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Minimizing Soil Impacts from Forest Operations

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Abstract. *Several studies were conducted by Forest Service researchers and University and Industrial collaborators that investigated the potential for lessening soil surface disturbances and compaction in forest operations through modifications of machine components or harvest systems. Specific machine modifications included change in tire size, use of dual tire systems, reduction of tire inflation pressures, reductions in load size and ground pressure. Soil surface disturbances were most evident in sites with high soil moisture content that were lessened by lowering tire inflation pressures or using a dual tire configuration. Traffic intensity increased rutting potential of harvest sites, especially with the use of narrow tires. Traffic intensities varied spatially and in intensity in clear cut harvest operations with intensities that ranged between none to 100 or more. Soil physical properties responded to choice of tire size and inflation pressure with narrower tires and/or higher inflation pressures associated with increased soil compaction. Soil disturbance data collected in three clear cut operations in Alabama indicated no differences among the operations by location, but soil response varied depending on site properties. Soil physical properties did not necessarily reflect the intensity of soil disturbance.*

Keywords. Disturbance class, bulk density, tire, inflation pressure, soil strength

Introduction

Mechanized forest operations have induced changes in soil physical properties with the potential to negatively impact soil sustainability and forest productivity. The final compaction status of a harvested site varies in intensity and variability as a result of machine and site interactions throughout the harvest tract. Machine factors that have been linked to increased compaction include load size, machine ground pressures, tire type and size, and traffic intensity while site factors have included landscape position, soil texture, soil moisture status, and organic matter content (Soane and others, 1981; Horn and others, 1995). The change in soil volume (bulk density) and/or soil strength can affect soil structure, soil aeration, air and water infiltration, nutrient and organic matter status and erosion potential (Greacen and Sands, 1980; Reisinger and others, 1988).

Minimizing soil impacts has been accomplished by use of wider tires, lowered inflation pressures, lighter vehicles, and/or lighter/smaller loads per trip (Soane and others, 1981). The replacement of standard width tires with wider tires has improved productivity and reduced soil surface disturbance in forest settings, especially on poorly drained sites (Aust and others, 1993; Brinker and others, 1996; Klepac and others, 2001; McDonald and others, 1996). Decreased load sizes and reduced ground contact pressures have reduced the degree and depth of soil compaction depending on soil conditions at the time of impact (Greacen and Sands, 1980; Smith and others, 1997a; Horn and others, 2004). Soil disturbances, a typical occurrence in mechanized forest operations, have varied by machine configuration and type of operations that can be exacerbated by soil conditions at the time of impact, especially soil moisture content (Aust and others, 1998). Knowledge of the type and intensity of machine related impacts likely to occur can improve machine and systems productivity while limiting deleterious site impacts.

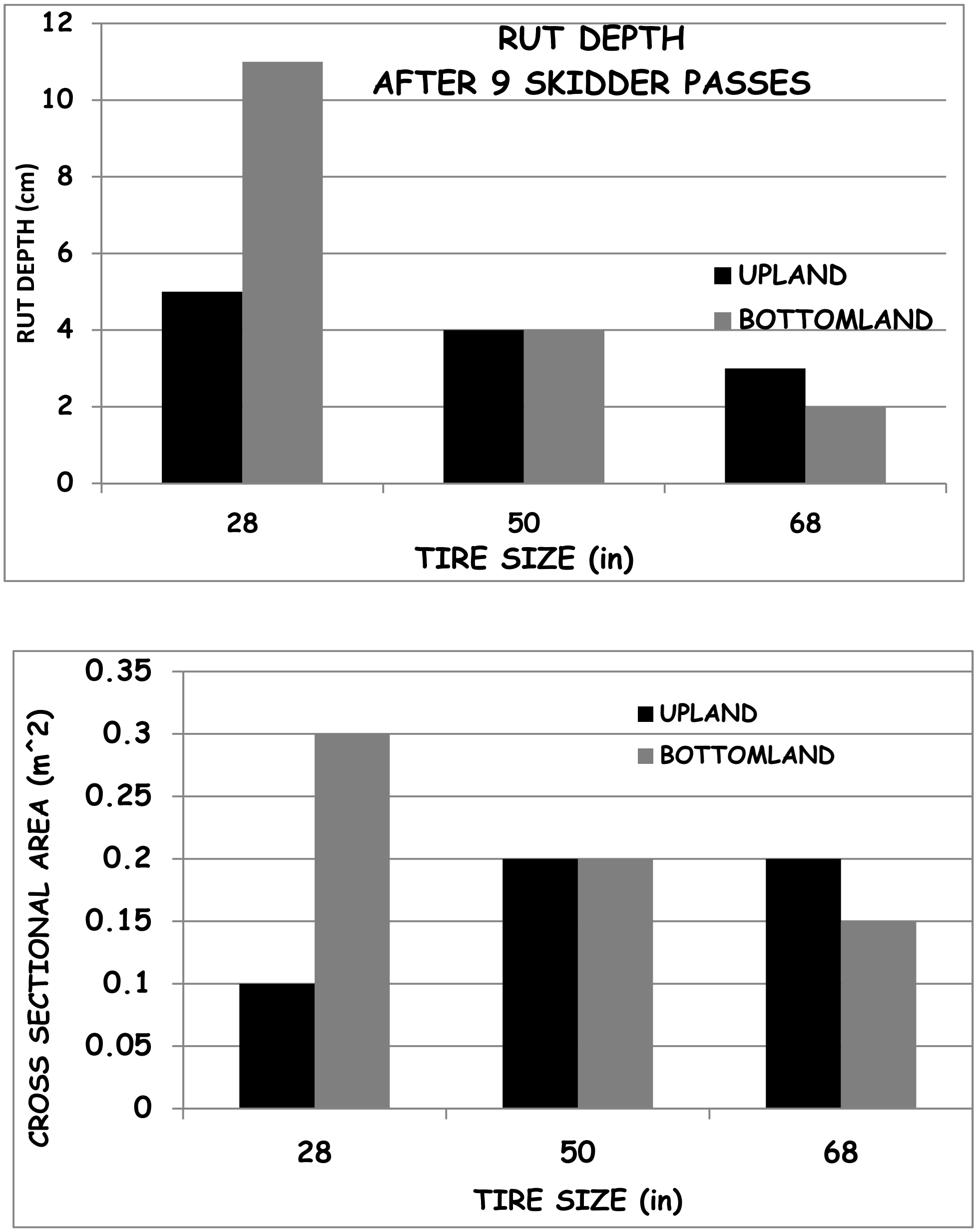
Objectives

This paper reviews select studies of machine modifications and soil responses to forest operations conducted by Forest Service researchers and university and industrial collaborators. Soil inherent and dynamic properties of soil texture, bulk density and strength were utilized as indicators of soil response to machine systems and expected response of soil systems.

Results and Discussion

Machine Systems

Soil response to machine trafficking was linked to traffic intensity and the choice of tire or tire configuration (McDonald et al., 1995). Soil surface disturbances that resulted from specific tire size and configurations were evaluated on upland and bottomland sites in Alabama (wet vs. dry) with disturbance most evident (~rutting) on sites with high soil moisture content. Rut depths and cross sectional areas were greater on wet sites compared to dry sites but varied with tire size and configuration. Smaller tire sizes most often resulted in deeper ruts and greater cross sectional areas but disturbances were offset by decreasing inflation pressures or use of dual tire configurations. The number of passes had an influence on soil response with the two smaller tire sizes resulting in the deeper ruts and greater cross sectional area (fig 1). A similar study on a bottomland site in Alabama examined soil physical responses and observed tire size, tire configuration and traffic intensity had a significant impact on bulk density and total porosity (Table 1). Machine weight (~load) and tire inflation pressures have influenced soil response



Source: McDonald and others, 1995

Figure 1. Effect of Tire Size on Rut Depth and Cross Sectional Area of Two Sites in Alabama.

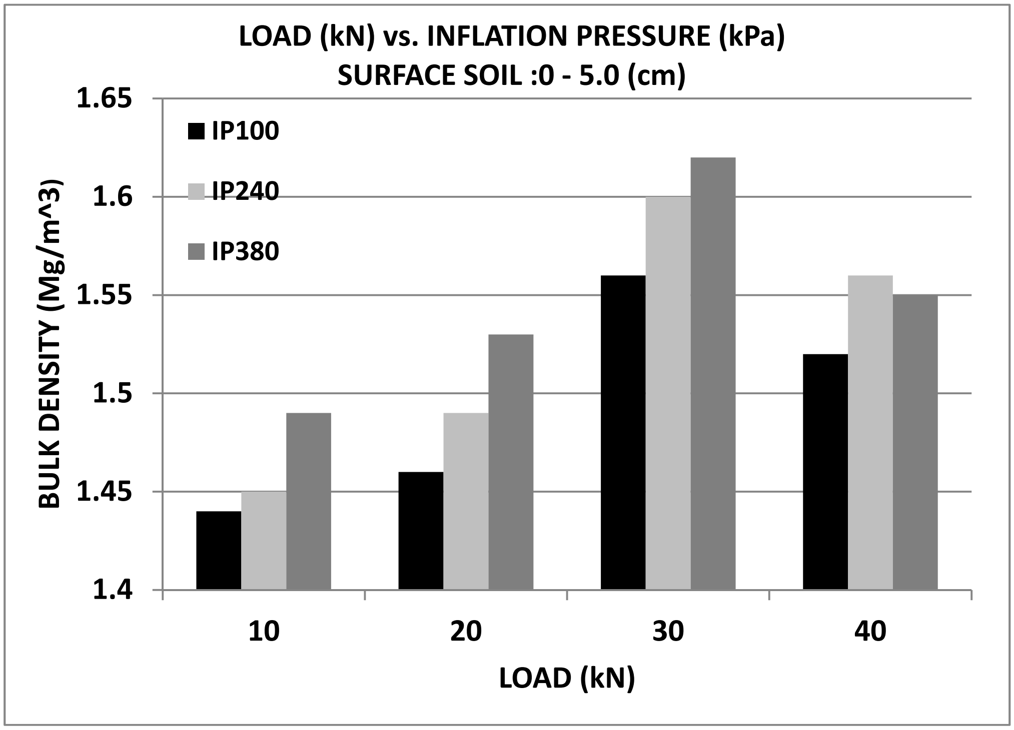
TABLE 1. Impact of tire size and inflation pressures (IP) on select soil physical properties subjected to wet site harvesting, Alabama.

TIRE SIZE (in)	**BULK DENSITY (Mg/m^3)**	**TOTAL POROSITY (%)**
28	1.38 d	50 a
43 LOW IP	1.10 bc	60 bc
43 HIGH IP	1.25 d	55 b
50	0.90 a	65 e
28/23	1.10 c	58 c
30.5/30.5	1.15 c	57 c
43/43	1.05 b	61 d

Source: Aust and others, 1993

(McDonald and others, 1996). Bulk density increased with increasing inflation pressures (IP) under a specific load size at two sampling depths and peaked at IP of 380 kPa and a load size of 30 kN; subsurface results were less consistent (fig 2). Aust and others (1993) noted that a reduction in IP resulted in less impact on soil resources under wet conditions.

Machine movements (~number of passes) in the course of harvesting or thinning are highly dispersed and as a consequence, soil disturbances and compaction vary spatially and in intensity. An evaluation of traffic intensities and their distribution was conducted in a conventional harvest operation by monitoring machine movements by GPS mounted receivers and converting to a raster map of traffic intensities (McDonald and others, 2002). Results indicated that areas of the harvest tract experienced traffic



Source: McDonald and others, 1996

Figure 2. Effect of Load and Inflation Pressure (IP) on Bulk Density of a Davidson soil.

intensities that ranged between none to 100 or more passes. Soil surface disturbances were correlated with number of traffic passes and areas classified as slightly disturbed were subjected to 1 to 3 passes, areas tabulated as disturbed were subjected to 4 to 20 passes and decks and trails were subjected to more than 20 passes. Linking soil physical changes to traffic passes indicated that maximum BD was reached after 3 passes, soil saturation after 4 passes and soil strength greatest after 1 pass (Carter and others, 1999; Carter and others, 2000).

Soil disturbances and compaction as a result of harvesting machines, harvesting systems, silvicultural prescriptions, and specific locations have been well documented (Kluender and Stokes, 1994; Seixas and others, 1995; Seixas and McDonald, 1997; Carter and others, 2005; Carter and others, 2006). Soil physical changes occurred in response to machine trafficking on both poorly drained and well drained soils (Aust and others, 1993; McDonald and others, 1995). Soil disturbances (~ ruts) were reported under both moisture conditions but evidence of trafficking was more apparent on wet sites. Narrow tires resulted in the formation of deep ruts which were reduced with the use of wider tires, both single and duals, after 9 passes (McDonald and others, 1995). Changes in soil physical properties were influenced by the size and configuration of tires under wet conditions with bulk density and total pore space impacted less by use of wide tire arrangements (Aust and others, 1993). Traffic intensities have a critical influence on subsequent soil disturbance and soil physical changes due to repeated passages on the soil surface although differences in soil disturbance may vary depending on soil conditions. Lowering inflation pressures have provided soil protection under dry and wet soil conditions and offset impacts from higher loads (McDonald and others, 1995). Further mitigation of soil disturbances and soil physical changes may be obtained by the use of tracks or placement of a slash barrier, although results may be inconsistent depending on soil conditions (Seixas and others, 1995; Seixas and McDonald, 1997).

Machine movements inevitably impact site conditions and produce soil surface disturbances and alter soil properties throughout the harvest tract. As machines traverse the soil surface, soils react to the stresses imposed on it by undergoing compaction and deformation. Lessening the impact of machines has required development of newer machine types and removal systems (~Cut-To-Length), varying machine components including tire size, tire configurations, and inflation pressures, and assessing traffic patterns and intensities in the course of harvesting or thinning (McDonald and others, 1995; McDonald and others, 1996; Stokes and Schilling, 1997; McDonald and others, 2002). Soil responses to machine forces are influenced by soil characteristics related primarily to soil texture, soil moisture content, and organic matter content (Smith and others, 1997a; 1997b). Each soil property has contributed to soil compaction/surface disturbances but soil moisture content has been cited most often in the final compaction status in response to trafficking. Soil moisture content has a critical role in the compaction status through its influence on soil strength and bulk density responses to applied pressure (Ayers and Perumpral, 1980). Soil moisture content has been postulated to weaken internal forces that reduce resistance to compaction and maximum bulk densities and soil strength are attained at an optimum moisture content (Greacen and Sands, 1980). Similarly, rutting potential is increased when soil strength is lessened with increased moisture content that reduces the ability of a soil to bear the weight of machinery. In terms of soil texture and organic matter composition, soil response to machine trafficking was more responsive to fine textured soils than more coarse textured soil; higher levels of organic matter content contributed to compaction resistance (Smith and others, 1997a). The final compaction status is a reflection of the interaction of machine configuration, machine systems, and soil properties at the time of implementation of forest operations. Mitigation of compacted/disturbed soils is possible through natural processes or factors that have included climate (~freeze-thaw cycles), wetting and drying cycles, root growth, invertebrate activity, clay content and mineralogy, while more immediate intervention has depended on mechanical disruptions via tillage (Dexter, 1991; Drewry, 2006). Previous investigations have reported no loss of productivity of rutted, deeply disturbed soils in South Carolina (Eisenbies and others, 2005) that may be due in part on less pronounced reductions in drainage and aeration in sites with elevated moisture conditions compared with sites where loss of drainage and aeration were greater (Aust and others, 1995).

Soil Impacts

The impact to soil resources as a result of forest operations has been evaluated through the tabulation of soil disturbance class data and/or measurement of changes in soil physical properties. The assessment of soil disturbances has served as an indication of the intensity of management impacts and the distribution throughout the harvest tract (McMahon, 1995). The type and frequency of disturbance class and distribution throughout has permitted comparisons by treatment type and soil conditions (McDonald and others, 2002; Carter and others, 2005; Carter and others, 2006). Among clear cut treatments in three locations in Alabama, soil disturbance classes were similar in type and frequency (Table 2); similar results were reported in the implementation of three management prescriptions in an upland hardwood stand in northern Alabama (Carter and others, 2006). The final tally for the disturbance classes cited in the previous studies closely approximates the findings for tabulating disturbance classes by GPS derived data (McDonald and others, 2002). However, differences in the final soil disturbance tabulations depending on purpose of the assessment (Kluender and Stokes, 1994; Seixas and others, 1995). Bulk density and soil strength have increased in response to machine trafficking with soil strength more responsive to harvest impacts (Shaw and Carter, 2002; Carter and others, 2005; Carter and others, 2006). The relationship between soil disturbance class and soil response was more evident for soil strength than bulk density (Table 3).

Table 2. Soil Disturbance Classes (%) for Three Clear Cut Treatments in Alabama.

	DISTURBANCE CLASS CATEGORIES					
	UNTRAFFICKED (UNT)	**SLIGHTLY DISTURBED (SD)**	**HIGHLY DISTURBED (HD)**	**NON SOIL (NS)**	**n †**	**GRID (m)**
UPPER± CLEARCUT	18	57	17	8	180	18 x 18
CENTRAL CLEARCUT	10	38	45	7	250	10 x 10
LOWER CLEARCUT	15	42	32	11	421	3 x 30

† n = number of sample points evaluated; ± = location of plots in Alabama - UPPER located in Moulton,AL; CENTRAL located in Chambers County, AL; LOWER located in Andalusia, AL.

Table 3. Soil Physical Property Measurements Associated with Soil Disturbance Categories in Three Clear Cut Sites in Alabama.

		DISTURBANCE CLASS CATEGORIES		
SOIL PROPERTIES	**Depth (cm)**	**UNTRAFFICKED (UNT)**	**SLIGHTLY DISTURBED (SD)**	**HIGHLY DISTURBED (HD)**
BD (Mg/m^3)[†]				
UPPER ±	0 – 10 cm	1.04 (23.6) ±	1.10 (22.6)	1.14 (26.4)
	10 - 20 cm	1.33 (14.7)	1.35 (16.8)	1.35 (18.8)
CENTRAL	0 – 10 cm	0.98 (19.4)	1.08 (19.7)	1.06 (23.1)
	10 - 20 cm	1.35 (11.9)	1.29 (11.2)	1.31 (12.3)
LOWER	0 – 10 cm	1.03 (22.5)	1.04 (17.6)	0.89 (31.5)
	10 - 20 cm	1.33 (11.2)	1.36 (10.8)	1.35 (12.6)
GMC (%)				
UPPER	0 – 10 cm	29.5 (51.8)	32.4 (40.3)	32.1 (47.5)
	10 - 20 cm	22.7 (30.4)	22.7 (28.4)	25.1 (46.7)
CENTRAL	0 – 10 cm	24.9 (36.6)	22.3 (24.7)	24.1 (24.8)
	10 - 20 cm	22.1 (13.1)	22.8 (19.0)	24.5 (16.5)
LOWER	0 – 10 cm	10.5 (16.8)	11.5 (24.5)	14.8 (50.6)
	10 - 20 cm	8.7 (20.1)	9.0 (23.8)	9.7 (16.8)
CI (MPa)				
UPPER	0 – 10 cm	0.77 (60.8)	0.95 (54.0)	1.12 (50.7)
	10 - 20 cm	0.81 (68.8)	1.07 (51.3)	1.59 (40.6)
CENTRAL	0 – 10 cm	1.20 (62.5)	1.50 (39.6)	1.46 (43.9)
	10 - 20 cm	1.90 (36.3)	2.20 (27.9)	2.16 (27.4)
LOWER	0 – 10 cm	0.57 (45.8)	0.90 (45.0)	0.98 (44.5)
	10 - 20 cm	1.16 (38.9)	1.66 (36.1)	2.09 (43.5)

† Soil Physical Properties: BD – bulk density; GMC – gravimetric water content; CI – cone index; ± = location of plots – Upper located in Moulton, AL; CENTRAL located in Chambers County, AL; LOWER located in Andalusia, AL.

An assessment of the impact to soil resources from forest operations is feasible through the tabulation of soil disturbance classes and/or measurements of soil properties either singly or in context of the disturbance class assessment. Aust and others (1998) determined that for a wet pine flat in South Carolina visually determined soil disturbance classes were significantly related to bulk density and soil strength while soil strength only was found to be significant for soil disturbance class in two upland sites in Alabama (Carter and others, 2005; Carter and others, 2006). Soil strength has been singled out as the most relevant measure of soil compaction due to its influence on bearing capacity and root penetration, although bulk density measurements have been reported as a relative measure of compaction (Greacen and Sands, 1980; Soane and others, 1981). Final compaction status, whether indicated by soil strength or bulk density, is influenced by soil moisture content and soil texture (Ayers and Perumpral, 1980; Soane and others, 1981). Predicting the compaction response of a specific soil has been accomplished by means of creating soil moisture-density/strength curves (~Proctor test), and examining its behavior as soil moisture increases under a specific compactive effort (Ayers and Perumpral, 1980; Smith and others, 1997a; 1997b). This information is invaluable in predicting the soil response to trafficking when soil texture and soil moisture are known. Land managers can utilize moisture-density/strength curves to evaluate when soil moisture conditions are optimal or too moist for trafficking and determine areas within a stand that might be highly susceptible to compaction (Smith and others, 1997a; 1997b). Also, simple measures of compaction – bulk density and soil strength – can be compared to previously published limits of root growth (Taylor and Gardner, 1963; Daddow and Warrington, 1983). If it is possible to link soil physical data with soil disturbance classes for a harvest tract then the prediction of soil strength and bulk density changes may be easily assessed. Ultimately minimizing compaction and soil disturbances would best be done by determining areas of the harvest tract where the landing and skid trails would be located and limiting the number of passes to which a site would be subjected.

Summary

Forest operations can induce disturbances on the soil surface and alter soil properties, both surface and subsurface properties. The impact of these operations can be mitigated by lessening the pressures applied to a soil system by changing tire size, reconfiguring tires, lowering inflation pressures, reducing load size, limiting the number of passes of a machine, and confining traffic to specific areas of a tract.

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