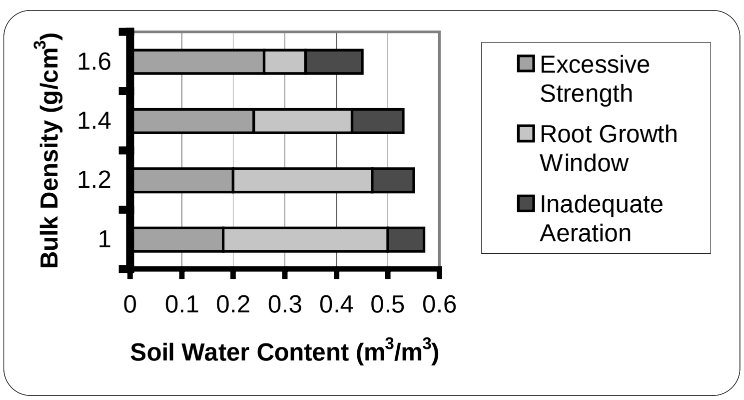

Figure 1. Root growth window chart (adapted from Childs et al., 1989).

Soil Organic Matter

Soil organic matter is central to many natural soil processes that are essential for tree growth. Organic matter in soils acts as a slow release source of nutrients that stores and cycles nitrogen, phosphorus, and sulfur (Warring and Schlesinger, 1985). Organic matter is also important for the creation and maintenance of soil macroporosity and, as a result, is important to reducing soil bulk density. Additions of organic matter to soils generally improve drainage of the soil profile with increased aeration, adequate aeration over a greater range of moisture contents, increased microbial activity, and easier plant root penetration. Soil organic matter also improves soil structure, soil water holding capacity (Childs et al., 1989), soil cation exchange capacity, and soil pH buffering capacity (Khanna and Ulrich, 1984).

Soil Organic Matter Losses and Silvicultural Activities

Soil organic matter can be greatly affected by silvicultural practices used in pine plantation forestry. Removal of the forest canopy allows sunlight to reach the ground directly and at a greater intensity. This causes an increase in soil temperature that encourages microbial decomposition of soil organic matter. Nutrients from this process may then be lost through surface and groundwater movement if the plant and tree uptake on site are not sufficient to capture and incorporate these nutrients into new biomass (Ellert and Gregorich, 1995). Large additions of slash to the forest floor during harvesting may enhance these effects. Site preparation methods such as root raking, slash piling, and windrowing concentrate organic matter into small areas on the site and thus deprive the majority of crop trees of nutrients released by the decomposition of this material. Whole-tree harvesting methods remove tree tops and branches from the site, which can result in significant loss of nutrients. Site preparation burning can also result in the loss of nutrients from the site (McColl and Powers, 1984).

Loss of this organic matter and associated plant nutrients may lead to long- and short- term soil productivity declines (Nambiar, 1996). Under unsaturated conditions, the increased decomposition of buried organic matter and any applied fertilizers will release nutrients into the soil and remaining soil moisture. Phosphate levels in soil moisture will likely be low (0.002 to 0.003 ppm) due to the tendency of phosphate to be adsorbed by clay minerals and incorporated into secondary compounds with iron and aluminum (Tisdale et al., 1985). Verry (1972) reported phosphate in groundwater values from mineral and organic soils in Minnesota that averaged 0.12 ppm prior to clearcutting and 0.17 ppm after clearcutting.

Ammonium cations released into the soil by organic matter decomposition will likely exist at easily detectable levels in soil moisture, especially under saturated conditions. Verry (1972) reported ammonium in groundwater values from mineral and organic soils in Minnesota that averaged 0.35 ppm prior to clearcutting and 0.55 ppm after clearcutting.

Ammonium cations in the presence of oxygen are converted to nitrate anions in bedded soils during unsaturated conditions (Waring and Schlesinger, 1985). These ions (nitrate) might be abundant in soil moisture because they are not attracted to the negatively charged soil cation exchange complex. Under saturated and very acidic conditions, ammonium will not be readily converted to nitrate (Tisdale et al., 1985), and soil moisture samples might have lower levels of nitrate as a result. Verry (1972) reported nitrate in groundwater values from mineral and organic soils in Minnesota that averaged 0.31 ppm prior to clearcutting and 0.16 ppm after clearcutting. Verry stated that the reduction in nitrate after harvest is not typical and was probably due to the cold climate and subsequent slow organic matter breakdown in Minnesota.

Harvesting and Site Preparation Impact Amelioration Techniques

Recently harvested forested wetlands are often mechanically site-prepared in an effort to ameliorate the harvesting process and to enhance site conditions that may limit pine plantation establishment.

Drainage as an Ameliorative Technique

Campbell and Hughes (1991) summarized the results of their wetland drainage research. Drainage of wetland sites is often used to lower average water tables and increase the periods when soils are not saturated (Hughes et al., 1990). Drainage is accomplished by digging a complex system of secondary and tertiary ditches that drain into primary ditches. Drainage is usually responsible for an 800 to 1300 percent tree growth response (Ralston, 1965) and a 3- to 5-meter increase in site index (base age 25) that is maintained through a 35-year rotation (Terry and Hughes, 1975). "During wet seasons, plantations with free drainage often have water tables 30 cm to 60 cm lower, with less fluctuation, than undrained pocosin" (Campbell and Hughes, 1991). Drainage may not actually serve as an ameliorative practice for harvesting disturbances, but drainage or water management can be used to lower water tables prior to harvest. This practice can minimize harvest disturbances by as much as 90 percent (Miwa, 1999).

Bedding as an Ameliorative Technique

Bedding of wetland sites is a process that involves either a large crawler tractor or large skidder pulling a mechanical plow (Savannah trailing 6 disc bedding plow, Georgia). The bedding plow pulls soil and organic matter upward and forms it into a long, elevated continuous strip. The surfaces of these beds are generally 0.5 to 1 foot higher than the surrounding soil surface. The bedding plow also creates a ditch on each side of the beds approximately 1 foot (0.30 m) wide and 1 foot (0.30 m) deep. The plow is pulled across the site to create a system of parallel beds at a spacing that is dictated by planting density requirements (USDA, 1997a).

Bedding is an effective treatment for reversing the soil compaction caused by heavy equipment traffic during timber harvesting (Aust et al., 1998; Belli et al., 1993). The bedding plow breaks up compacted soil into smaller aggregates, thereby decreasing soil bulk density while increasing soil macroporosity, aeration, and drainage (Allen and Campbell, 1988; Morris and Lowery, 1988). As a result, soil volumetric moisture will generally be less in the bed than in the off-bed areas. The associated improvements in aeration and root volume exploitation are important to seedling survival in forested wetlands. Bedding gang blades pile soil onto the previous soil surface and may actually leave a layer of compacted soil underneath the bed. This compacted layer may eventually inhibit root growth below the bed (USDA, 1997a). Bedding also increases effective seedling rooting volume by raising the soil surface farther above the water table and concentrates organic matter and associated nutrients near seedling roots in the bed (Attiwill et al., 1985). Bedding also partially controls early development of competing woody vegetation on the beds by destroying previously established vegetation (Williams, 1988). Bedding with and without mulching may also increase the decomposition of incorporated organic matter and subsequent release of soil nutrients within the bed by increasing exposure of organic matter to soil microbes (Waring and Schlesinger, 1985). Overall, bedding increases the volume and quality of the early seedling rooting environment (Allen and Campbell, 1988). Scheerer (1994) noted that bedding "appears to be an indispensable site preparation treatment because it increases early survival of pine seedlings and eventual stand volume."

Mulching as an Ameliorative Technique

Mulching of organic matter prior to bedding will increase the surface area of a given mass of slash and might also increase decomposition and nutrient release by further increasing exposure of organic matter to microbes. Due to poor aeration and low associated oxygen levels in saturated soils, incorporation of this organic matter might preserve it against decomposition under saturated conditions within the bed. These saturated soil conditions will not likely exist in beds for extended periods of time, especially during the growing season when evapotranspiration is high.

Incorporated organic matter additions might benefit rutted and compacted soils by mixing in the soil profile and consequently lowering the soil bulk density while increasing soil macroporosity. These changes in soil physical properties will improve soil aeration and increase suitable rooting volume within the soil profile. The "root growth window" of these amended soils might be enhanced, as discussed previously (Figure 1) (Childs et al., 1989; Warring and Schlesinger, 1985).

Organic matter incorporation and decomposition might also elevate total organic carbon levels in soil moisture in the beds. Total organic carbon concentrations vary widely in forest soil solutions and generally range from 5 to 50 ppm in A horizons, 3 to 10 ppm in B horizons, and 1 to 5 ppm in C horizons (Herbert and Bertsch, 1995). Mulholland (1981) found TOC concentrations to average 2.5 ppm in the surface water of an eastern North Carolina swamp-stream ecosystem.

Tillage as an Ameliorative Technique

Tilling mechanically mixes mineral soil and surface organic matter with a rotary tiller or a disc harrow. Tillage breaks organic matter into small pieces and incorporates it into the soil profile (Dickerson, 1976; Williams, 1988). The effects of tillage on soil physical and chemical properties are very similar to those discussed previously for bedding under unsaturated conditions (i.e., decreases bulk density, increases macroporosity, aeration, water infiltration and movement, and suitable rooting volume). Tillage alone in wetlands does not increase the elevation or volume of the rooting environment (USDA, 1997a), and organic matter decomposition and associated nutrient evolution and movement may not occur as with bedding. Aust et al. (1998) found that tillage of skid trails without bedding or fertilization actually decreased loblolly pine survival and growth compared to a non-treated skid trail on wet flat sites in South Carolina.

Tilling an area prior to bedding may result in effects on soil physical and chemical properties that are very similar to those of bedding alone. This combination, however, will ensure that compacted soil will not be buried beneath the bed and possibly inhibit root growth below the bed. This combination will also break organic matter into smaller pieces and possibly distribute it more uniformly within the bed. The smaller organic matter pieces will be more easily decomposed under unsaturated conditions and may lead to greater nutrient and carbon concentrations in soil moisture as well as increased carbon dioxide evolution.

Fertilization as an Ameliorative Technique

Scheerer (1994) noted that fertilization is less expensive than bedding or tilling (by 300-400%) and can alleviate tree nutrition problems that are often caused by the soil physical property damage done by forest harvesting (Allen and Campbell, 1988; Hart et al., 1985). Fertilization makes nutrients more available to tree root systems that are growth- prohibited by poor soil physical conditions. Nitrogen (DAP and UREA) and phosphorus (DAP - diammonium phosphate) are the most commonly applied nutrients at various rates on loblolly pine plantations in the southeast. Several researchers have noted significant height growth and survival gains in loblolly plantations that had DAP applications at or near the time of planting (Pritchett and Comerford, 1982; Wilhite and McKee, 1986). Nitrogen is often applied to loblolly pine plantations at intervals of 5 to 15 years to enhance the inherent productivity of a site.

METHODS AND MATERIALS

Site Descriptions

The study sites were in the lower coastal plain, near Washington in Beaufort County, North Carolina (latitude $37^{o}27’37’’$, longitude $77^{o}02’50’’$) on Weyerhaeuser Company lands (Figure 2). The Pamlico River flows west to east through the center of Beaufort County, and the general elevation of the county is about 25 feet (7.6 m) above mean sea level.

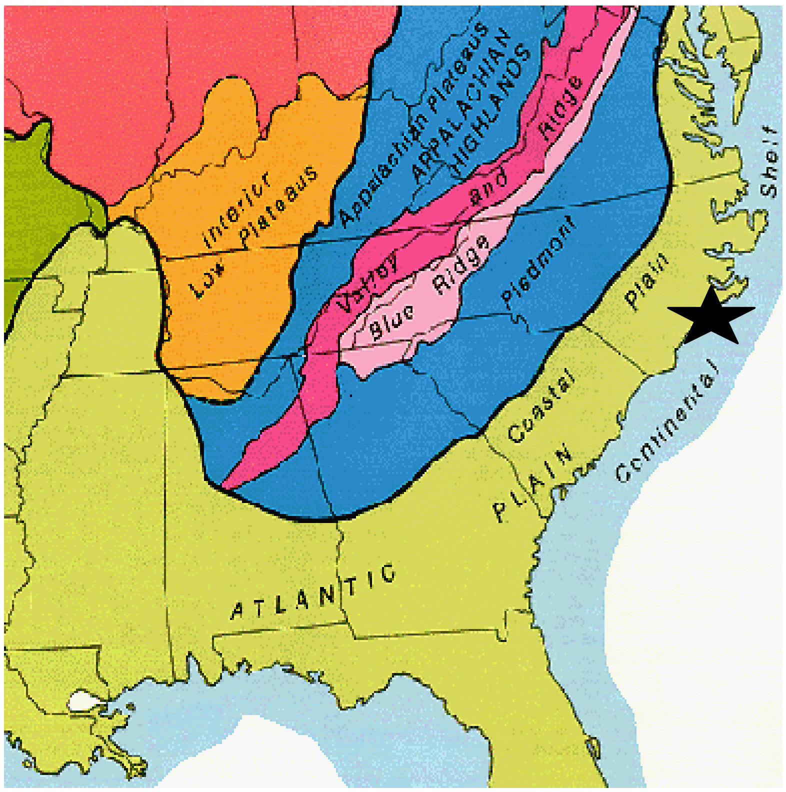

Figure 2. Map of the general physiographic provinces of the southern United States and general location of the study sites marked with a star (Miwa, 1999).

The average daily maximum temperature in January is 55^{o}F (13^{o}C) and the average daily minimum temperature is 34^{o}F (1^{o}C). The average daily maximum temperature in July is 87^{o}F (31^{o}C) and the average daily minimum temperature is 70^{o}F (21^{o}C). Total annual precipitation is approximately 53 inches (134.6 cm), with 55% falling in April through September (USDA Natural Resources Conservation Service, 1995).

The two sites were a pocosin site with a moderately deep organic surface horizon (histic epipedon) and a wet flat site having a sandy loam horizon (ochric epipedon) over a clay (argillic) subsurface horizon (USDA Soil Conservation Service, 1997b). The pocosin site is an Umbric Paleaquult (Pantego Loam) and the wet flat is an Aeric Paleaquult (Lenoir Loam) (USDA, Natural Resources Conservation Service, 1995).

The wet flat site was most recently harvested in January 1997. The trees were harvested with a conventional sawhead feller-buncher and rubber-tired skidder operation. A whole-tree chipper was used on site to chip hardwoods into fuel chips prior to transportation. This stand was established in 1970 by means of natural regeneration. On this site, approximately 5.6 cunits/acre (45.5 m^3/ha) of loblolly pine were removed as roundwood for various product uses. Approximately 12.0 cunits/acre (83.9 m^3/ha) of wood from various hardwood species were removed as chips for energy fiber uses. Common hardwood species included sweetgum, red maple, water oak, yellow-poplar (*Liriodendron tulipifera*), and black gum (*Nyssa sylvatica*). The loblolly pine site index at base age 25 years was approximately 60-65 ft (18.3-19.8 m).

The pocosin site was most recently harvested in January and August 1997. The trees were harvested with a conventional sawhead feller-buncher and rubber-tired skidder operation. A whole-tree chipper was used on site to chip hardwoods into fuel chips prior to transportation. This stand was regenerated in 1963 with direct seeding of loblolly pine. On this site, approximately 19.2 cunits/acre (134.3 m^3/ha) of loblolly pine were removed as roundwood for various product uses. Approximately 0.5 cunits/acre (3.5 m^3/ha) of wood from various hardwood species were removed as chips for pulp and energy fiber uses. Common hardwood species included red maple and water oak.

These two sites were intensively managed for the production of loblolly pine sawtimber. This management includes artificial drainage (ditching), mechanical and chemical site preparation, weed competition control, and pest control with two commercial thinnings before final harvest at age 35 to 40 years. Installation of treatments was overseen by the

USDA Forest Service and Weyerhaeuser Company. Due to the great differences between sites, each was considered to be an independent experiment.

Layout and General Statistical Design

Each treatment plot measured 132 ft (40.2 m) on each side and included 0.4 acres (0.16 ha). The center of each treatment plot served as the center of a single 1/50 acre (1/124 ha) circular measurement plot. All measurements (pre- and post-treatment) were taken in this measurement plot. A 33-ft (10.1-m) buffer of land (post-harvest condition) was left between all blocks and treatment plots (Figures 3 and 4). A hand compass and 50-foot tape were used to install these plots.

Bed-lines were positioned and marked beginning 12 feet inside the treatment plot boundary and located every 18 feet thereafter, for a total of 7 beds per plot. All bedding treatments were performed along these established locations. The treatments are described below.

- Treatment 1 (**conventional**). The conventional treatment consisted of conventional site preparation methods for the North Carolina coastal plain. These methods included a tractor-mounted (Caterpillar™ D8) V-shear blade to push slash and debris away from the bed-lines, followed by bedding with a tractor-mounted Savannah™ plow.
- Treatment 2 (**mulch/bed**). The strip-surface mulch with bedding treatment consisted of strip-surface mulching of slash and stumps along the bedline followed by traditional bedding. A tractor-mounted Rayco™ hydra stumper mulching head was used to perform the mulching tasks. This mulching head was used to mulch all slash and stumps in a 6.5-ft (2.0-m) wide strip along the left and right side of the bed line. The resulting mulched strip was 13 feet (4.0 m) wide, centered on the bed lines, and was then incorporated into the beds by the plow.
- Treatment 3 (**mulch/till/bed**). The strip mulch with tillage and bedding treatment consisted of the exact manipulations described for Treatment 2, except that the Rayco™ mulching head was set to till the soil to a soil depth of 4 inches (10.2 cm) prior to bedding.

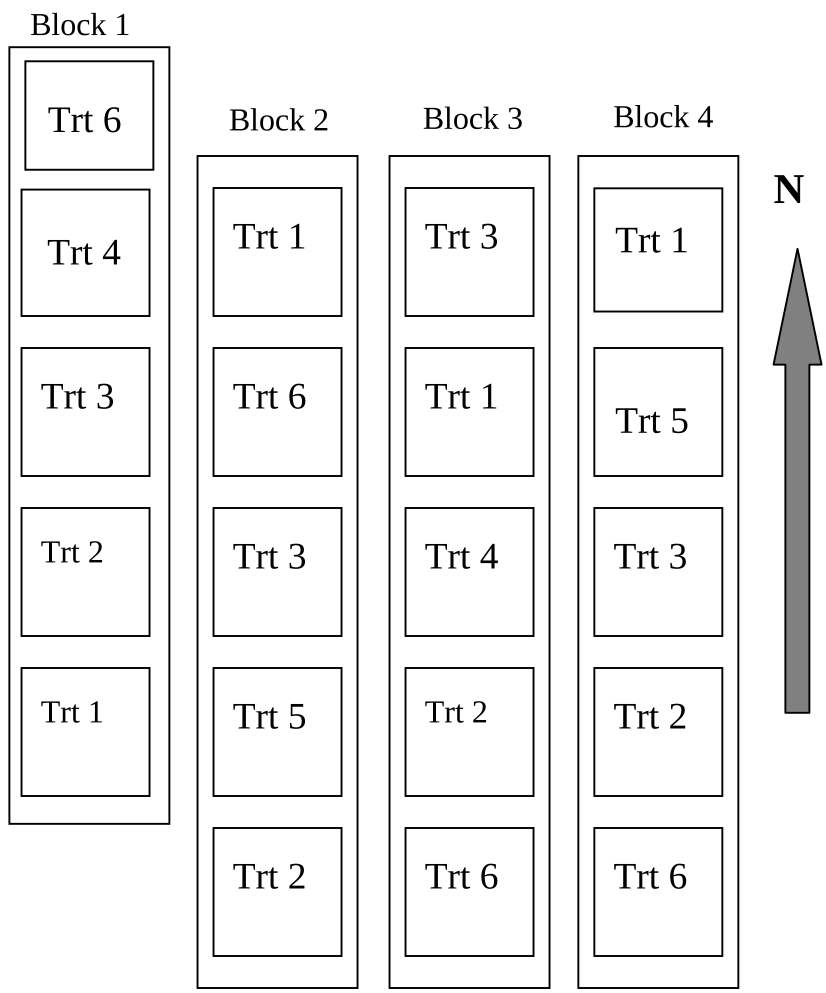

Figure 3. Layout of the treatment plots and blocks on the wet flat site. Treatment one (Trt 1) is conventional site preparation, treatment two (Ttrt 2) is strip surface mulch with bedding, treatment three (Trt 3) is strip mulch with tillage and bedding, treatment four (Trt 4) is broadcast mulch with bedding, treatment five (Trt 5) is broadcast mulch without bedding, and treatment six (Trt 6) is flat planted control. (Figure not to scale.)

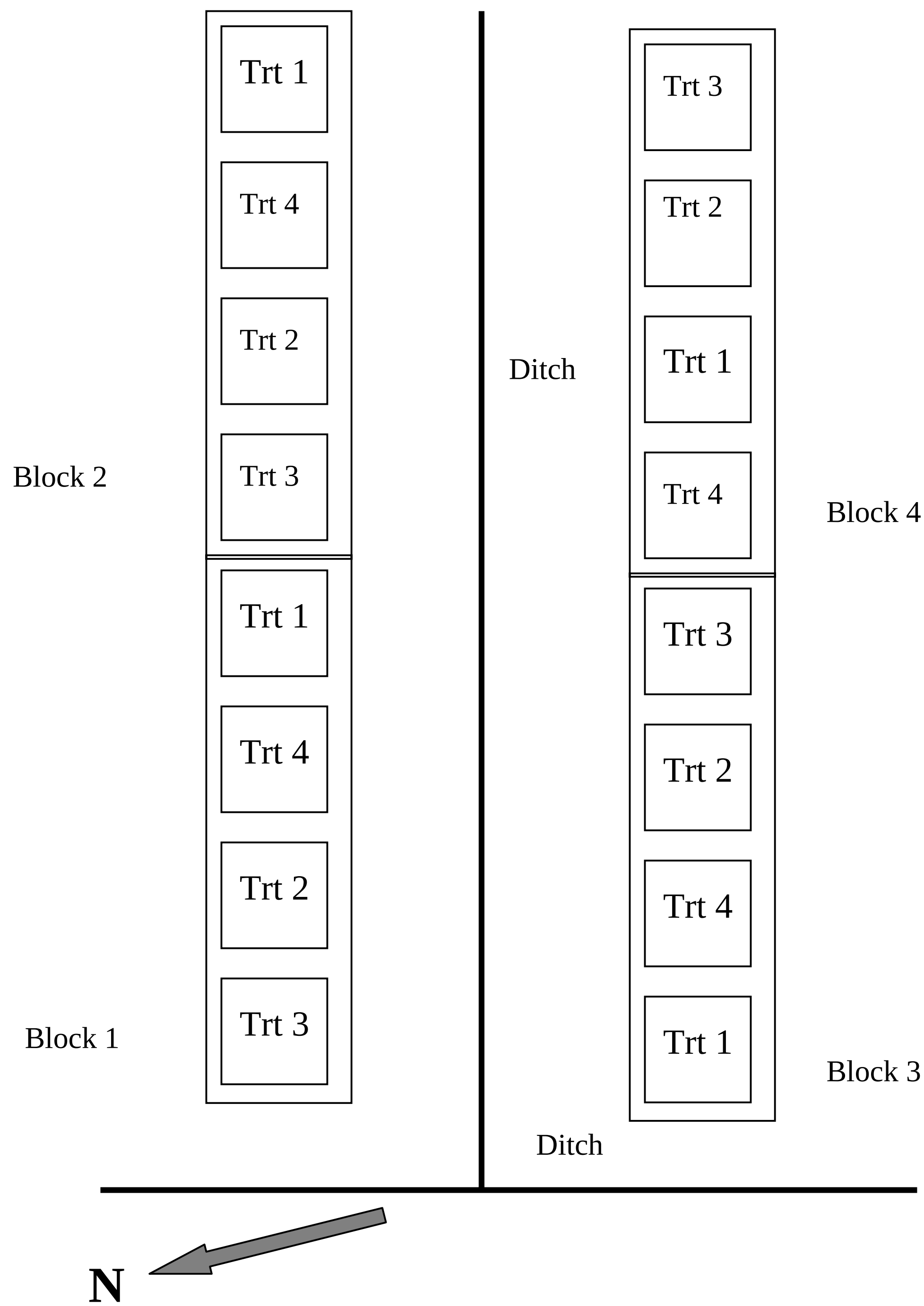

Figure 4. Layout of the treatment plots and blocks on the pocosin site. Treatment one (Trt 1) is conventional site preparation, treatment two (Trt 2) is strip surface mulch with bedding, treatment three (Trt 3) is strip mulch with tillage with bedding, and treatment four (Trt 4) is flat planted control. (Figure not to scale.)

- Treatment 4 (**broadcast mulch**). The broadcast mulch without bedding treatment was identical to Treatment 3 except that there was no bedding after broadcast mulching.
- Treatment 5 (**broad-mulch/bed**). The broadcast mulch with bedding treatment consisted of broadcast surface mulching all slash and stumps within the treatment plot followed by bedding along the bed lines.
- Treatment 6 (**flat plant/control**). This was the control treatment, which was left in post-harvest condition and flat planted.

All treatments were planted with genetically improved loblolly pine seedlings. Seedlings were pre-treated with Pounce^R (38.4% permethrine) insecticide at the nursery, and monthly backpack foliar applications began in May 1998 to control Nantucket pine tip moth (*Rhyacionia frustrana*). Backpack-applied chemical weed control was utilized across the entire experiment area to minimize competition effects. Four oz/ac Arsenal^R (Imazapyr) and 2 oz/ac Oust^R (sulfometuron-methyl) were banded along the beds for herbaceous release in April 1998. Diammonium phosphate (DAP) was pre-plant applied (banded) at a rate of 210 lbs/ac (235 kg/ha), which provided 40 lbs/ac of elemental phosphorus (44.8 kg/ha) and 35 lbs/ac of ammonium (39.2 kg/ha). These chemical treatments were applied to both study sites.

Installation of Field Instruments

Measurements were taken near two major sampling points (one on the bed, one off the bed) within each 1/50-ac (.0081-ha) measurement plot within each treatment plot that involved bedding. The on-bed and off-bed areas nearest the plot center were the areas where measurements were taken. For each treatment plot that did not involve bedding, measurements were taken at one location within each measurement plot. The following instruments were installed within each of the measurement plots:

1. One WL-40 groundwater stage recorder (Remote Data Systems Inc., Whiteville, North Carolina) was installed on the wet flat, and two were installed on the pocosin site, to provide a continuous measure of water table fluctuations. The stage recorders were installed using a 4-inch bucket auger. The well screens were backfilled with sand and sealed at the ground surface with bentonite clay. These stage recorders were located in a

measurement plot within a control plot so that measurements of site hydrology within each well could be correlated with the WL-40 measurements. The stage recorders were set to take measurements 4 times during each 24-hour day. Measurement times were set at 12:00 midnight, 6:00 a.m., 12:00 noon, and 6:00 p.m. EST.

2. One standard soil profile description was conducted to a depth of 6 ft (2 m) in both the on-bed and off-bed areas within each measurement plot (Appendix B). A 3-inch bucket auger and profile tray were used. One description was conducted in plots that did not have beds.
3. These augered holes were used later to install two water table wells (1 on-bed, 1 off-bed) within each measurement plot with beds. One well was installed on each measurement plot without beds. These wells were constructed from schedule 40 PVC pipe and were 6.5 ft (2.0 m) long and 2.5 in (6.4 cm) in diameter. Holes approximately 0.25 in (0.64 cm) in diameter were drilled into the PVC pipe lengths with a drill press. The wells were placed in the 3-inch auger holes and backfilled with native soil. The soil surface around each was sealed with bentonite clay to prevent surface water contamination.
4. One tension lysimeter was installed in each of the upper three soil horizons on the pocosin site and the upper two soil horizons on the mineral site within the measurement plots. Each bedded plot had lysimeters both on and off the bed. A 4-inch bucket auger was used to create the installation holes and native soil backfill was used to secure the lysimeters in the holes. These lysimeters were used to collect soil water chemistry samples that were later analyzed for nitrogen (NO_3^- and NH_4^+), phosphate, and total organic carbon (TOC). The tension lysimeters were constructed at Virginia Tech according to the design of Wagner (1962).
5. Soil volumetric moisture percent was also measured in the immediate vicinity of each well, both on-bed and off-bed. Measurements were taken in the upper three soil horizons on the pocosin site and the upper two soil horizons on the wet flat site with a time domain reflectometry (TDR) meter (Trase Systems Inc., and Soil Moisture Equipment Corp., Santa Barbara, California). Sampling rods were permanently installed in each horizon. The sampling rods (5/32 inch in diameter) were stainless steel welding rods without flux that were 36 inches (91.4 cm) long. These rods were cut to desired lengths to fit the

horizon depths for each plot using a manual impact cable cutter. A hammer was used to insert these rods into the ground.

6. A rusty rod was inserted by hand near each well location (on-bed and off-bed) so that the average reducing conditions for iron could be evaluated. The rods were regular steel welding rods without flux 36 inches long and 5/32 inch in diameter. The upper 4 inches of each rod were bent over at a 90^o angle to facilitate installation and regular field inspection (Bridgham et al. 1991).

Sampling

Soil Properties and Characterization

Intact Soil Cores

Two standard 2-in (5.1-cm) diameter x 2-in long cylindrical soil cores were collected by USDA Forest Service crews prior to treatment installation on each site from each horizon. Core samples were collected using a bucket auger, bulk density double cylinder sampler, and metal cores (Blake and Hartage, 1986). The horizons sampled were A, E, and Bt in the wet flat and Oa, A, and Btg in the pocosin in each measurement plot. These cores were used to evaluate soil bulk density (g/cm^3), micro-, macro-, and total porosity (%), and saturated hydraulic conductivity (cm/hr) on the treatment plots prior to treatment. These parameters were evaluated using laboratory methods described by Blake and Hartage (1986), Daniels and Sutherland (1986), and Klute and Dirksen (1986).

Post-treatment soil cores were taken in the same manner both on-bed and off-bed. The post-treatment horizons sampled were the A + E combined and the Bt off the beds and the Ap and Bt on the beds in the wet flat. The post-treatment horizons sampled in the pocosin were the Oa, A, and Btg off the beds and the Ap, A, and Btg on the beds. Only data from the on-bed Ap horizon on the bedded plots and the off-bed A+E or Oa horizon on the non-bedded plots were analyzed post-treatment. It was assumed that the treatment effect on soil physical properties below the plow layer was negligible. The pre-treatment data were analyzed to determine if the study site was uniform with respect to these parameters, while the post-treatment data were analyzed to determine the effects of the treatments on these parameters.

Loose Bulk Soil Samples

Loose soil samples were collected from the treatment plots in both study sites prior to treatment. The horizons sampled were the A, E, and Bt in the wet flat and the Oa, A, and Btg in the pocosin. Post-treatment loose soil samples were collected from the immediate vicinity around each on-bed well from each soil horizon within each measurement plot. The Ap horizon was sampled at both study sites. These samples were analyzed for soil organic carbon utilizing the Leco CR12 carbon analyzer (Leco Corporation, 1987). The pre-treatment data were analyzed to determine if the study site was uniform with respect to these parameters, while the post-treatment data were analyzed to determine the effects of the treatments on these parameters.

Periodic Repeated Measurements

Water Nutrients and Carbon

One of the major concerns about these treatments was the concentration and movement of nutrients and dissolved carbon in soil water within the soil profile. Soil water was extracted through the tension lysimeters in each soil horizon within each measurement plot on each study site, as described previously. A hand-operated irrometer-style vacuum pump was used to apply tension to the lysimeters 24 hours prior to the desired sampling period. The accumulated water samples were extracted from the lysimeters using the vacuum pump and a 500-ml Erlenmeyer flask (Wagner, 1962). The flask used to collect water samples from the lysimeters was rinsed with deionized distilled water after each sample to prevent contamination. In the laboratory, the samples were filtered through Whatman^{R} No.1 qualitative filters that retain particulates larger than 11 microns. The filtered samples were then frozen and stored until lab procedures could be performed.

These samples were analyzed for nitrogen (NO_3^- and NH_4^+), phosphate, and total organic carbon (TOC). Ammonium analysis utilized the colorimetric method (industrial method numbers 270-73W) utilized by the Technicon^{TM} AutoAnalyzer II (Technicon, 1973). Nitrate was analyzed by ion chromatography as performed by Dionex (1998) utilizing the EPA method as described by Pfaff (1993). Phosphate was analyzed using the colorimetric method described in Methods of Soil Analysis: Part 2 as "Phosphorus Soluble in Water'' (Olsen and

Sommers, 1982). Total organic carbon analysis utilized the persulfate carbon oxidation method performed by the Dohrmann DC 80 carbon analyzer (Dohrmann Inc., 1985). All values were reported as ppm in solution.

Data from the on-bed lysimeter water samples were used for bedded treatments. Off-bed water sample data were averaged with on-bed data and analyzed to determine the effect of the treatment on the plot as a whole, but the results for the combined data were not included in the analysis due to lack of significant findings. The statistical results of that data set were very similar to those from the on-bed only data sets. The effect of the growing and dormant seasons on the water chemistry data was left from the original model due to the low number of water samples collected during the unusually dry fall and winter months.

Soil Volumetric Moisture Percentage

The TDR measurement rods were installed to cover the upper two soil horizons on the wet flat study site and the upper three horizons on the pocosin study site. At each measurement station, a pair of rods was installed to the lower boundary of the upper horizon. Another pair of rods was installed through the upper horizon and to the lower boundary of the middle horizon or to the maximum length of the rod. On the pocosin site only, another pair of rods was installed through both the upper and middle horizons extending to the lower boundary of the lower horizon or to the maximum length of the rod (36 inches). This allowed for the measurement of the upper horizon independently, the measurement of the upper two horizons combined, and the measurement of the upper three horizons combined.

A ratio system was used to determine the soil volumetric moisture percentage of each horizon independently from cumulative TDR measurements (Figure 5).

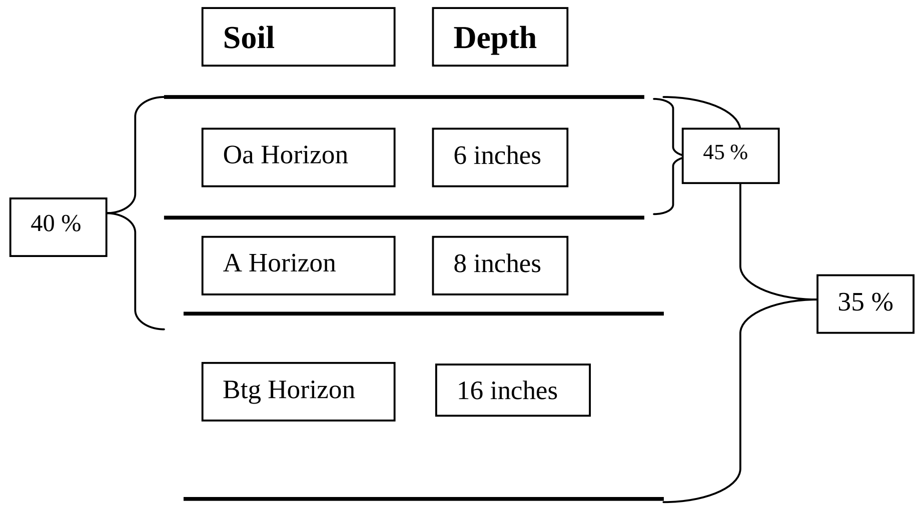

Figure 5. The ratio method used to determine the volumetric moisture percentage of each soil horizon on each site for the site preparation study near Washington, North Carolina.

This figure diagrams a soil profile and the associated horizon depths and volumetric moisture percentages as measured in the field with the TDR meter. The following calculations demonstrate how volumetric moisture percentage values were calculated for each horizon.

$$[(6 \text{ in}) \times (45\%)] + [(8 \text{ in}) \times (y\%)] = [(14 \text{ in}) \times (40\%)]$$

Solving for *y* reveals that the volumetric moisture percentage for the A horizon is 36.25%. The volumetric moisture percentage for the Btg horizon is solved for in a similar manner:

$$[(6 \text{ in}) \times (45\%)] + [(8 \text{ in}) \times (36.25\%)] + [(16 \text{ in}) \times (z\%)] = [(30 \text{ in}) \times (35\%)]$$

Solving for *z* reveals that the volumetric moisture percentage for the Btg horizon is 30.63.

Depth of Iron Oxidation

The depth of iron oxidation within the soil profile was measured on and off the bed within each measurement plot on each site using the rusty rod technique (Kelting, 1999). This measurement represents the average depth of iron-reducing conditions from the soil surface. This approximates the depth at which anaerobic microbes have removed soil oxygen and reduced iron within the soil profile. These iron rods were monitored approximately monthly.

Rods were extracted and the depth to which the iron rod surface was oxidized was measured. The rod was then reinserted.

Elevation of Water Table

The elevation of the ground at each well riser was determined by differentially leveling each location. These elevations were based on a common reference on each study site. The reference on each site was assigned an arbitrary elevation of 100 feet (30.5 m). All well readings were then compared to this reference elevation to determine the depth of the water table at each well below the reference point.

The measured well elevations were examined, and the well with the highest elevation on each study site was assigned a new arbitrary elevation of zero inches. The elevation of each well on the site was then compared to this zero elevation, and a negative elevation for every other well was calculated. The negative elevation for each well was then subtracted from the positive depth of water table below soil surface value for each corresponding well. The result is the elevation of the water table in that well as compared to the standard elevation (0) of the highest well. This is also the depth of the water table of each well below the soil surface elevation of the highest well. These predicted water table elevations were correlated with the daily water table depth predictions to predict a water table elevation for each day of the year.

Depth to Water Table

The height of each well above the ground after installation, or "riser height," was measured and recorded. A well reader was manufactured using a 1-inch diameter PVC pipe 7 feet (2.1 m) long. The well reader was inserted into each well to determine the distance to the water table below the top of the well riser. The riser height was then subtracted from each reading to find the depth of the water table below the soil surface. All wells were measured monthly.

The well reading was taken in centimeters from the top of the well to the water level in the well. The known riser height was then subtracted from this reading to find the depth of the water table below the soil surface at the time of the reading. The reading of the WL-40 stage recorder(s) on each site was then recorded for that day and time as well. The well readings accumulated over time were then correlated with the corresponding stage recorder readings, and a linear regression prediction equation was produced for each well on each site. With this equation, it was possible to use daily stage recorder measurements to predict a daily well water level for each well on each study site.

Seedling Height and Survival

The mean height (cm) and survival (%) of planted tree seedlings in the central portion of the treatment plots was measured prior to the beginning of the second growing season. The bed closest to each plot center was chosen, along with one bed each on the right and left. The 10 trees on each bed closest to the plot center were chosen for measurement. Trees with missing or brown needles were counted as dead and not measured for height. Spaces missing trees altogether were counted as dead trees. All living trees were tallied, and the height of the terminal buds above the ground was measured in centimeters.

The number of live trees was divided by 30 (maximum number) to determine the survival percentage for each treatment plot. The tree heights for each plot were also averaged to obtain a mean tree height for each treatment plot.

Data Analysis

The experiment on the wet flat site was analyzed as an incomplete block design, while the experiment on the pocosin site was analyzed as a randomized complete block design, each with four blocks. Analysis of variance procedures were used to test hypotheses about treatment least square means. The general model is described in Tables 1 and 2.

Tukey's studentized range mean separation tests were used to determine the alpha values between treatment means. An alpha value of 0.10 was used to determine significant differences unless noted otherwise (Ott, 1993).

The soil water chemistry and soil moisture percentage data were analyzed with the plots split by soil horizons (Tables 3 and 4).

Table 1. General model* used for the analysis of variance procedure for the site preparation study on the wet flat site near Washington, North Carolina.

Source	Degrees of Freedom
Treatment	4
Block	3
Error	12
Total (corrected)	19

*This model varied depending upon which parameter was being analyzed.

Table 2. General model* used for the analysis of variance procedure for the site preparation study on the pocosin site near Washington, North Carolina.

Source	Degrees of Freedom
Treatment	3
Block	3
Error	9
Total (corrected)	15

*This model varied depending upon which parameter was being analyzed.

Table 3. Models used to analyze soil water chemistry and soil moisture percentage data for the site preparation study on the pocosin site near Washington, North Carolina.

Source	Degrees of Freedom	
Treatment	(t-1)	3
Block	(b-1)	3
Error a	(t-1) (b-1)	9
Horizon	(h-1)	2
Horizon*Trt	(h-1) (t-1)	6
Error b		24
Total (corrected)	(tbh)-1	47

Table 4. Models used to analyze soil water chemistry and soil moisture percentage data for the site preparation study on the wet flat site near Washington, NC.

Source	Degrees of Freedom	
Treatment	(t-1)	4
Block	(b-1)	3
Error a	(t-1) (b-1)	12
Horizon	(h-1)	1
Horizon*Trt	(h-1) (t-1)	4
Error b		15
Total (corrected)	(tbh)-1	39

RESULTS AND DISCUSSION: WET FLAT SITE

Intact Soil Cores and Bulk Soil Samples

The intact soil core and bulk soil samples were analyzed to determine the homogeneity of the soil properties on the study site prior to treatment installation and the effect of the treatments on soil physical properties. Laboratory methods were performed to determine bulk density (BD), saturated hydraulic conductivity (Ksat), and porosity (micro-, macro-, and total) of the soil cores. Laboratory methods were performed to determine the percentage of organic carbon in the soil samples.

Pre-Treatment

The saturated hydraulic conductivity, bulk density, microporosity, macroporosity, total porosity, and soil organic carbon data show that the null hypotheses for the treatment effect (H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$) were not rejected at the $\alpha = 0.10$ level (Table 5). There were no significant differences between treatment least square means, and the wet flat site was homogeneous prior to treatment with respect to all of these variables.

The null hypotheses for the horizon effect ($H_o : H_1 = H_2 = H_3$) were not rejected at the $\alpha = 0.10$ level for Ksat and total porosity, but it was determined that bulk density, microporosity, macroporosity, and organic carbon percentage varied by soil horizon when pooled across all treatments (Table 5). Soil bulk density generally restricts root and tree growth at approximately 1.4 g/cm^3 in fine-textured soils (Gent et. al., 1984). The wet flat bulk densities (Table 6) range from 1.36 to 1.46 pooled across all horizons. There are no significant differences between horizon ls means ($\alpha = 0.10$). These values correspond well with those of Gent and Morris (1986), which reported a post-harvest range of 1.50 to 1.62 g/cm^3, and Gent et. al., (1984), which reported a post-harvest range of 1.36 to 1.51 g/cm^3.

Table 5. Partial analysis of variance information for the wet flat site pre- and post-treatment intact soil core and bulk soil sample data. The reported P-value (no parentheses) is the probability of committing a Type I error (incorrectly rejecting the null hypothesis) where H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$ for the treatment effect and H_o : $H_1 = H_2 = H_3$ for the horizon effect. The reported F-value for each effect is in parentheses below each corresponding P-value.

Source	Ksat		Bulk Density		Microporosity		Macroporosity		Total Porosity		Soil Organic Carbon	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Treatment	0.309 (1.37)	0.688 (0.64)	0.814 (0.44)	0.045 (3.45)	0.248 (1.57)	0.003 (8.30)	0.174 (1.90)	0.171 (1.96)	0.374 (1.19)	0.055 (3.21)	0.559 (0.82)	0.015 (4.76)
Horizon	0.300 (1.26)		0.011 (5.32)		0.054 (3.24)		0.027 (4.11)		0.126 (2.24)		0.000 (41.93)	
Trt*Horizon	0.418 (1.07)		0.354 (1.16)		0.884 (0.49)		0.836 (0.55)		0.899 (0.46)		0.540 (0.85)	

Table 6. Treatment effect least square means by horizon for the wet flat site pre- and post-treatment intact soil core and bulk soil sample data. Treatment significance at α = 0.10 is indicated by lower case letters listed with the least square mean values (pooled across all horizons). Post-treatment data was for the Ap horizon only.

Treatment	Horizon	Ksat		Bulk Density		Microporosity		Macroporosity		Total Porosity		Soil Organic Carbon	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
		cm/hour		g/cm^3		%							
Conventional	Ap	0.35	2.80 a	1.33	1.02 ab	42.3	42.70 a	6.90	14.03 a	49.15	56.74 ab	3.73	4.26 ab
	Bt1	1.47	---	1.52	---	39.3	---	4.86	---	44.14	---	0.94	---
	Bt2	0.17	---	1.35	---	42.4	---	4.25	---	46.66	---	---	---
	pooled	0.67 a	---	1.40 a	---	41.3 a	---	5.34 a	---	46.65 a	---	2.34 a	---
Mulch/Bed	Ap	0.36	15.78 a	1.36	1.04 ab	43.6	45.29 ab	6.20	12.07a	49.81	57.36 ab	2.33	5.13a
	Bt1	2.89	---	1.43	---	40.4	---	5.19	---	45.57	---	0.67	---
	Bt2	1.66	---	1.40	---	42.7	---	5.31	---	48.00	---	---	---
	pooled	1.64 a	---	1.40 a	---	42.2 a	---	5.60 a	---	47.79 a	---	1.50 a	---
Mulch/Till/ Bed	Ap	0.21	0.43a	1.47	1.27 a	37.2	40.94 a	6.17	9.86 a	43.39	50.80 a	3.19	5.00 a
	Bt1	0.01	---	1.50	---	38.9	---	4.49	---	43.43	---	0.71	---
	Bt2	0.16	---	1.40	---	42.0	---	3.67	---	45.66	---	---	---
	pooled	0.13 a	---	1.46a	---	39.4 a	---	4.78 a	---	44.16 a	---	1.95 a	---
Broadcast Mulch	Ap	0.04	0.07 a	1.43	0.94 ab	37.7	60.32 c	8.81	6.56 a	46.53	66.90 b	3.33	1.61 c
	Bt1	0.23	---	1.44	---	37.5	---	8.65	---	46.08	---	1.07	---
	Bt2	0.03	---	1.19	---	39.5	---	5.85	---	45.31	---	---	---
	pooled	0.10 a	---	1.36 a	---	38.2 a	---	7.77 a	---	45.97 a	---	2.20 a	---
Broadcast Mulch/Bed	Ap	0.24	0.04 a	1.32	0.95 ab	42.4	43.48 ab	6.90	17.60 a	49.30	61.06 ab	3.03	5.31 a
	Bt1	1.02	---	1.46	---	38.7	---	7.97	---	46.69	---	0.84	---
	Bt2	1.07	---	1.47	---	43.5	---	6.58	---	50.16	---	---	---
	pooled	0.78 a	---	1.42 a	---	41.5 a	---	7.15a	---	48.71a	---	1.93a	---
Flat Plant/ Control	Ap	0.44	1.05 a	1.29	0.81 b	41.3	53.19 bc	10.99	13.52 a	52.33	66.67 b	4.91	2.54 bc
	Bt1	0.13	---	1.50	---	38.5	---	6.80	---	45.30	---	0.95	---
	Bt2	2.25	---	1.41	---	40.7	---	6.07	---	46.75	---	---	---
	pooled	0.94 a	---	1.40 a	---	40.2 a	---	7.95 a	---	48.13 a	---	2.93 a	---

Macroporosity decreased significantly with depth, as expected due to the clay loam texture of the A+E horizon and the clay texture of the Bt horizons. The differences between horizon least square means are due to the root growth-restricting bulk densities on this site and the inability of roots to penetrate into the Bt horizons of the profile. Total porosity did not vary by horizon or treatment, while microporosity varied by horizon, but this variation is unexplained (Tables 5 and 6). The soil organic carbon ls mean was greater in the A+E horizon than in the Bt (Table 5) due to the natural concentration of organic matter near the soil surface.

The on-bed saturated hydraulic conductivity ls means (table 6) are relatively low when compared to undisturbed wet flat values reported by Aust et al. (1993), which ranged from 44.6 cm/hr to 57.8 cm/hr at soil macroporosity values of 18 and 20.6%, respectively. The same study also reported post-harvest disturbed and rutted soil Ksat values for the same wet flat of 20.5 and 0.2 cm/hr at macroporosity values of 12.2 and 11.4%, respectively. Table 6 reports macroporosity values ranging from 4.78 to 7.95%, which explains the low Ksat values measured for these post-harvest highly disturbed clay soils. Marshall and Holmes (1979) reported that fine-textured soils generally have Ksat values less than 0.036 cm/hr. Saturated hydraulic conductivity is generally correlated positively with macroporosity (Aust et al., 1993) and the wet flat pre-treatment data (Table 6) support that contention.

Post-Treatment

The data show that the null hypothesis for the treatment effect (H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$) is not rejected at the $\alpha = 0.10$ level for Ksat and macroporosity, but there were significant treatment differences for bulk density, microporosity, total porosity, and soil organic carbon percentage (Table 5).

Bulk density was higher for the mulch/till/bed treatment than for the flat/planted control treatment, but no other treatment differences were detected. It is likely that the soil tillage prior to bedding served to actually increase bulk density in the Ap horizon. This could be caused by the small losses in macroporosity due to excessive tillage that were significant at $\alpha > .10$ (Tables 5 and 6). Micro- and total porosity were higher in general on the unbedded treatments (broadcast mulch and flat planted/control) due to the tillage involved with bedding and the associated loss of natural soil porosity. This tillage did not have a significant effect on macroporosity values (Table 5, Figure 6).

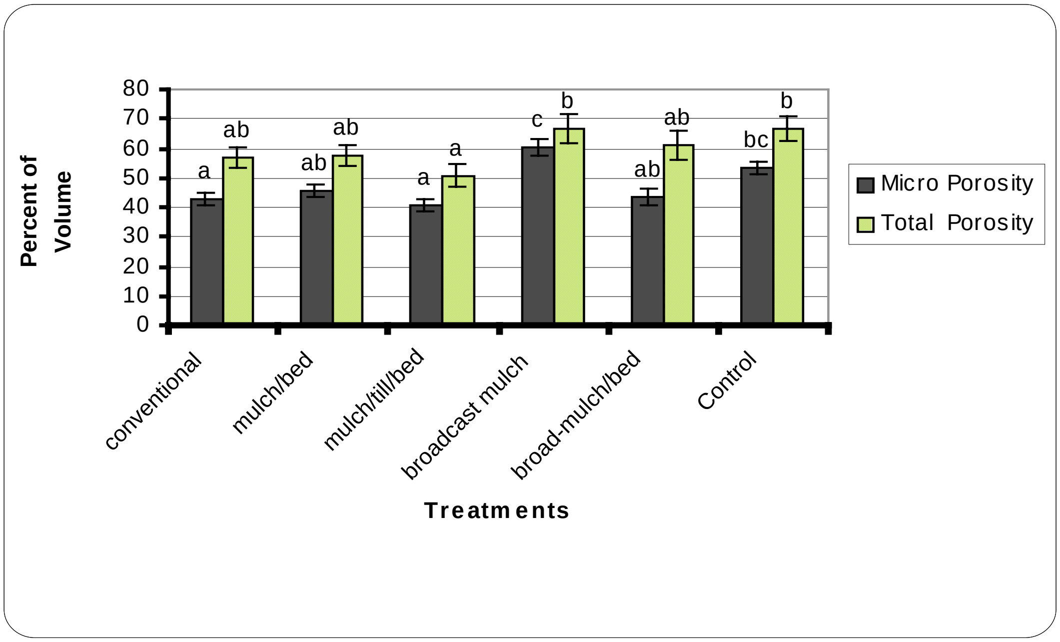

Figure 6. Wet flat site micro- and total porosity least square means and standard error bars for the on-bed Ap horizon data sets. Lower case data labels indicate significance at the α = .10 level.

The organic carbon percentage ls means were significantly greater for the bedded treatments (Table 6) due to the incorporation of slash into the bed and subsequent breakdown of that slash. The exception is that the conventional treatment was not significantly greater than the control treatment (Figure 7). This is probably due to the relatively large size of incorporated slash in the conventional beds (no mulching). The slash mulching involved with the other bedded treatments broke organic matter into smaller pieces that decomposed more quickly and completely, thus elevating organic carbon percentages further in the fine soil fraction.

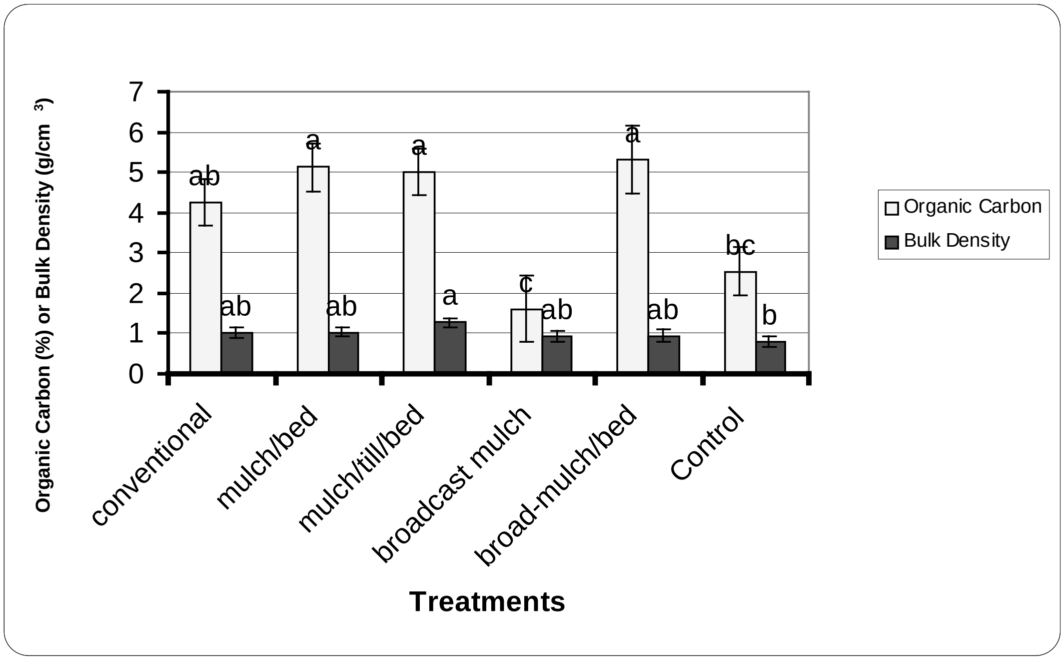

Figure 7. Wet flat site post-treatment bulk density and soil organic carbon least square means and standard error bars for the on-bed, Ap horizon data sets. Lower case data labels indicate significance at the α = .10 level.

Periodic Repeated Measurements -- Wet Flat Site

Groundwater Chemistry

The soil water samples were collected from tension lysimeters in the field, and laboratory procedures were performed to determine the concentration of ammonium, nitrate, phosphate, and total organic carbon.

The wet flat site on-bed ammonium, nitrate, phosphate, and total organic carbon data reveal (Table 7) that the null hypothesis for the treatment effect (H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$) is not rejected at the $\alpha = 0.10$ level. As a result, it is determined that there are no significant differences between treatment least square means (Tables 7 and 8, Figure 8) for these variables on the wet flat site. This is probably due to the significant fertilizer rates applied across all treatments. These fertilizer applications confound any nutrient differences created by the organic matter and soil manipulations involved with the treatments.

The null hypothesis for the horizon effect (H_o: $H_1 = H_2$) is not rejected at the $\alpha = 0.10$ level for ammonium or nitrate, but significant differences between horizons were detected for phosphate and total organic carbon (Table 7) when horizon ls means were pooled across all treatments. Those horizon differences were not always significant within individual treatments due to the substantially fewer measurements and thus larger standard errors associated with horizon ls means within any single treatment (Table 8).

Table 7. Partial analysis of variance information for the wet flat site post-treatment, on-bed soil water chemistry data including ammonium, nitrate, phosphate, and total organic carbon. The reported P-value (no parentheses) is the probability of committing a Type I error (incorrectly rejecting the null hypothesis) where H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$ for the treatment effect and H_o : $H_1 = H_2 = H_3$ for the horizon effect. The reported F-value for each effect is in parentheses below each corresponding P-value.

Source	NH_4^+	NO_3^-	Phosphate	TOC
Treatment	0.1448 (2.08)	0.6741 (0.64)	0.3903 (1.15)	0.7985 (0.46)
Horizon	0.1468 (2.36)	0.1233 (2.72)	0.0131 (2.72)	0.0001 (37.44)
Trt*Horizon	0.1351 (2.04)	0.6369 (0.69)	0.4105 (1.09)	0.4188 (1.07)

The data indicate that ammonium and nitrate concentrations tend to be greater in the Ap horizon at alpha levels less than 0.15. This suggests that most nitrogen from fertilizer and organic matter is concentrated in the upper horizon, but some nitrogen is probably leaching into the Bt horizon with water percolation (Table 8, Figure 8). The tendency of precipitation to perch above the Bt horizon partially explains why nitrate is not leaching extensively. Ammonium ions do not leach in groundwater and typically remain concentrated in the upper soil horizons.

Phosphate concentrations were significantly greater in the Ap horizon than in the Bt horizon (Table 8, Figure 8). This is due to the organic matter and fertilizer applications in the Ap horizon and the lack of mobility of phosphorus in soil water. Labile phosphorus is quickly bound with soil minerals to form stable compounds that are not affected by water movement.

Some of these phosphorus-containing compounds are slowly broken down to release labile phosphorus as the labile pool is depleted (Waring and Schlesinger, 1985).

Table 8. Treatment effect least square means and associated standard error values (in parentheses) for the wet flat site post-treatment, on-bed soil water chemistry data. Horizon within treatment and treatment significance at $\alpha = 0.10$ are indicated by lower and upper case letters, respectively, listed with the least square mean values.

Treatment	Horizon	NH_4^+	NO_3^-	Phosphate	TOC
		-------------------- ppm --------------------			
Conventional	Ap	5.75a (1.06)	3.51a (1.23)	0.68a (0.38)	93.35a (23.71)
	Bt1	0.29b (1.06)	0.25a (1.23)	0.04a (0.38)	61.35a (23.71)
	pooled	3.02A (0.76)	1.88A (0.93)	0.36A (0.27)	77.35A (19.98)
Mulch/Bed	Ap	0.35a (1.06)	1.81a (1.42)	0.92a (0.38)	93.1a (23.71)
	Bt1	0.30a (1.06)	0.68a (1.23)	0.04a (0.38)	11.63a (23.71)
	pooled	0.33A (0.76)	1.24A (0.93)	0.48A (0.27)	52.39A (19.98)
Mulch/Till/Bed	Ap	0.63a (1.06)	3.61a (1.23)	0.99a (0.38)	108.43a (23.71)
	Bt1	0.23a (1.06)	0.76a (1.23)	0.06a (0.38)	10.32b (23.71)
	pooled	0.44A (0.76)	2.18A (0.93)	0.53A (0.27)	59.37A (19.99)
Broadcast Mulch	Ap	0.32a (1.49)	0.42a (1.74)	0.00a (0.54)	79.37a (33.54)
	Bt1	0.25a (1.49)	0.36a (1.74)	0.02a (0.54)	11.23a (33.54)
	pooled	0.29A (1.07)	0.39A (1.32)	0.01A (0.39)	45.30A (28.27)
Broadcast Mulch/Bed	Ap	0.30a (1.49)	0.78a (1.74)	2.26a (0.77)	124.47a (33.54)
	Bt1	0.09a (1.49)	0.47a (1.74)	0.01a (0.54)	14.78b (33.53)
	pooled	0.19A (1.07)	0.62A (1.32)	1.13A (0.47)	64.91A (23.71)
Flat Plant/Control	Ap	0.34a (1.06)	0.28a (1.23)	0.01a (0.38)	64.91a (23.71)
	Bt1	0.11a (1.06)	0.28a (1.23)	0.00a (0.38)	12.81a (23.71)
	pooled	0.23A (0.76)	0.28A (0.93)	0.01A (0.27)	38.86A (19.99)

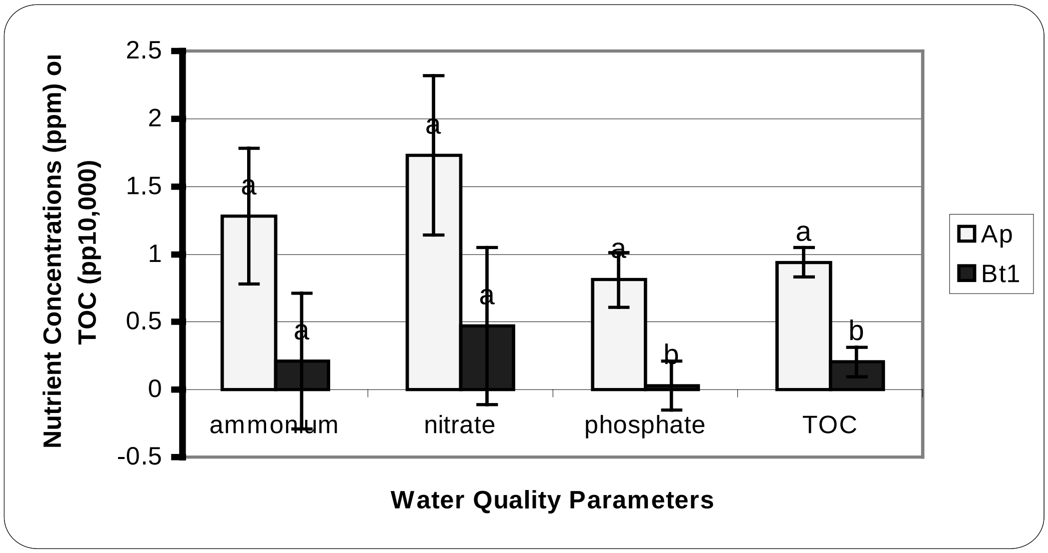

Figure 8. Wet flat site post-treatment, one-year average water nutrient concentration ls means pooled across all treatments. Significance between horizons within each parameter is indicated by lower case letters.

The total organic carbon data indicate that most dissolved carbon-containing compounds remain concentrated in the Ap horizon near the incorporated organic matter (Table 8, Figures 8 and 9). The Bt1 concentration indicates that a relatively small amount of dissolved carbon did move with water percolation into the Bt1 horizon. The tendency of precipitation to perch at the top of the Bt1 horizon partially explains the lack of TOC movement into the Bt1 horizon (Herbert and Bertsch, 1995).

These ls mean Bt horizon ammonium and nitrate values correspond well with those reported by Otte and Loftin (1983) for a Croatan National Forest mineral soil (0 to 0.70 ppm and 0 to 0.19 ppm, respectively). Ammonium, nitrate, and TOC values reported by Perison et al. (1997) for a wetland site (mineral soil) logged conventionally are 0.95, 0.002, and 21.6 ppm, respectively. These values also are comparable to the values for both horizons reported in Table 8. Noltemeier (1984) also monitored the waters of E. Brice Creek and Mill Creek in Croatan National Forest and reported ammonium, nitrate, and phosphate concentration ranges of 0.02-0.05 ppm, 0.87-0.99 ppm, and 0-0.095 ppm, respectively. All these values compare reasonably to the values for the wet flat site reported in Table 8 and Figure 8.

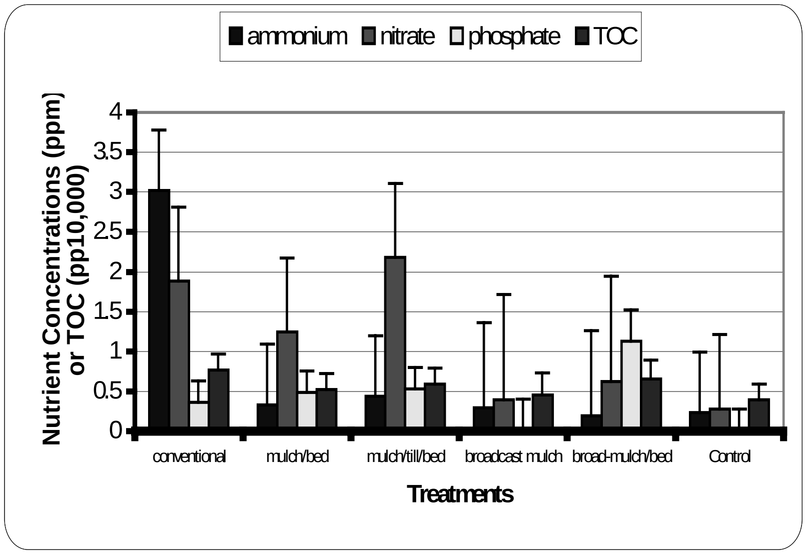

Figure 9. Wet flat site soil water nutrient (ppm) and TOC (pp10,000) concentrations pooled across all horizons by treatment.

Site Hydrologic Factors

Site hydrologic data such as soil volumetric moisture percentage, depth of iron oxidation, water table elevation, and water table depth below the soil surface were analyzed to determine the effects of the treatments on soil moisture and site hydrology relationships. On-bed data only were used for bedded treatments, and off-bed data were used for the unbedded treatments. The horizon effect was analyzed for the soil volumetric moisture data only.

The wet flat site soil volumetric moisture, water table elevation, and water table depth data show that the null hypothesis for the treatment effect (H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$) is not rejected at the $\alpha = 0.10$ level. It is determined that there are significant differences between treatment least square means (Table 9) for the depth of iron oxidation data only.

Table 9. Partial analysis of variance information for the wet flat site post-treatment, on-bed site hydrology data including soil volumetric moisture, depth of iron oxidation, water table elevation, and water table depth. The reported P- value (no parentheses) is the probability of committing a Type I error (incorrectly rejecting the null hypothesis) where H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$ for the treatment effect and H_o : $H_1 = H_2 = H_3$ for the horizon effect. The horizon effect is a term in the model for volumetric moisture data only. The reported F-value for each effect is in parentheses below each corresponding P-value.

Source	Volumetric Moisture Percentage	Iron Oxidation Depth	Water Table Elevation	Water Table Depth
Treatment	0.3352 (1.29)	0.0026 (7.63)	0.5776 (0.79)	0.5993 (0.76)
Horizon	0.5049 (0.47)			
Trt*Horizon	0.2287 (1.58)			

The depth of iron oxidation least square means for the bedded treatments are significantly greater than those of the non-bedded treatments (broadcast mulch without bedding and flat planted/control) (Table 10, Figure 10). This is due to the increased aeration in the elevated rooting environment created by the bedding plow, regardless of organic matter mulching. This reflects the tendency of bedding to increase the volume of suitable seedling rooting environment on wet sites. In this particular situation, the beds were elevated above the Bt1 horizon, where precipitation tended to form a perched water table.

The soil volumetric moisture data reveal that the null hypothesis for the horizon effect (H_o: $H_1 = H_2$) is rejected at the $\alpha = 0.5049$ level (Table 10). It is determined that there are no significant differences between horizon least square means for this variable on the wet flat site. The volumetric moisture percentage data show that the incorporation of organic matter or the surface application of mulched slash did not have any soil moisture-preserving qualities as might be expected. A possible reason for this is that the whole-tree harvest that took place on this site prior to treatment left very little slash behind to be surface-applied or incorporated. The lack of slash and subsequent low levels of mulch to apply probably negated any effect that the treatment might have on soil moisture in similar situations. The lack of differences between soil horizons reveals the periodic and brief nature of both the perched water table and elevated groundwater conditions.

Table 10. Treatment effect least square means and associated standard error values (in parentheses) for the wet flat site post-treatment, site hydrology data including soil volumetric moisture, depth of iron oxidation, water table elevation, and water table depth. Horizon and treatment significance at α = .10 is indicated by lower and upper case letters, respectively, listed with the least square mean values.

Treatment	Iron Oxidation Depth	Water Table Elevation	Water Table Depth	Horizon	Volumetric Moisture Percentage
	------------------- cm	-------------------			%
Conventional	11.10A (1.06)	100.01A (0.77)	33.47A (6.41)	A+E Bt1 pooled	31.68a (4.09) 33.33a (4.09) 32.50A (2.89)
Mulch/Bed	12.40A (1.06)	98.53A (0.77)	42.38A (6.41)	A+E Bt1 pooled	27.42a (4.09) 35.52a (4.09) 31.48A (2.89)
Mulch/Till/Bed	14.00A (1.06)	100.50A (0.77)	46.67A (6.41)	A+E Bt1 pooled	25.50a (4.09) 33.38a (4.09) 29.44A (2.89)
Broadcast Mulch	5.45B (1.51)	100.14A (1.09)	30.05A (9.07)	A+E Bt1 pooled	46.90a (5.79) 30.05a (5.79) 38.48A (4.09)
Broadcast Mulch/Bed	14.15A (1.51)	99.32A (1.09)	41.45A (9.07)	A+E Bt1 pooled	22.50a (5.79) 31.00a (5.79) 26.75A (4.09)
Flat Plant/Control	7.55B (1.06)	99.26A (0.77)	35.58A (6.41)	A+E Bt1 pooled	34.60a (4.09) 36.53a (4.09) 35.56A (2.89)

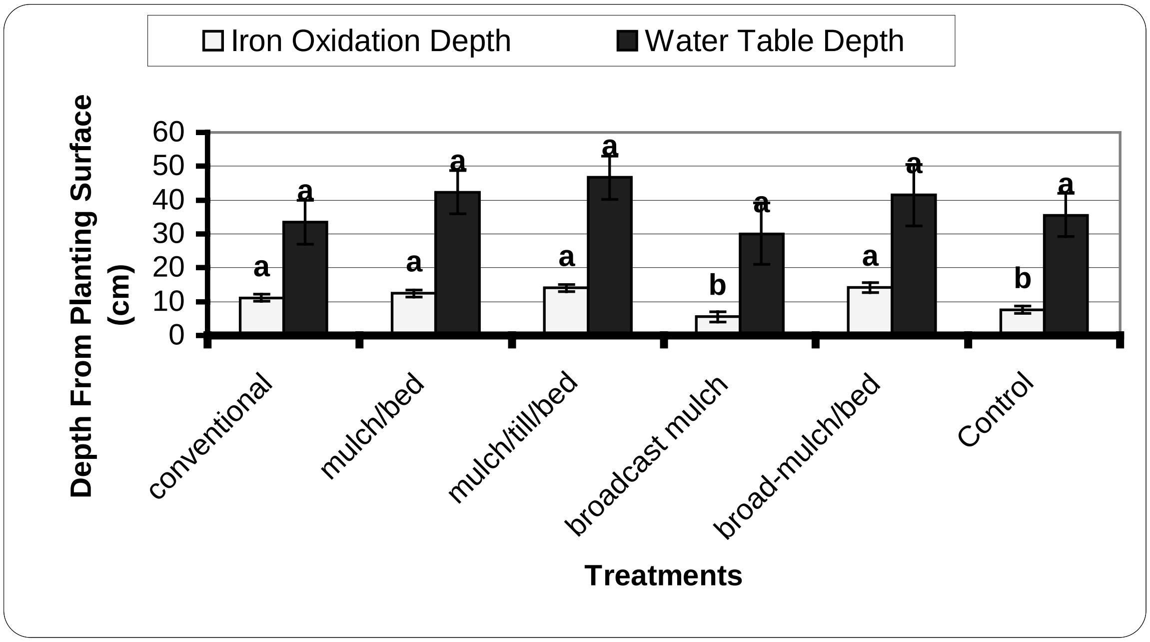

Figure 10. Wet flat site post-treatment iron oxidation depth and water table depth ls means. Significance at the α = .10 level is indicated by lower case letters.

The water table and elevation data show that this site is not often saturated at or near the soil surface, and subsequent low water table levels were not likely to be affected by a soil surface treatment (Figure 10, Table 10). Even the bedding did not significantly affect these deep water table values. The data thus imply that tree growth on this site is probably not often inhibited by the close proximity of groundwater to the soil surface, but by a combination of poor soil physical properties and periodic perched water from precipitation.

The depth to iron oxidation data does show that in general the bedded treatments provided a much more effectively aerated rooting environment within the bed. The conventional treatment however is not significantly different from the flat planted/control treatment (Table 10, Figure 10). This is probably due to the lesser effect of large incorporated slash with the conventional treatment on soil aeration within the bed. It is likely that the incorporation of mulched slash lead to increased aeration within the bed due to the more efficient distribution of mulched organic matter within the beds. This conclusion is not supported by the post-treatment soil macroporosity data (Table 6), which show no significant differences between treatments. The validity of the soil macroporosity data is in question due to the inability of the soil core sampling procedures to include large organic matter pieces (conventional treatment) in the sample.

First-Year Seedling Height and Survival

The Year 1 seedling height and survival data were analyzed to determine the effect of the treatments on overall site quality from an early seedling growth and survival perspective. The wet flat site Year 1 seedling height and survival data show that the null hypothesis for the treatment effect (H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$) is rejected at the $\alpha = 0.0001$ and 0.3180 levels, respectively (Table 11). As a result, it is determined that there are significant differences between treatment least square means (Table 11) for the seedling height data only. The bedded treatments' least square means are significantly greater than those of the non-bedded treatments.

Table 11. Treatment effect least square means and associated standard error values (in parentheses) for the wet flat site post-treatment seedling height and survival data. Significance at $\alpha = .10$ is indicated by lower case letters listed with the least square mean values.

Treatment	**Seedling Height** p = 0.0001 (inches)	**Seedling Survival** p = 0.3180 (%)
Conventional	31.03a (1.40)	95a (4.00)
Mulch/Bed	26.05a (1.40)	86a (4.00)
Mulch/Till/Bed	25.73a (1.40)	87a (4.00)
Broadcast Mulch	14.55b (2.00)	82a (6.00)
Broadcast Mulch/Bed	26.25a (2.00)	92a (6.00)
Flat Plant/Control	12.55b (1.40)	82a (4.00)

The seedling survival data indicate that the wet flat site is not wet enough during the growing season to require bedding to insure seedling survival (Table 11, Figure 11). The bedding did, however, increase seedling height growth in the first year due to the overwhelming positive affect of the bedding and organic matter incorporation on the seedling rooting environment. The bedding did raise the rooting environment above the surrounding soil surface sufficiently to decrease the negative affects of temporary soil saturation conditions on seedling growth. The varying methods of slash incorporation or application did not have an effect on seedling survival or height growth (Figure 11).

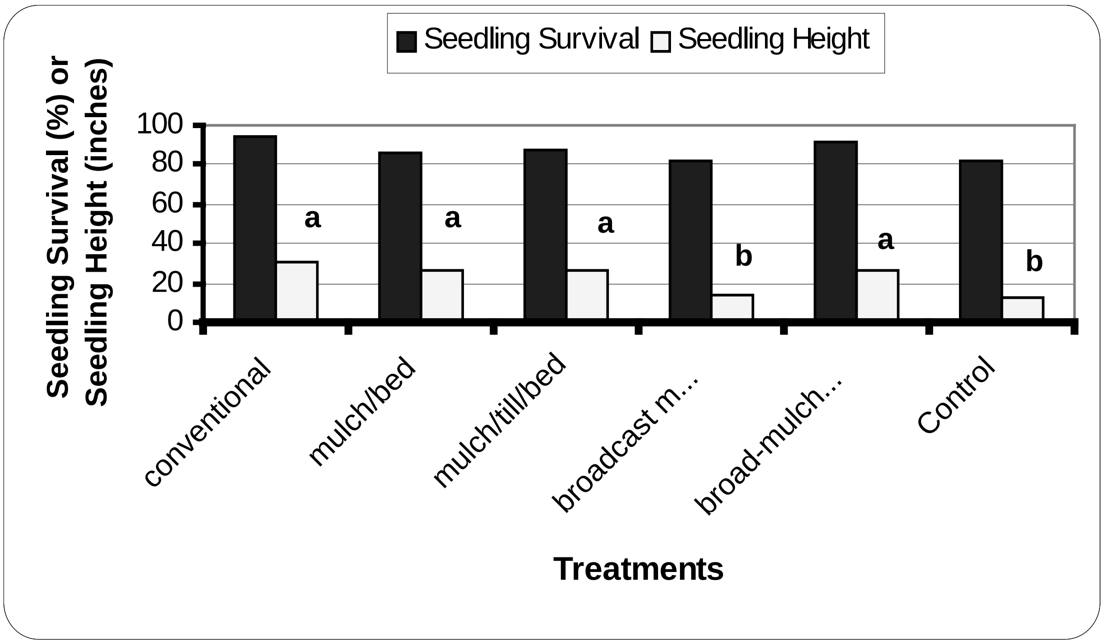

Figure 11. Wet flat site year one seedling height and survival ls means. Seedling height values (inches) are labeled with each column and seedling survival (%) is labeled on the y-axis.

It is also likely that the core sampling method and associated laboratory methods used to evaluate post-treatment soil physical properties are incapable of accurately measuring the effect of undecomposed organic matter on soil physical properties. This explains why the soil physical property data does not support the likelihood that the bedding treatments had positive impacts on soil bulk density and macroporosity. It is also likely that adverse core sampling conditions experienced by the USDA Forest Service during the wet winter months led to the unavoidable use of soil core samples of inadequate quality. The increased organic carbon percentages due to incorporation within the beds undoubtedly concentrated soil nutrients near the seedling roots, but no soil nutrient extraction data were collected.

RESULTS AND DISCUSSION: POCOSIN SITE

Intact Soil Cores and Bulk Soil Samples

The intact soil core and bulk soil samples were analyzed to determine the homogeneity of the study site prior to treatment installation and the effects of the treatments on soil physical properties. Laboratory methods were performed to determine bulk density (BD), saturated hydraulic conductivity (Ksat), and micro-, macro-, and total porosity of the soil cores. Laboratory methods were performed to determine the percentage of organic carbon in the bulk soil samples.

Pre-Treatment

The saturated hydraulic conductivity, bulk density, micro-, macro-, and total porosity, and soil organic carbon data show that the null hypothesis for the treatment effect (H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$) is not rejected at the $\alpha = 0.10$ level (Table 12). It was determined that there are no significant differences between treatment least square means for these variables, and the wet flat site was homogeneous prior to treatment with respect to all of these variables.

Table 12. Partial analysis of variance information for the pocosin site pre- and post-treatment intact soil core and bulk soil sample data. The reported P-value (no parentheses) is the probability of committing a Type I error (incorrectly rejecting the null hypothesis) where H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$ for the treatment effect and $H_o : H_1 = H_2 = H_3$ for the horizon effect. The reported F-value for each effect is in parentheses below each corresponding P-value.

	Ksat		Bulk Density		Microporosity		Macroporosity		Total Porosity		Soil Organic Carbon	
Source	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Treatment	0.739 (0.43)	0.463 (0.94)	0.435 (1.00)	0.644 (0.58)	0.576 (0.70)	0.201 (1.89)	0.744 (0.42)	0.016 (5.98)	0.599 (0.66)	0.629 (0.60)	0.566 (0.72)	0.739 (0.43)
Horizon	0.613 (0.50)		0.000 (159)		0.000 (61.89)		0.000 (10.14)		0.000 (61.2)		0.000 (482)	
Trt*Horizon	0.293 (1.32)		0.418 (1.06)		0.077 (2.28)		0.203 (1.58)		0.163 (1.74)		0.832 (0.29)	

The null hypothesis for the horizon effect ($H_o : H_1 = H_2 = H_3$) is rejected at the $\alpha = 0.10$ level for all variables except Ksat. It was determined that the ls means for all other parameters varied by soil horizon when pooled across all treatments (Table 12). Mitsch and Gosselinik (1993) reported that saturated hydraulic conductivity measurements vary widely for organic soils and that there has been considerable disagreement over whether or not Darcey's law applies to organic soils. The core samples for the organic site were collected during a very wet period and as a result were of poor stability and not fully intact. It is for this reason that the Ksat data will not be discussed.

Bulk density ls mean values increased significantly with soil depth (Table 13, Figure 11). The Oa horizon was the least dense due to its organic nature (11.30% organic carbon). The A and Btg horizons are clay loams, and their bulk density values are typical of such undisturbed mineral soils with moderate amounts of organic carbon. Gent and Morris (1986) reported 1.25 g/cm^3 for undisturbed A horizons and Gent et al. (1984) reported 1.12 to 1.16 g/cm^3 for similar A horizons. The significant bulk density increase from the A to the Btg horizon is due to the increase in clay percentage with depth. Micro-, macro-, and total porosity values all decreased significantly from the Oa to the A and from the A to the Btg horizon (Table 13). This is also due to the increase in clay and decrease in rooting activity with depth. The organic carbon ls mean values decreased significantly with depth (Table 13) as expected, given the organic nature of the peat (Oa) horizon and the fact that the A horizon is a residual mineral soil.

Table 13. Treatment effect least square means by horizon for the pocosin site pre- and post-treatment intact soil core and bulk soil sample data. Significance at α = .10 is indicated by lower case letters listed with the least square mean values (pooled across all horizons).

Treatment	Horizon	Ksat		Bulk Density		Microporosity		Macroporosity		Total Porosity		Soil Organic Carbon	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
		cm/hour		g/cm^3		%							
Conventional	Oa	4.98	68.59a	0.67	0.48a	59.89	55.10a	8.26	15.08a	68.15	70.18a	11.03	18.75a
	A	4.21	---	1.12	---	48.93	---	6.15	---	55.08	---	2.54	---
	Btg	16.33	---	1.39	---	44.92	---	5.51	---	50.43	---	---	---
	pooled	8.51a	---	1.06a	---	51.25a	---	6.64a	---	57.88a	---	6.79a	---
Mulch/Bed	Oa	10.64	46.81a	0.63	0.49a	60.55	58.55a	10.18	15.05a	70.73	73.60a	10.65	17.71a
	A	5.65	---	1.25	---	47.98	---	5.66	---	53.39	---	2.14	---
	Btg	0.39	---	1.53	---	37.26	---	4.84	---	41.80	---	---	---
	pooled	5.56a	---	1.14a	---	48.60a	---	6.89a	---	55.30a	---	6.39a	---
Mulch/Till/Bed	Oa	1.70	147.1a	0.65	0.47a	64.70	59.04a	6.67	14.06a	71.37	73.10a	11.63	17.64a
	A	10.39	---	1.36	---	40.07	---	5.77	---	45.84	---	2.52	---
	Btg	12.79	---	1.50	---	40.67	---	5.43	---	46.10	---	---	---
	pooled	8.29a	---	1.15a	---	48.48a	---	5.96a	---	54.44a	---	7.08a	---
Flat Plant/Control	Oa	1.06	7.52a	0.60	0.56a	66.29	64.22a	6.76	5.91a	73.06	70.14a	11.89	17.39a
	A	8.59	---	1.16	---	50.10	---	6.73	---	56.83	---	2.53	---
	Btg	2.57	---	1.46	---	35.94	---	5.09	---	40.77	---	---	---
	pooled	4.07a	---	1.07a	---	50.78a	---	6.19a	---	56.89a	---	7.21a	---

Post-Treatment

The data show that the null hypothesis for the treatment effect (H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$) is rejected at the $\alpha = 0.10$ level for macroporosity data only (Table 14). The bedded treatments least square means are significantly greater than those of the flat planted/control treatment (Table 13, Figure 12). This is due to the creation of soil macropores in the organic soil Ap horizon by the bedding and incorporation of undecomposed organic matter. There are no significant differences between the ls means for the bedded treatments, which implies that differing methods of slash incorporation did not affect soil physical properties but that bedding did increase soil macroporosity on the pocosin site.

Table 14. Partial analysis of variance information for the pocosin site post-treatment, on-bed soil water chemistry data including ammonium, nitrate, orthophosphate, and total organic carbon. The reported P-value (no parentheses) is the probability of committing a Type I error (incorrectly rejecting the null hypothesis) where H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$ for the treatment effect and H_o : $H_1 = H_2 = H_3$ for the horizon effect. The reported F-value for each effect is in parentheses below each corresponding P-value.

Source	NH_4^+	NO_3^-	Phosphate	TOC
Treatment	0.4508 (0.96)	0.0275 (4.90)	0.2567 (1.60)	0.2190 (1.79)
Horizon	0.0004 (10.81)	0.6987 (0.36)	0.0019 (8.26)	0.0001 (17.38)
Trt*Horizon	0.5639 (0.82)	0.9740 (0.20)	0.1964 (1.58)	0.1837 (1.62)

These bulk density values range well below the root growth restricting limit of approximately 1.4 g/cm^3 (Gent et. al., 1984). The bulk density ls means are well below the root restricting values of 1.50 to 1.62 g/cm^3 reported by Gent and Morris (1986) and 1.36 to 1.49 g/cm^3 reported by Gent et. al. (1984) for post-harvest mineral soils.

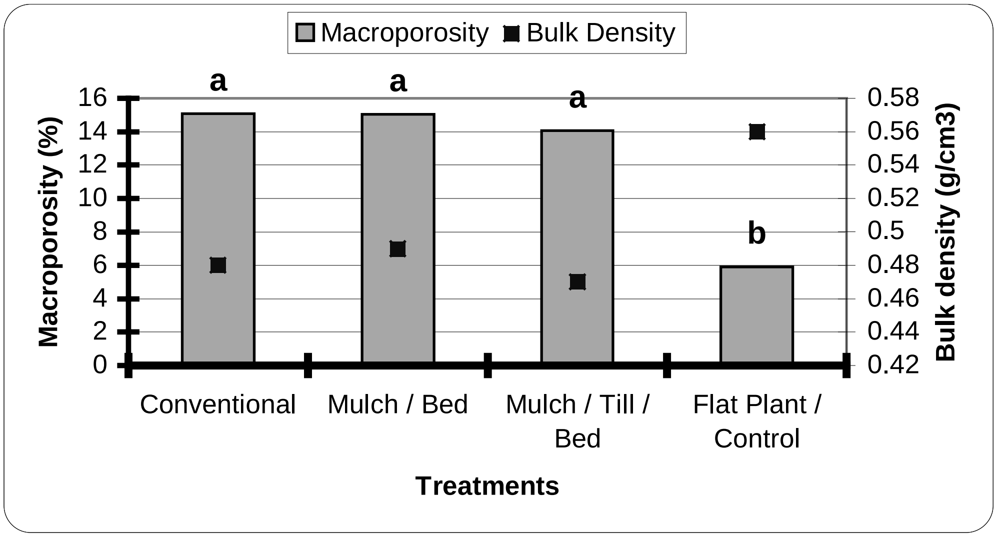

Figure 12. Pocosin site macroporosity (columns) and bulk density (squares) ls mean values for the pocosin site post-treatment, on-bed data. Significance is indicated by lower case letters.

The soil bulk density values for pocosin (organic) soils range from 0.04 to 0.10 g/cm^3 (Table 13), and the organic carbon percentage ranges from 75 to 95 % in most pocosins (Richardson, 1991). Highly decomposed peats may have bulk densities greater than 2.0 g/cm^3 (Brady, 1990). The pocosin site bulk density and organic carbon data (Table 13) show that this soil generally has a significant mineral fraction that is unusual for pocosins. This is probably due to the loss of a significant amount of organic peat from this site as a result of past intensive draining and burning to convert the site to a pine plantation.

Periodic Repeated Measurements

Groundwater Chemistry

The soil water samples were collected from tension lysimeters in the field, and laboratory procedures were performed to determine the concentration of ammonium, nitrate, phosphate, and total organic carbon as described previously.

The pocosin site on-bed ammonium, nitrate, phosphate, and total organic carbon data show that the null hypothesis for the treatment effect (H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$) is rejected at the $\alpha = 0.10$ level for nitrate only (Table 14). It was determined that there are no significant differences between treatment least square means for ammonium, phosphate, and total organic carbon on the pocosin site.

The null hypothesis for the horizon effect (H_o: $H_1 = H_2$) is rejected at the $\alpha = 0.10$ level for all parameters except nitrate (Table 14). It was determined that the Ap horizon least square means (pooled across all treatments) for ammonium, phosphate, and TOC (Table 15, Figure 13) are significantly greater than the respective ls means of the A and Btg horizon.

The horizon least square means for the nitrate data (Table 15) show that nitrate from fertilizer and organic matter decomposition in the Ap horizon for all treatments in general have leached with water movement into both the A and Btg horizons (Figure 13). This nitrogen is in the nitrate form because of the unusually dry weather during this year. Intermittent rainfall patterns allowed this nitrate to leach downward through the soil profile with percolating groundwater.

The ammonium, phosphate, and total organic carbon data demonstrate the lack of mobility of these ions in water (Figures 13 and 14). The ion concentrations are all significantly greater in the Ap horizon due to fertilizer and organic matter incorporation. The relative lack of these ions in deeper soil horizons demonstrates that these ions are not leaching downward with water movement.

A comparison of nitrate and ammonium ls means shows that on this relatively wet, acidic pocosin site, ammonium is the dominant form of nitrogen present in soil water (Figures 13 and 14). This is as expected, given these conditions. The presence and leaching of nitrate is unexpected, given the extremely wet and acidic nature of this site. The nitrate is present in the soil profile as a result of the periodic and unusually dry soil conditions during this year and the intermittent rainfall. The unusually high amounts of oxygen in the soil profile have encouraged the activity of aerobic bacteria (*Nitrobacter* spp.) that convert ammonium to nitrite and then nitrate.

Table 15. Treatment effect least square means and associated standard error values (in parentheses) for the pocosin site post-treatment, on-bed soil water chemistry data. Horizon and treatment significance at α = .10 are indicated by lower and upper case letters, respectively, listed with the least square mean values.

Treatment	Horizon	NH_4^+	NO_3^-	Phosphate	TOC
		-------------------- ppm	--------------------	--------------------	--------------------
Conventional	Ap	7.05a (2.41)	0.37a (0.29)	1.10a (0.49)	84.30a (25.08)
	A	0.50b (2.41)	0.27a (0.29)	0.01b (0.26)	33.20a (25.08)
	Btg	0.23b (2.41)	0.54a (0.29)	0.01b (0.49)	13.00a (25.08)
	pooled	2.59A (1.43)	0.39A (0.17)	0.37A (0.29)	43.50A (15.30)
Mulch/Bed	Ap	11.64a (2.41)	1.29a (0.29)	2.58a (0.49)	162.76a (25.08)
	A	0.73b (2.41)	0.93a (0.29)	0.01b (0.49)	32.18b (25.08)
	Btg	0.18b (2.41)	1.00a (0.29)	0.00b (0.49)	10.17b (25.08)
	pooled	4.18A (1.42)	1.08B (0.17)	0.87A (0.29)	68.37A (15.30)
Mulch/Till/Bed	Ap	7.43a (2.41)	0.55a (0.29)	1.15a (0.49)	143.84a (25.08)
	A	0.50b (2.41)	0.26a (0.29)	0.01b (0.49)	41.86ab (25.08)
	Btg	0.19b (2.41)	0.40a (0.29)	0.00b (0.49)	13.38b (25.08)
	pooled	2.69A (1.43)	0.40A (0.17)	0.39A (0.29)	66.36A (15.30)
Flat Plant/Control	Ap	2.27a (2.41)	0.25a (0.29)	0.01a (0.49)	44.41a (25.08)
	A	0.26a (2.41)	0.30a (0.29)	0.01a (0.49)	34.18a (25.08)
	Btg	0.14a (2.41)	0.18a (0.29)	0.00a (0.49)	9.39a (25.08)
	pooled	0.89A (1.43)	0.24A (0.17)	0.01A (0.29)	29.33A (15.30)

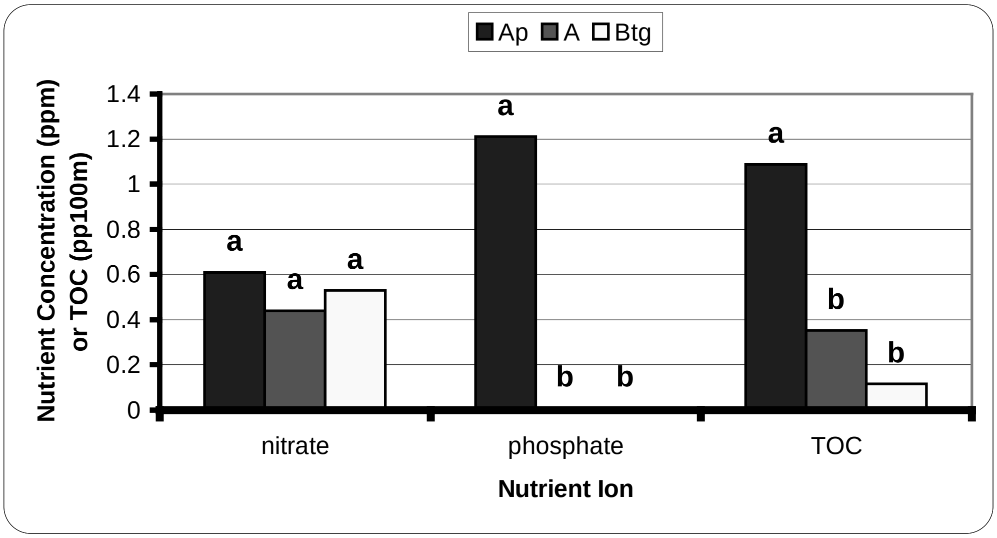

Figure 13. Pocosin site relative nutrient ion concentrations in soil water by horizon (pooled across all treatments) and nutrient type. Significance between horizons within each parameter is indicated by lower case letters.

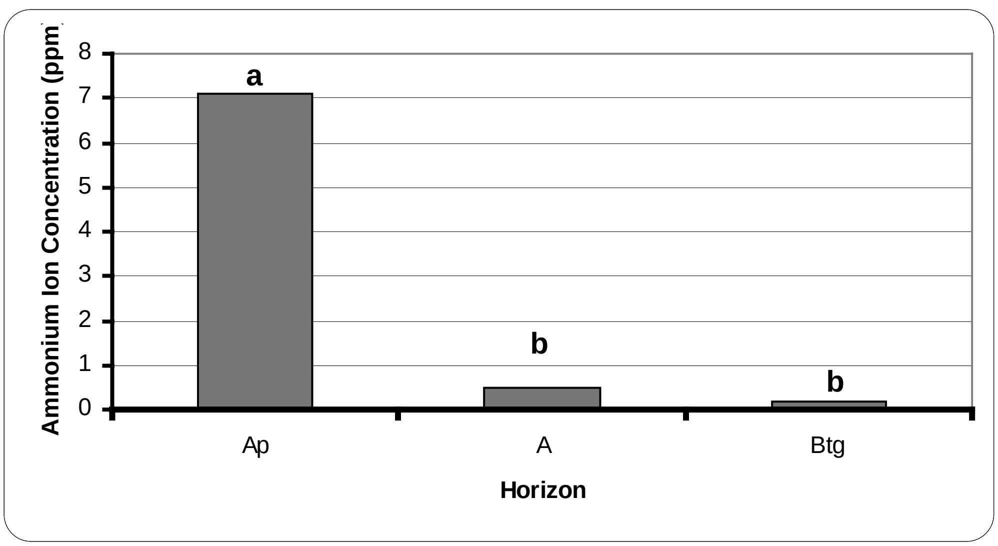

Figure 14. Column chart showing the ammonium ion concentrations in soil water from each sampled soil horizon pooled across all treatments. Significance between horizons is indicated by lower case letters.

The nitrate concentrations in soil water for the mulch/bed treatment is significantly higher than the nitrate in water concentrations in all other treatments (Table 15, Figures 13 and 15). This is not likely due to the method of organic matter incorporation given the significantly different mean for the very similar mulch/till bed treatment. This is most likely due to uneven fertilizer application and distribution of organic matter across the treatment plots.

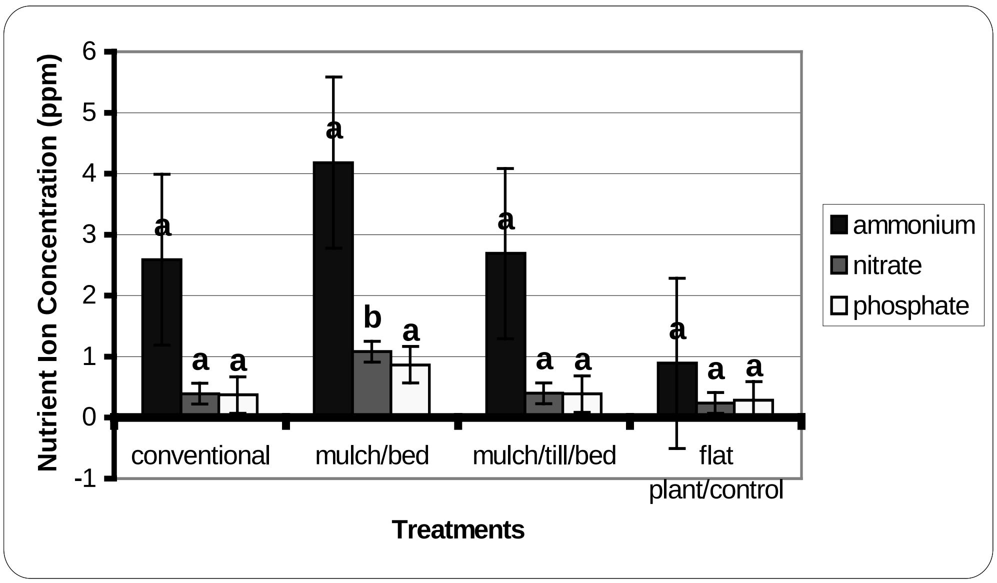

Figure 15. Pocosin site nutrient ion concentration ls means pooled across all horizons by treatment and nutrient ion type. Significance between treatments within each nutrient is indicated by lower case letters.

Site Hydrologic Factors -- On-Bed Data

Site hydrologic data such as soil volumetric moisture percentage, depth of iron oxidation, water table elevation, and water table depth below the soil surface were analyzed to determine the effects of the treatments on soil moisture and site hydrology relationships. On-bed data only were used for bedded treatments, and off-bed data were used for the unbedded treatments. The horizon effect was analyzed for the soil volumetric moisture data only.

The pocosin site depth of iron oxidation, water table elevation, and water table depth data show that the null hypothesis for the treatment effect (H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$) is rejected at the $\alpha = 0.10$ level (Table 16). It was determined that there are significant differences between treatment least square means for all variables except soil volumetric moisture percentage. The depth of iron oxidation least square means for the bedded treatments are significantly greater than those of the unbedded treatment (flat planted/control) (Table 17). The water table elevation least square mean for the conventional treatment is significantly greater (depth below a standard elevation) than that of the flat planted control treatment. The water table (depth below soil surface) least square mean for the conventional treatment is significantly greater than that of the flat planted/control treatment.

The soil volumetric moisture data show that the null hypothesis for the horizon effect (H_o: $H_1 = H_2$) is rejected at the $\alpha = 0.0002$ level (Table 16). It is determined that the Ap and A horizon least square means are significantly greater than those of the Btg horizon at the α = 0.003 and 0.009 levels, respectively. This implies that moisture inputs to this site are mainly from precipitation and that organic matter in the upper two soil horizons holds significant amounts of moisture.

Table 16. Partial analysis of variance information for the pocosin site post-treatment on-bed site hydrology data including soil volumetric moisture, depth of iron oxidation, water table elevation, and water table depth. The reported P-value (no parentheses) is the probability of committing a Type I error (incorrectly rejecting the null hypothesis) where H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$ for the treatment effect and $H_o : H_1 = H_2 = H_3$ for the horizon effect. The horizon effect is for volumetric moisture data only. The reported F-value for each effect is in parentheses below each corresponding P-value.

Source	Volumetric Moisture Percentage	Iron Oxidation Depth	Water Table Elevation	Water Table Depth
Treatment	0.3454 (1.26)	0.0176 (5.76)	0.0496 (3.88)	0.0465 (3.98)
Horizon	0/0002 (13.10)			
Trt*Horizon	0.0026 (4.99)			

Table 17. Treatment effect least square means and associated standard error values (in parentheses) for the pocosin site post-treatment, site hydrology data including soil volumetric moisture, depth of iron oxidation, water table elevation, and water table depth. Horizon and treatment significance at α = .10 is indicated by lower and upper case letters, respectively, listed with the least square mean values.

Treatment	Iron Oxidation Depth	Water Table Elevation	Water Table Depth	Horizon	Volumetric Moisture Percentage
	-------------------- cm	--------------------	--------------------		%
Conventional	5.28A (0.74)	23.94A (1.96)	23.41A (1.99)	Ap	43.65a (4.48)
				A	40.57a (4.48)
				Btg	40.90a (4.48)
				pooled	41.71A (3.06)
Mulch/Bed	6.08A (0.74)	21.19AB (1.96)	20.73AB (1.99)	Ap	46.37a (4.48)
				A	55.21a (4.48)
				Btg	33.45b (4.48)
				pooled	45.01A (3.06)
Mulch/Till/Bed	6.25A (0.74)	20.22AB (1.96)	19.83AB (1.99)	Ap	40.46a (4.48)
				A	51.15a (4.48)
				Btg	28.18b (6.10)
				pooled	63.58A (4.48)
Flat Plant/Control	2.88B (0.74)	16.06B (1.96)	15.08B (1.99)	Ap	63.58a (4.48)
				A	41.38b (4.48)
				Btg	32.89b (5.08)
				pooled	45.95A (3.16)

The pocosin site soil profile was frequently saturated during wet periods, and this frequent soil saturation is unaffected by organic matter incorporation. Capillary fringe within the soil encouraged the movement of groundwater upward into the bed during very wet periods. The iron oxidation depth was much greater for the bedded treatments due to the increased elevation of the soil and the inability of capillary water to occupy macropores in the beds.

The water table elevation below a standard point was not the same for all treatments. The conventional treatment water table elevation was significantly farther below the standard elevation than the water table elevation for the flat planted control (Table 17, Figure 16). The conventional beds were probably responsible for increasing the soil surface area exposed to sunlight and air, thus causing an increase in evaporation from the conventional treatment plots. The beds on other treatments did not appear to maintain the same physical integrity due to the mulching of incorporated slash. This lesser bed integrity may be partly responsible for the lack of this effect in other bedded treatments. The dark color of the pocosin soils might have contributed to increased soil temperatures and evaporation. This effect occurred on organic soils in Alabama as described by Lockaby et al. (1994).

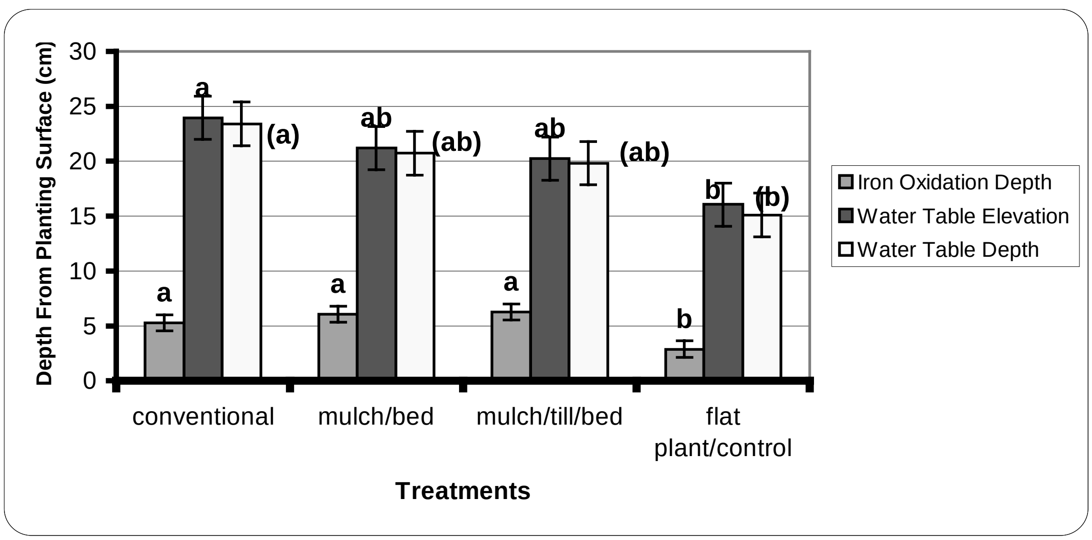

Figure 16. Site hydrology parameter ls means by treatment for the pocosin site. Significance between treatments is indicated by lower case letters.

The water table depth results were very similar to those of the water table elevation (Figure 16). There were no differences between the bedded treatments, but the conventional treatment only was greater than the flat planted/control. The conventional beds might be taller than the other beds, and this might be due to the large slash material incorporated into the conventional beds. This large slash might add structural integrity and stability to the beds. No measurements were taken to confirm this possibility.

Neither mulching nor bedding had any overall effect on soil volumetric moisture percentage in the soil profile. Soil volumetric moisture was greater in the upper two soil horizons across all treatments. This might be due to the perching of groundwater on top of the clay (Btg) horizon following rainfall events.

First-Year Seedling Height and Survival

The Year 1 seedling height and survival data was analyzed to determine the effect of the treatments on overall site quality from an early seedling growth and survival perspective.

The wet flat site Year 1 seedling height and survival data show that the null hypothesis for the treatment effect (H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$) is rejected at the $\alpha = 0.0001$ and 0.0002 levels, respectively (Table 18). As a result, it is determined that there are significant differences between treatment least square means for both variables. The bedded treatments least square means for both variables are significantly greater than those of the unbedded treatment (flat planted/control)

Table 18. Treatment effect least square means and associated standard error values (in parentheses) for the pocosin site post-treatment seedling height and survival data. Significance at α= .10 is indicated by lower case letters listed with the least square mean values.

Treatment	Seedling Survival p = 0.0002 (%)	Seedling Height p = 0.0001 (cm)
Conventional	72a (6.00)	24.38a (1.52)
Mulch/Bed	69a (6.00)	23.35a (1.52)
Mulch/Till/Bed	84a (6.00)	21.58a (1.52)
Broadcast Mulch	33b (6.00)	11.63b (1.52)

The results show that the method of organic matter incorporation is not important to seedling survival or height growth in Year 1 on the pocosin site. The bedding drastically increased both seedling height growth and survival. This site is generally saturated at or near the soil surface during the growing season. Bedding is obviously imperative to early pine seedling success on organic pocosins with similar hydrologic characteristics.

Bedding increased soil macroporosity, soil surface height above the water table, and soil aeration within the rooting environment, while it decreased soil bulk density (Table 18, Figure 17). The bedding treatments equally improved both effective rooting volume and the quality of that volume. This is what is expected and required on wet sites in order to achieve acceptable early seedling survival and growth. The varying methods of slash incorporation had no impact on seedling survival or growth (Table 18, Figure 17).

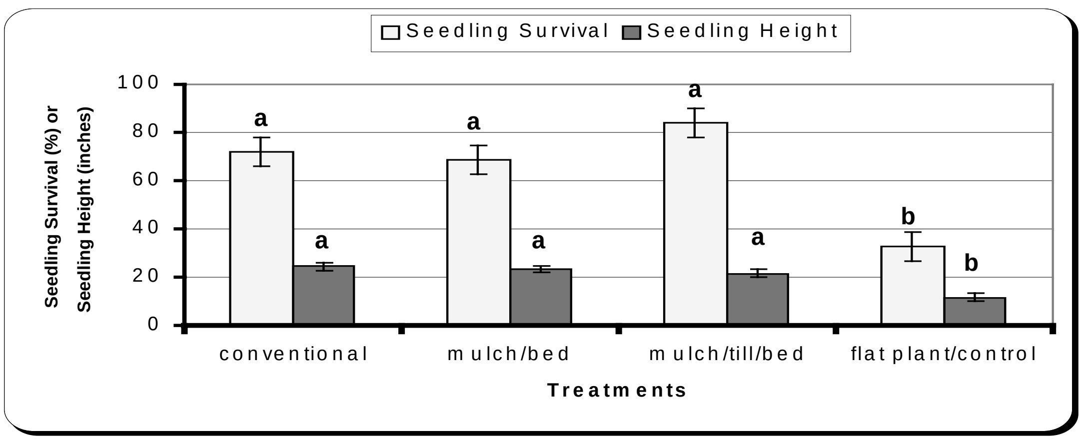

Figure 17. Pocosin site seedling height and survival after one growing season by treatment. Significance by treatment is indicated by lower case letters.

SUMMARY AND CONCLUSIONS

Wet Flat Site

The treatments on the wet flat site in general had little effect on soil physical properties. The lack of changes in soil porosity and bulk density within the beds for all treatments suggests that the soil core sampling methods used were unable to incorporate large pieces of slightly decomposed slash into the sample. The bulk soil samples showed that any form of slash incorporation into the bed significantly increased the percentage of organic carbon in the plow layer.

The wet flat site soil water sample data showed that the bedding and varying methods of slash incorporation had no significant effect on soil water chemistry with respect to ammonium, nitrate, phosphate, and total organic carbon (TOC). The data indicated that ammonium and nitrate concentrations were not significantly different by horizon and suggest limited leaching of nutrients from fertilizer and organic matter decomposition into the Bt horizon. The phosphate and TOC data show that phosphate and carbon did not leach significantly in soil water from the plow layer.

The site hydrology data for the wet flat site revealed that the treatments had minimal effect on soil water table elevations below a standard elevation or the depth of the water table below the bed surface. This is due to the nonalluvial nature of this site. Soil volumetric moisture percentage did not vary by treatment or horizon. The depth to iron oxidation was significantly greater for all bedded treatments but did not vary between different methods of slash incorporation.

Year 1 seedling height was significantly greater on the bedded treatments but did not vary between different methods of slash incorporation. Year 1 seedling survival was not significantly greater on any particular treatments. Neither bedding nor slash incorporation significantly impacted survival of seedlings at Year 1.

Pocosin Site

The soil physical property data intimated that the treatments had no significant effects on total porosity, microporosity, or saturated hydraulic conductivity. However, all bedded treatments did show a significant increase in soil macroporosity in the plow layer. Varying methods of slash incorporation had no effect on any of these properties.

The soil water chemistry data suggested no significant impacts of the treatments on ammonium, phosphate, or TOC. The slash mulching followed by bedding treatment nitrate concentration was significantly greater than all other treatments. There is no obvious explanation other than possible inequalities in fertilizer rates during site preparation. The concentrations of ammonium, phosphate, and TOC were significantly greater in the plow layer than in the subsurface soil horizons. This suggests that these nutrients were relatively immobile in water on this site during the study period. The nitrate concentrations were not significantly different for any of the three horizons sampled. This suggests that the nitrate from the fertilizer application and incorporated slash decomposition did leach into the lower portion of the soil horizon with the downward percolation of soil water.

The site hydrology data revealed that soil volumetric moisture percentage did not vary by treatment, but iron oxidation depth increased significantly with bedding. Varying methods of slash incorporation did not affect iron oxidation depth. The water table elevation above a standard and the water table depth below the bed surface was greater for the conventional treatment than for the flat planted treatment, but no other significant differences between treatments exist. It is possible that the conventional beds maintained better structural integrity and thus increased exposure of the bed to sunlight and air. This might explain the increased evaporation from the bed necessary to cause this difference.

Year 1 seedling height and survival were significantly greater for all bedded treatments than for the flat planted treatments. There was no growth or survival advantage among the varying methods of slash incorporation on this site.

Overall, mulching of harvest slash material and varying methods of incorporation into beds or onto the soil surface did not significantly affect site hydrology or ameliorate soil compaction. As a result, tree survival and growth were largely unaffected by mulching treatments. Bedding in general did improve both tree survival and growth.

Future studies should evaluate sites with greater moisture concerns, poorer nutrient status, significant residual slash, and varying soil properties. Soils with inherently low levels of natural organic matter might benefit from and be affected by similar treatments. Subsampling within each measurement plot should be encouraged to eliminate systematic measurement bias. Unequal replication of treatments often creates data analysis problems due to incompatibility with some linear models as well as inadequate replication of some treatments and should be avoided wherever possible. Alternative methods of measuring the impact of medium and large organic material on soil physical properties should be explored. Eliminating time of planting fertilization will allow the study to monitor the effects of organic matter manipulation on nutrient availability and movement across treatments and soil horizons.

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VITA

William A. Lakel, III, was born in Frederick, Maryland, on February 4, 1974. He lived in Woodbine, Maryland, and graduated from South Carroll High School in 1992. He began his undergraduate program in Forestry at Virginia Polytechnic Institute and State University in August 1992 and spent the year of 1995 in Sussex County, Virginia, as a co-op student employed by Resource Management Service, Inc. He returned to Virginia Tech, completed a B.S. in May 1997 and began work on a Master of Science program in August of that year. He is currently employed as a district forester with Resource Management Service, Inc. in Chester, Virginia, and resides in Glen Allen, Virginia, with his wife Holly.