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Site Impacts Associated with Biomass Removals in Lower Alabama

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Abstract. *A study was initiated during summer 2003 to evaluate site impacts associated with conversion of a slash pine stand to long leaf pine. Site impacts were evaluated by placing 10 transects over a subsection of the harvest tract and classifying the type of soil surface disturbance every 3 meters. Bulk density, gravimetric water content and cone index were measured on sampling points that corresponded to three disturbance classes: trafficked with litter (DC1), skid trails (DC5), and non-trafficked (DC6). Statistical analyses indicated significant differences were detected only for cone index measurements with skid trail locations significantly higher in the surface and immediate subsurface layer. Erosion estimates of harvested and undisturbed areas were made by measuring soil accumulations in silt fences placed on slopes of similar steepness and length. Soil accumulations in the harvested site exceeded soil accumulated in un-harvested sites.*

Keywords: bulk density, cone index**,** Coastal Plain, erosion, silt fence, disturbance class

Introduction

Forest operations related to harvesting and thinning often have unintended consequences including stand damage, rutting, soil displacement, and soil compaction (Hatchell et al., 1970; Greacen and Sands, 1980; Murosky and Hassan, 1991). The extent of soil compaction is of concern to forest land managers due to its impact on soil structure, soil aeration, soil water availability, nutrient and organic matter status and erosion potential (Howard et al., 1981; Gent et al., 1983; Pye and Vitousek, 1985; Incerti et al., 1987). Soil compaction is often reported as either a change in bulk density, defined as the amount of dry soil per sampling volume, increases in soil strength, defined as the ability of the soil to resist penetration, or both. The final bulk density or soil strength status due to machine trafficking is dependent on several factors including soil texture, organic matter status, soil moisture content, machine components, number of machine passes, and total load weight (Hatchell et al., 1970; Greene et al., 1985; Shetron et al., 1988; Meek, 1996; Smith et al., 1997a; 1997b).

Machine trafficking during the course of harvest operations is highly dispersed as trees are felled and skidded to a landing for processing and transport. As a consequence, soil impacts vary widely in intensity and exhibit a high degree of spatial variability. The extent and intensity of soil compaction have been assessed in previous studies through tabulation of visually determined soil surface disturbance classes (Miller and Sirois, 1986; McMahon, 1995), tracking by GPS (McDonald et al., 2002) or soil sampling on a predetermined grid or transect pattern (Shaw and Carter, 2002). The tabulation of soil disturbance classes in conjunction with bulk density and/or cone penetrometer measurements is often selected as a measure of soil compaction extent and intensity (Lanford and Stokes, 1995). The change in soil bulk density and soil strength in combination with disturbance class tabulations have the potential to provide important information on the extent of machine impacts in the harvest tract and future tree regeneration. This information would be especially valuable in the restoration of native pine species e.g. long leaf (*Pinus palustris* Mill.) where impact data from forest operations are not typically available.

In addition to soil compaction, mechanical manipulations of forested areas (e.g. harvesting, tilling) increases the likelihood of erosion through reductions in water infiltration that can lead to increased runoff and soil movement (Patric, 1976). Estimates of erosion potential in response to forest operations are valuable as they can provide critical information on the impacts of management decisions.

Objectives

The goal of this investigation was an assessment of the soil compaction status and erosion potential as a result of the conversion of a slash pine (*Pinus elliottii* Engelm.) plantation to long leaf pine. The objectives were 1) an evaluation of machine impacts on select soil physical properties; and 2) measurement of erosion potential of sites subjected to harvesting operations.

Methods

A study site was located within the Conecuh National Forest, Covington and Escambia Counties, Alabama and subjected to a complete removal of slash pine and replacement by long leaf pine designated as forest health restoration (fig 1). The site was located within the Gulf Coastal Plain physiographic region, a broad belt of unconsolidated sands, silts, and clays that were deposited in previous eras. The study area is located within the Southern Pine Hills section of the East Gulf Coastal Plain, a southward sloping dissected plain that ranges in altitude between 120 m in the north and 30 m in the south where the study site is located. The relief of the Southern Pine Hills is characterized as cuesta-like in the north and more subdued in the south with low, rounded hills (GSA, 1968). The climate is temperate with temperatures that range between 7 and 35 degrees C and average annual rainfall of approximately 1500 mm. Soils that developed within deposited materials are typically deep with sandy textures on the surface underlain by sandy loam and sandy clay loam subsoil layers (SCS, 1989).

The boundary of a subsection of the harvested tract that represented typical site conditions was delineated by using the global positioning system (GPS) and a soil sampling system established by placement of ten transects of varying lengths. Each transect originated from a common top slope position and extended to the perimeter of the harvest tract. Soil disturbance classes were tabulated visually every 3 m between the transect origin and termination points (fig 1). Soil disturbance classes assigned included: DC1 – trafficked with litter in place; DC2- trafficked with soil exposed; DC3 – ruts less than 10 cm; DC4 – ruts greater than 10 cm; DC5 – skid trail; DC6 – non-trafficked; DC7 – non-soil. A total of 423 point locations was assessed and assigned a soil disturbance category. Sampling points for determination of soil physical properties were selected that corresponded to specific disturbance classes from which soil cores removed for bulk density (BD) and soil moisture determination (GMC); additional sampling points were selected for soil strength (CI) determination by cone penetrometer. Bulk density and GMC were determined for a non-harvested (NH) area to compare with trafficked areas. The determination of bulk density and soil moisture was performed according to Grossman and Reinsch (2002) and cone penetrometer measurements expressed as cone index (CI) were performed according to ASAE Standards (2000). In addition, GMC was converted to volumetric water content (VWC) from which water saturation (WS) was calculated. Impact assessment was limited to disturbance classes DC1, DC5, and DC6 in order to have a sufficient number of samples for analysis.

The significance of transect position (TP) and disturbance class (DC) on BD, GMC, and CI was evaluated in an ANOVA for two soil depth increments: 0 – 10 and 10 – 20 cm (SAS, 1999). If significance was detected, means were separated by a Duncan's Multiple Range Test at the $P < 0.05$ level of significance.

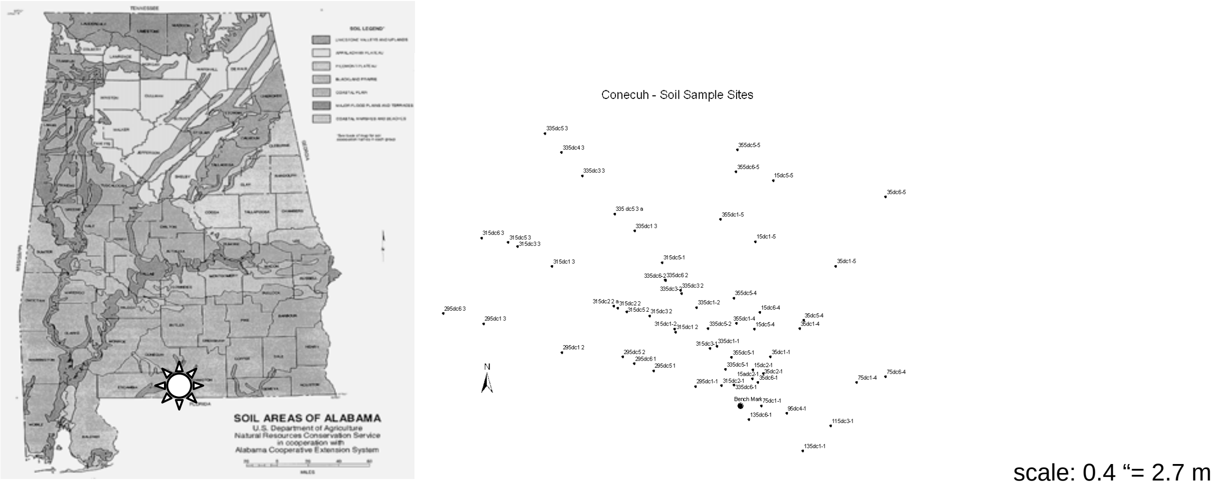


Figure 1. Location of forest health restoration project and sampling layout, Conecuh National Forest, Alabama

Erosion potential of the harvested plots was determined by placing 5 silt fences on slopes of approximately 8% steepness and 25 m of slope length and capturing sediment that was displaced in response to rainfall events (Robichaud and Brown, 2002). Five silt fences of similar length and steepness were placed in NH to serve as control plots. Actual plot length and slope steepness were determined for each fence by GPS based RTK survey grade instrument in the harvested section and a total station in NH. The survey data indicated slope steepness ranged between 6.4 and 9.4 % in the harvested area and 8.0 and 11.0 % in NH. Plot lengths were estimated to be approximately 27.9 and 21.3 m in harvested and NH, respectively. Soil was allowed to accumulate by each silt fence for either 190 days (all NH and SF1 in harvested site) or 229 days (SF2 – 5 in harvested site). Tipping bucket and static rain gauges were placed in the vicinity of the harvested and undisturbed tracts.

Results

No statistical differences were detected for BD and GMC among soil disturbance classes in either soil layer (Table 1). However, statistical differences for CI were detected among the disturbance classes and indicated that trafficked areas, classified as DC1 and DC5, were significantly different from areas where no evidence of trafficking was present, or DC6. All disturbance classes were found to be significantly different from each other when mean comparisons were conducted at P = 0.10. Cone index data from NH were not available. Cone index results underscored the ability of CI to discriminate between trafficked and un-trafficked areas. Further examination of CI results indicated the highest CI level was associated with DC5, or skid trail locations, as might be expected due to the increased level of trafficking associated with skidding followed by DC1. Water saturation levels, or the relationship between soil moisture content relative to pore volume, were calculated as an indication of trafficking impacts but no statistical differences were detected.

Trends in the BD and GMC data indicative of a possible relationship between the disturbance classes under consideration and trafficking response were not evident unlike CI. The results for BD and GMC may not have indicated a difference among the disturbance classes due to less sensitivity to changes in response to trafficking. Maximum BD and CI levels of approximately 1.36 Mg m $^{-3}$ and 2.09 MPa, respectively, were measured in subsoil layers; GMC was elevated to14.8 % in the soil surface layer of DC5 and WS ranged between 39 and 106%.

Table 1. Soil physical property response to harvest trafficking in a forest health restoration site, Conecuh National Forest, Alabama. Value in parentheses is coefficient of variation (CV).

Soil Depth (cm)	**DC1 †**	**DC5**	**DC6**	**NH**
BD (Mg m^{-3}) ‡				
0 -10	1.04 a ¶ (17.6)	0.89 a (31.5)	1.03 a (22.5)	0.85 a (19.1)
10- 20	1.36 a (10.8)	1.35 a (12.6)	1.33 a (11.2)	1.18 a (11.6)
GMC (%)				
0 - 10	11.5 a (24.5)	14.8 a (50.6)	10.5 a (16.8)	11.0 a (24.4)
10 - 20	9.0 a (23.8)	9.7 a (16.8)	8.7 a (20.1)	8.3 a (29.9)
WS (%)				
0 - 10	59.4 a (46.9)	51.6 a (75.7)	60.1 a (61.5)	38.7 a (26.4)
10 - 20	92.2 a (28.2)	106.3 a (43.7)	88.9 a (41.3)	57.6 a (27.3)
CI (MPa)				
0 - 10	0.90 a (45.0)	0.98 a (44.5)	0.57 b (45.8)	ND §
10 - 20	1.66 a (36.1)	2.09 a (43.5)	1.16 b (38.9)	ND

† Disturbance Class Categories: DC1 – trafficked with litter in place; DC5 – skid trail; DC6 – no evidence of trafficking; NH – non-harvested;

‡ Soil Physical Properties: BD – bulk density; GMC – gravimetric water content; WS – water saturation; CI – cone index.

§ ND indicates no data were available.

¶ Values in rows followed by same letter do not differ significantly (P = 0.05) as determined in a Duncan's MR test.

No significant differences were detected among soil properties under consideration for transect position (TP). Results of the ANOVA are included in Table 2.

Table 2. Summary of analysis of variance results for select soil physical properties by disturbance class (DC) and transect position (TP) in a harvested pine plantation, Conecuh National Forest, Alabama.

	Soil Property by Depth					
	BD10 †	**BD20**	**GMC10**	**GMC20**	**CI10**	**CI20**
Disturbance Class						
df ‡	2	2	2	2	2	2
n	30	30	30	30	29	29
F	2.09	0.19	1.75	1.54	5.70	7.43
Pr>F	0.154	0.83	0.23	0.24	0.01	0.005
MSE	0.067	0.003	0.005	0.0003	355609.11	1872752.33
Transect Position						
df	9	9	9	9	9	9
n	30	30	30	30	29	29
F	1.00	0.62	0.87	2.17	1.17	0.64
Pr>F	0.477	0.76	0.57	0.08	0.37	0.75
MSE	0.032	0.01	0.002	0.0004	72932.79	162097.33

† Soil physical property by depth: BD10 & BD20 – bulk density 0 – 10 cm and 10-20 cm; GMC10 & GMC20– Gravimetric Water Content 0 – 10 and 10 – 20 cm; CI10 & CI20 – Cone index 0 – 10 & 10 – 20 cm.

‡ Statistical variables

Soil collected from 5 silt fences located in the harvested area measured approximately 18.63 kg and 9.23 kg collected in the non-harvested area (Table 3). Soil accumulation in the harvested area exceeded the non-harvested area, as might be expected. Soil accumulations in the harvested area ranged between 1.33 and 5.94 kg and eroded at a rate that ranged between 0.018 and 0.073 kg m^{-2} yr^{-1}, respectively. In contrast, soil accumulations in NH ranged between 0.2 and 2.78 kg and eroded at a rate between 0.002 and 0.037 kg m^{-2} yr^{-1}, respectively. The final accumulations may be related to specific site and soil characteristics and their interaction with precipitation events.

The data for each depth increment and disturbance class were combined for each soil property to examine potential relationships between specific soil properties. A positive relationship between BD and CI was detected in which CI increased linearly as BD increased in the upper 20 cm (r^2 = 0.64) (fig 2). An inverse relationship was detected between BD and GMC with decreased GMC noted as BD approached the maximum of 1.40 Mg m^{-3} (r^2 = 0.78); a stronger relationship was detected between BD and WS

($r^2 = 0.82$) (fig. 3). No relationship was detected between CI and GMC but conversely, the relationship between WS and CI was extremely strong ($r^2 = 0.93$) (fig. 4).

Table 3. Soil accumulation of 5 silt fences located in a harvested and 5 silt fences in a non-harvested slash pine stand in Conecuh National Forest, Alabama.

Silt Fence	**Soil Accumulation (kg)**	**Erosion Rate ($kg\ m^{-2}\ yr^{-1}$)**
Harvested		
1	5.94	0.073
2	3.35	0.042
3	4.92	0.053
4	1.33	0.018
5	3.09	0.032
TOTAL	**18.63**	
Non-Harvested		
1	2.48	0.033
2	1.61	0.021
3	2.78	0.037
4	2.16	0.029
5	0.20	0.002
TOTAL	**9.23**	

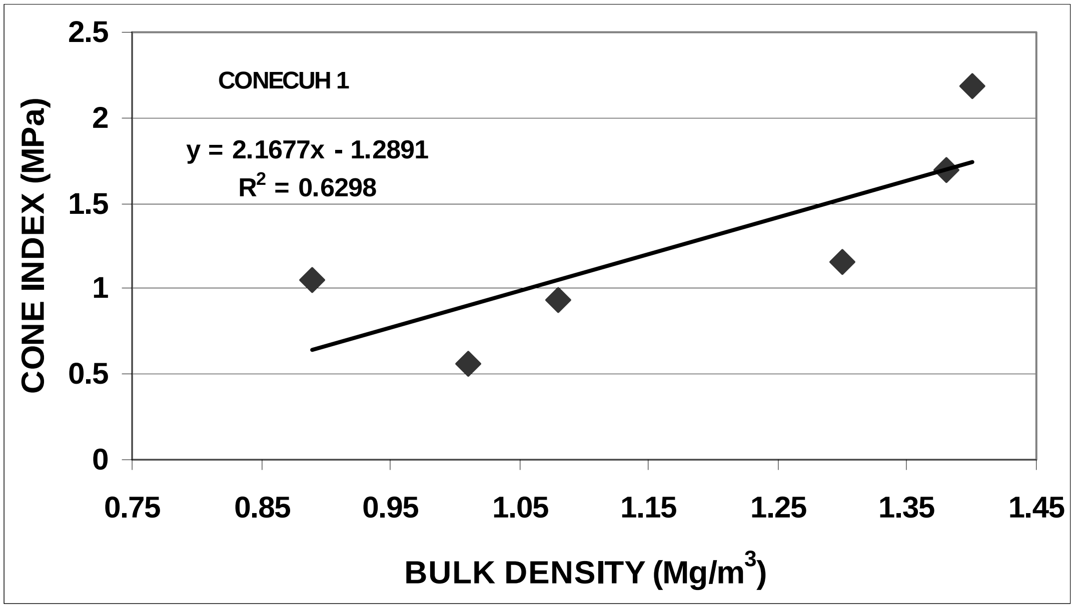
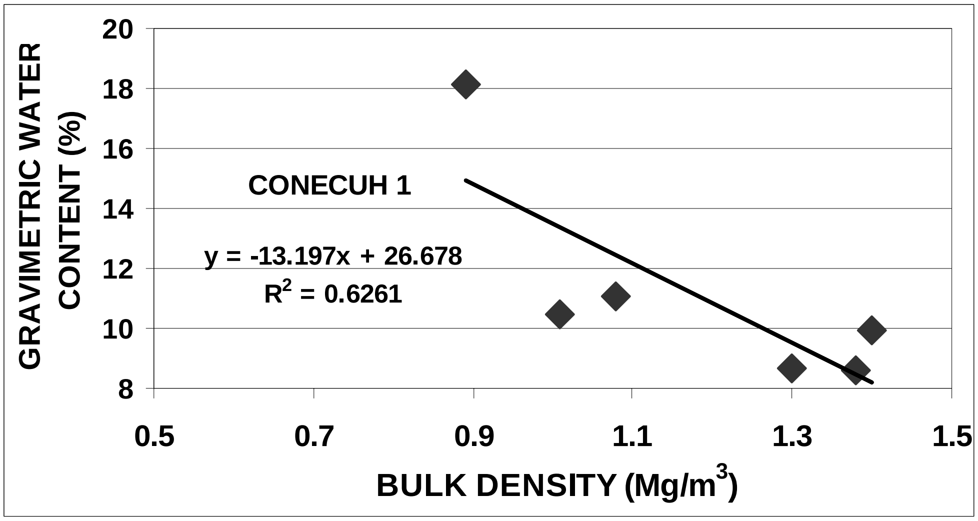


Figure 2. Relationship between bulk density and cone index in a harvested pine plantation, Conecuh National Forest, Alabama



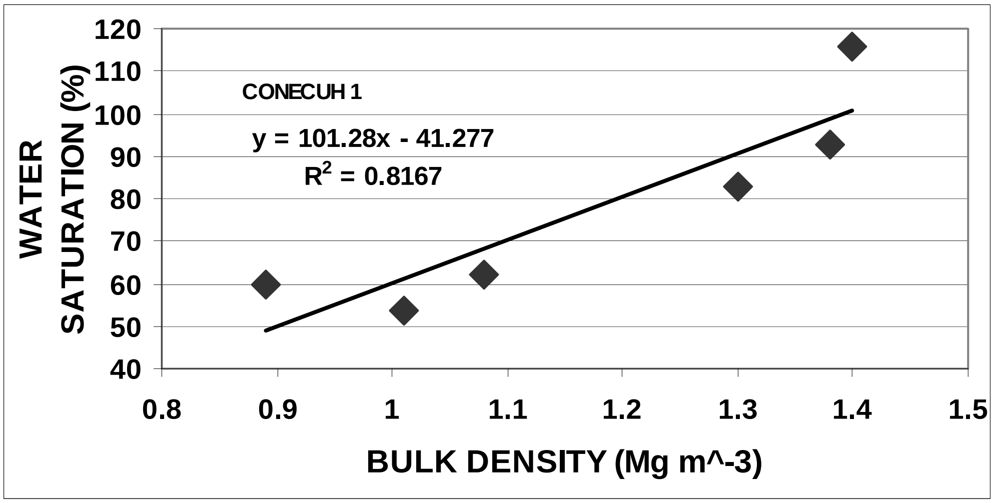


Figure 3. Relationship between bulk density and gravimetric water content (upper) and water saturation (lower) in a harvested pine plantation, Conecuh National Forest, Alabama.

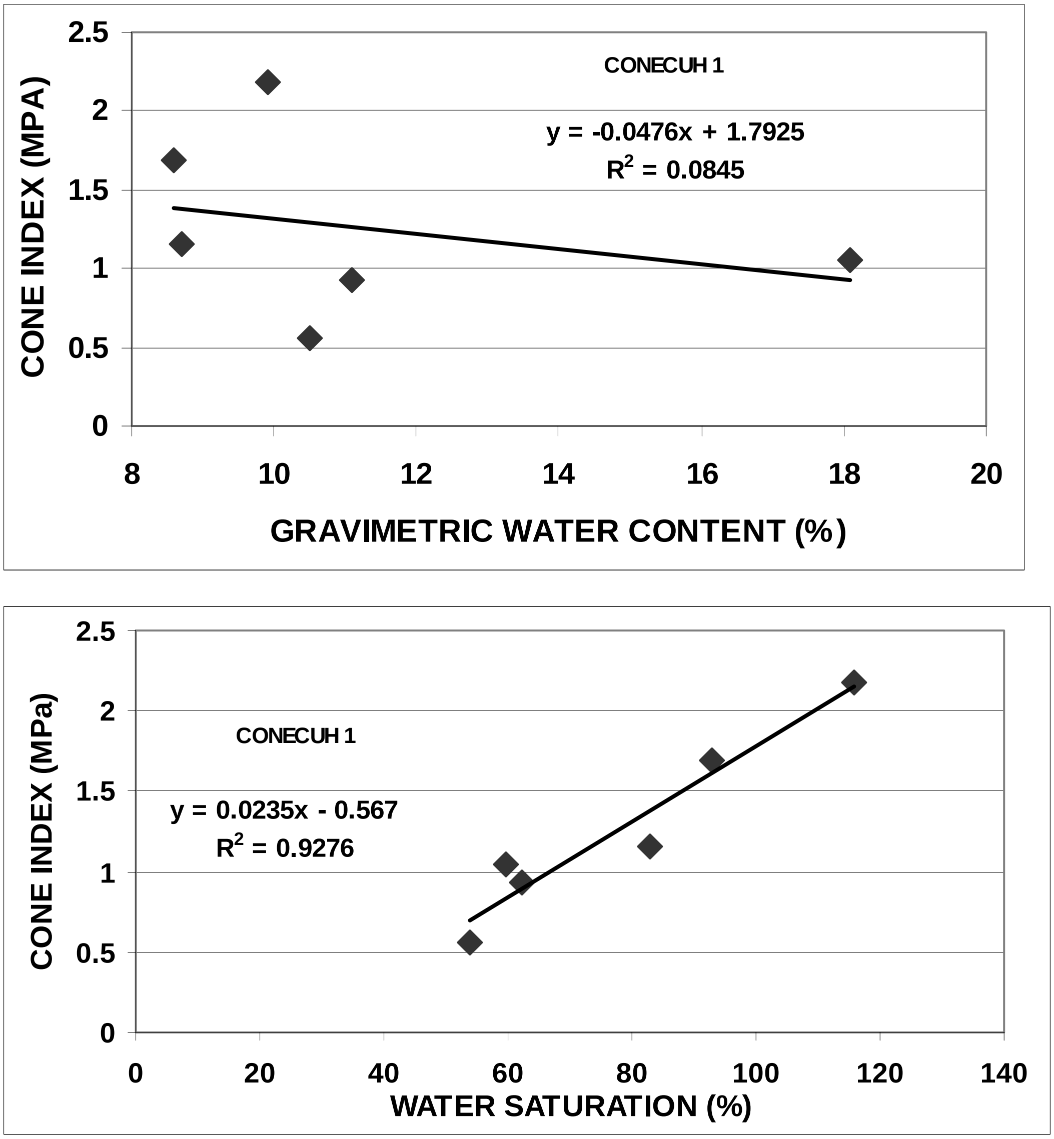


Figure 4. Relationship between gravimetric water content and cone index levels (upper) and water saturation and cone index (lower) in a harvested pine plantation, Conecuh National Forest, Alabama

Discussion

Changes in soil physical properties would be expected in response to trafficking, especially in skid trail locations which typically experience the highest impacts (Greacen and Sands, 1980; Gent et al., 1983; Reisinger et al., 1988; Shaw and Carter, 2002). This observation was supported by the results for CI but BD levels in both soil layers did not indicate a response to trafficking. Although previous studies have reported significant differences in BD due to trafficking (Gent et al., 1983; Incerti et al., 1987), the lack of BD response to trafficking in this study may be related to the response of specific site conditions to machine impacts. The final compaction status of a volume of soil exposed to mechanical stresses is typically the result of an interaction among soil moisture status (Howard et al., 1981; Smith et al., 1997a), soil organic matter content (Howard et al., 1981), soil texture (Meek,1996), compactive effort (Howard et al.,1981; Smith et al.,1997a) and axle load weights (Voorhees et al.,1986). Soil mapping of this area indicated that the most common soil type was Orangeburg loamy sand (USDA, 2002). This soil series is characterized as a deep, well drained, permeable soil typified by a loamy sand surface texture and underlain by a sandy loam in the upper subsurface layer. Previous research has indicated that sandy soils resist compaction regardless of soil moisture content and compaction effort while loamy soils were susceptible to compaction as moisture content and compaction effort increased (Smith et al., 1997a). Bulk densities reported for each disturbance class and NH in the soil surface layer were relatively similar while differences were more pronounced in the subsoil layer between disturbance classes and NH and may be related to textural and moisture differences that influenced the final response to harvest operations.

Penetration resistance was observed to reflect the expected response to trafficking in that the higher cone index was recorded in DC5 followed by DC1 and DC6. Cone index measurements were higher in DC5 for both soil layers and may reflect the interaction between soil moisture and texture. Previous research results have reported on the impact of soil moisture and soil texture on penetration resistance (Ayers and Perumpral, 1982; Smith et al., 1997b). Ayers and Perumpral (1982) noted that soil moisture and texture interacted to influence final penetration resistance and noted that sandier textured soils required a minimal amount of water to reach maximum resistance. They also noted that when textural and soil moisture conditions were constant, a higher compactive effort resulted in higher CI levels. Smith et al. (1997b) also noted similar results for a wider array of soil textures. The data of this study indicated that the highest CI was detected in the soil layers of DC5 followed by DC1 and DC6 and may support the previous research observation that the response was primarily due to machine traffic impacts. Soil moisture and BD status, singly or in combination, are known to influence CI measurements and the results appear to indicate that BD influenced the final CI level as indicated by the relatively strong relationship between BD and CI. Soil moisture content represented by WS appeared to be related to CI due to the very strong relationship between these variables. However, this relationship may not be representative of the influence of soil moisture but rather a surrogate for the impact of BD as WS levels increased linearly with BD. There might not have been sufficient moisture to minimize the impact of BD on final CI, necessary to evaluate the differences among disturbance classes.

Harvesting and tilling activities increase the likelihood of soil movement and runoff (Dickerson, 1975; Beasley et al.,1986). The most obvious reason for this is the loss of vegetative cover, both surface and canopy cover, that contributes to lower runoff and soil detachment by reducing throughfall and raindrop impact (Brandt, 1988; Savabi and Stott, 1994; Owoputi and Stolte, 1995). Simultaneously, changes in soil structure and function as a result of machine trafficking impedes water infiltration and contributes to erosion, the extent of which is influenced by soil texture, slope steepness, particle size and stability, soil strength, and soil moisture conditions (Agarwal and Dickinson,1991; Burroughs et al.,1992; Owoputi and Stolte,1995). The most obvious cause of erosion in this study as indicated by differences between harvested and non-harvested soil accumulations would be the removal of ground and canopy cover. It may be assumed that the change in soil physical status has increased surface runoff in response to rainfall impact and increased soil detachment and entrainment, but the specific mechanisms at work are out of the scope of this study.

Conclusion

The replacement of slash pine by long leaf pine in the Conecuh National Forest, Alabama required complete removal of slash pine in a clearcut operation. Harvesting was performed in Summer 2003 and the site impacts associated with the slash pine removal evaluated by tabulating soil disturbance classes, measuring soil physical response, and estimating erosion potential using the silt fence technique. Seven disturbance classes were identified at the initiation of the project and although all were present, the disturbance classes most commonly encountered consisted of trafficked with litter in place (DC1), skid trails (DC5), and no evidence of trafficking (DC6). A non-harvested area (NH) was sampled that served as a control. Soil physical properties related to BD, GWC, and CI were measured in two 10 cm soil depth increments for response by disturbance class; WS was calculated for each disturbance class and NH. Cone index measurements indicated significant differences existed among the disturbance classes in both soil layers but no differences were detected among disturbance classes and NH for BD, GMC, or WS in either soil depth increment. Soil accumulations in harvested locations were higher than NH and might be related to soil response to loss of cover and precipitation impacts.

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