PINE

APPLICATION OF GPS TECHNOLOGY TO MONITOR TRAFFIC INTENSITY AND SOIL IMPACTS IN A FOREST HARVEST OPERATION[1]

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Abstract-A study was initiated in the Winter of 1998 to examine the utility of employing Global Positioning Systems (GPS) to monitor harvest traffic throughout a loblolly pine plantation and utilize traffic intensity information to assess impacts of select soil physical properties. Traffic maps prepared from GPS positional data indicated the highest concentration of traffic intensities occurred in the landings and skid trails (11 or more) while approximately 94 percent of the site was subjected to 10 or less passes. Estimates of bulk density and gravimetric water content did not approach levels in any traffic intensity class considered to be restrictive to root penetration for either surface or subsurface layers. Soil strength levels for each traffic intensity dass in the surface layer did not indicate the presence of an impenetrable layer but subsoil modification may be necessary to provide a proper environment for regeneration.

INTRODUCTION

Mechanized forest harvest operations can alter soil physical properties which have the potential to influence subsequent management prescriptions and future forest productivity and soil sustainability. In the past, critical information on trafficking damage has relied on the tabulation of subjective surface disturbance classes. the measurement of changes in soil physical properties or a combination of the two methods. Both methods are hampered by the significant amount of time and labor required to implement them and the lack of accuracy required to truly estimate soii disturbance and soil compaction. Global Positioning Systems (GPS) have been employed recently in numerous forestry activities including utilization in thinnings, tracking movements of site preparation equipment, and locating soil disturbances related to harvest activities (McMahon 1997; Stjernberg 1997; Thor and others 1997). Recent studies have evaluated GPS systems and data to depict traffic maps of intensities, or the number of traffic passes to which a ground area of specific dimension has been subjected, and their distribution (McDonald and others 1998b; 1998c; McMahon 1997). Knowledge of the location of traffic intensities and their geographic distribution in a harvested landscape has the potential to provide a means of evaluating soil physical response to trafficking (Carter and McDonald 1998). Linking traffic damage to soil response may provide a framework for future decision making in application of site preparation and prediction of regeneration potential.

OBJECTIVE

The study was conducted in a loblolly pine plantation in the Piedmont region of Alabama with the following objectives: (1) the evaluation of GPS technology to monitor trafficking patterns and intensities, (2) measurement of the response of select soil physical properties to trafficking, and (3) correlation of soil changes to harvest traffic intensities.

MATERIALS AND METHODS

Site Characteristics

The study site was located in a 20-year-old loblolly pine (*Pinus taeda* L.) plantation, approximately 25.4 hectares in size, in Lee County, Alabama. Tree basal area was estimated to be 120 ft^2 per acre of loblolly pine and 20 ft^2 of hardwood with an expected yield of 90 green tons per acre. Soils within the harvest tract were primarily classified as clayey, kaolinitic, thermic members of the Typic Rhodudults (U.S. Department of Agriculture, Soil Conservation Service 1975). Two slope phases of the Gwinnett series were present within the portions of the harvest tract under evaluation.

Harvest and Global Positioning Systems

The harvest system configuration consisted of a single feller buncher (liydroax 5 11 E), two grapple skidders (Timberjack 460D and 450C) pulling to two separate decks, and two loaders (Prentice 270) located at each deck and equipped with an integrated delimber/slasher. Production averaged approximately seven to eight loads per day.

Global Positioning System data wascollected by means of two types of GPS receivers: a Trimble ProXR and Trimble GeoExplorer. The final GPS and harvest system configuration consisted of the GeoExplorer mounted on the feller-buncher and two ProXrs mounted on each skidder. Data were collected in 2-second increments throughout the harvest day, differentially corrected in the iaboratory, and exported to a GIS based system for editing. Detailed information on the transformation of vector based data into raster based maps used in this study has been previously published (McDonald and others 1998a).

Soil Physical Properties

The impact of traffic intensity on soil response was assessed by evaluating soil physical properties at select point locations corresponding to a specific traffic intensity. The relationship between soil physical response and traffic intensity was determined by fixing a ground position by GPS, matching coordinates to traffic maps and by collecting soil samples from these locations. A grid approximately 60 x 73 m in size (-0.4 ha) was established and soil physical data collected in situ or by removal of soil cores at each point. Soil strength was measured on a 3- x 6-m grid and soil bulk density and gravimetric water content evaluated on a 6- x 6-m grid basis. Soil penetrometer data was collected by a Rimik CP20 recording cone penetrometer to a depth of

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0.40 m in 0.025-m increments (ASAE 1997). Soil bulk density and gravimetric water content data were collected by removing soil cores to a depth of 0.2 or 0.4 m, subdividing each core into 0.10-m increments, weighing field moist samples, drying each soil sample for 24 hours at 105 °C and weighing to obtain dry weights (Blake and Hartge 1986). Final soil dry bulk density and gravimetric water content were computed using standard equations to estimate each soil property and correlated to a specific traffic intensity. Traffic intensities greater than four were combined to equally distribute sample numbers for statistical estimations.

RESULTS

Traffic intensity

Traffic maps depicting intensities and patterns within the harvest area under evaluation have been previously published (McDonald and others 1998b; 1998c). Traffic maps prepared from the GPS data indicated a higher intensity of trafficking in areas designated as landings and skid trails, both primary and secondary, and the degree of intensity reduced as traffic dispersed toward the outer sections of the harvest tract.

Evaluation of traffic intensities over the 25.4-ha harvest tract indicated approximately 94 percent of the harvest tract was subjected to 10 or less passes and 6 percent of the trafficked area sustained 11 or more passes; the highest number of passes recorded within one grid cell was 173 (table 1). Untrafficked areas (zero passes) comprised the largest area within the harvest tract and successive percentages of each traffic class declined as traffic intensity increased. A subsection of the harvest tract (- 5.3 ha) examined for traffic intensity showed similar trends in the percent of area which sustained impacts of <10 and >11 as well as a decline in areal percentage with intensity: the highest number of passes recorded within this section was 104. Similar results in the distribution of traffic intensity and patterns in another tract harvested under similar conditions were reported by McDonald and others (19986; 1998c).

Table 1—Areal percentages of traffic intensities throughout the whole and subsection of a harvested loblolly pine plantation, Alabama

Traffic intensity	Frequency 25.4 ha	5.3 ha
	------- *Percent* ------	
0	55.7	37.6
1	13.5	18.4
2	8.2	12.4
3	5.3	8.4
4	3.5	5.6
5	2.5	3.9
6	1.8	2.7
7	1.3	1.9
8	1.0	1.4
9	.81	1.1
10	.64	.87
11+	5.8	5.7
Σ 0-10	94.3	94.3

Soil Response and Traffic Intensity

Soil physical properties were modified in response to traffic intensity and achieved a peak value at a specific traffic intensity (tables 2 and 3). Soil bulk density and mechanical impedance values in the 0- to 10-cm layer achieved a maximum response of 1.12 Mg per m^3 and 1.60 MPa at the three and one pass level, respectively, and declined as

Table 2—Mean bulk density (BD) (Mg m^{-3}) and gravimetric water content (GMC) (percent) (w/w) with coefficients of variation (CV) (percent) of surface (0-0.10 m) and subsurface (0.10-0.20 m) soil layers by traffic intensity for a harvested loblolly pine plantation, Alabama

Traffic intensity	BD (0.1 m)	CV	BD (0.2 m)	CV	GMC (0.1 m)	CV	GMC (0.2 m)	CV
0	0.98	19.4	1.35	11.9	24.9	36.6	22.1	13.1
1	1.01	17.8	1.31	10.7	21.2	32.1	21.5	20.0
2	1.10	12.7	1.27	9.5	22.4	21.0	23.6	19.5
3	1.12	28.6	1.28	13.3	23.2	21.1	23.3	17.6
4	1.09	19.5	1.35	8.2	21.8	26.2	23.4	13.7
5–9	1.08	20.4	1.29	16.3	24.6	24.4	24.4	20.1
10-24	1.02	29.4	1.28	12.5	26.0	23.9	25.7	15.6

Table 3-Mean cone index (CI) (MPa) with coefficients cf variation (percent) of surface (0.0-0.10 m) and subsurface (0.10-0.20 m) soil layers for a harvested loblolly pine plantation, Alabama

	Soil physical properties			
Traffic intensity	CI (0.10 m)	c v	CI (0.20 m)	c v
0	1.20	62.5	1.90	36.3
1	1.60	37.5	2.24	32.6
2	1.40	38.6	2.06	25.7
3	1.50	42.7	2.31	25.5
4	1.51	50.3	2.37	25.7
5-7	I .48	52.0	2.06	36.4
8-10	1.45	46.9	2.16	25.5
11-24	1.40	26.4	2.06	19.9

traffic intensity increased. The highest level of gravimetric water content of 26 percent occurred within the highest traffic intensity range. Changes in bulk density and cone index values in the 10- to 20-cm layer appeared to peak at 1.35 Mg per m^3 and 2.37 MPa after four passes and declined slightly thereafter; gravimetric water content increased to a maximum value of 25.7 percent at the highest traffic intensity range.

Trends in the response of soil physical properties to traffic intensity was examined by plotting all possible data pairs and determining the best mathematical description of the relationship. The relationship between soil physical response and traffic intensity was not evident in any data set with the exception of the bulk density and gravimetric water content in the 0- to 10-cm layer (figs. 1 and 2). A quadratic function provided the best fit for bulk density (r^2 = 0.51) and gravimetric water content ® 2 = 0.51) in the surface layer of the trafficked soil; r 2 values for other physical properties under consideration were less than 0.30 for all subsurface soil properties data and surface layer soil strength. Bulk density versus traffic intensity when all data was considered appeared to peak at approximately seven passes and 1 .1 5 Mg per m^3 while gravimetric soil moisture content declined to 23 percent at an intensity of 4 passes before increasing with successive traffic intensities.

DISCUSSION

Monitoring harvest traffic by GPS yielded valuable information related to the intensity of trafficking throughout the harvest tract and its location in the landscape. Traffic intensities recorded by GPS were highest in landings and skid trails on approximately 6 percent of the harvest tract while traffic intensities of ≤10 dominated the tract. Information on the degree of traffic intensity and its distribution over a forested landscape has not been previously available. Rather, the degree and intensity of disturbance associated with harvesting and its distribution have been utilized as an indicator of traffic intensity and impact (Aust and others 1998. Carter and others 1997).

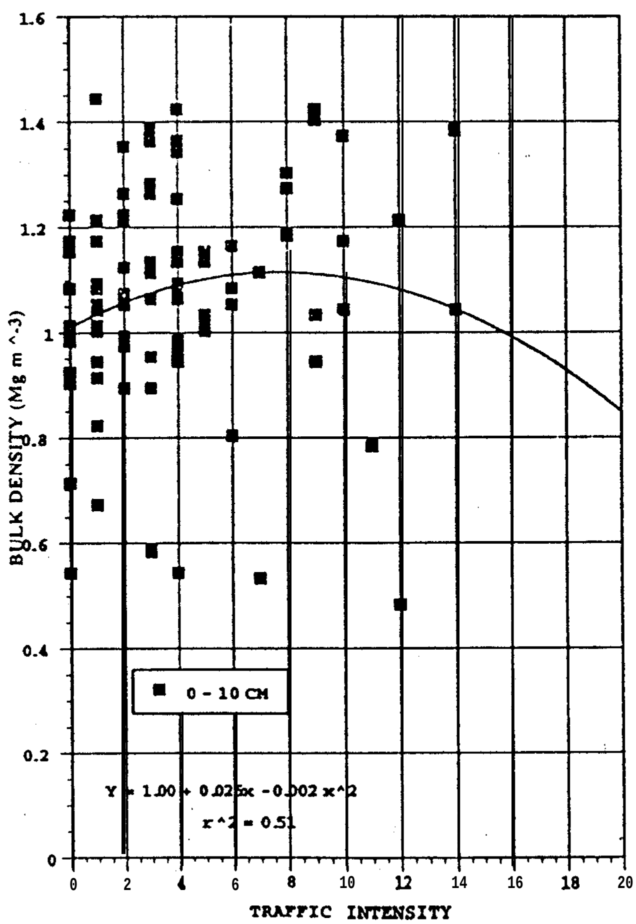

Figure I-Relationship between bulk density (Mg/m 3) and traffic intensity of the surface layer of a Gwinnett sandy loam soil in a harvested loblolly pine plantation. Alabama.

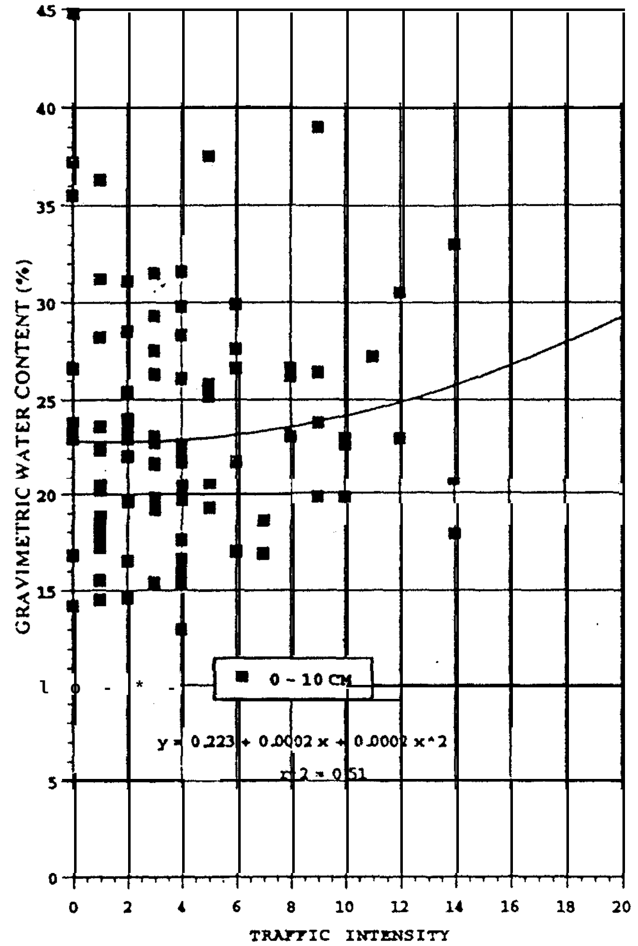

Figure Z-Relationship between gravimetric water content (w/w) (percent) and traffic intensity of the surface layer of a Gwinnett sandy loam soil in a harvested loblolly pine plantation. Alabama.

The use of GPS equipment to monitor harvest traffic has the potential to provide a permanent record of traffic related impacts and assist in decision making processes on site preparation activities and regeneration potential within a harvested tract.

Soil bulk density and soil strength are expected to increase in response to machine traffic due to soil volume reductions and closer proximity of soil particles and aggregates (Greacen and Sands 1980). The change in bulk density, gravimetric water content and soil strength in this study indicated a response to machine trafficking, especially in the surface layer. Bulk density increased by approximately 15 percent in the surface layer compared to the untrafficked condition (zero traffic intensity) and to a lesser degree in the subsurface layer. These results are within the range of percentages (3 and 50 percent) that have been previously reported in studies of bulk density changes in trafficked sites (Froehlich and McNabb 1983, Hatchell and others 1970, Incerti and others 1987. Wronski 1984). The maximum compaction status achieved after three passes was consistent with previously reported studies in which higher incremental changes in bulk density occurred within the first five traffic passes followed by progressively smaller increments of change (Greene and Stuart 1985, Hatchell and others 1970. Meek 1996). It should be expected that the results would vary with temporal and spatial changes in study conditions as underscored in studies by McNabb and Startsev (1995) and Meek (1996). They noted that differences in soil moisture status and texture contributed to a wide range of bulk density values as well as the point of maximum response to traffic intensity. Subsoil bulk density response did not exhibit a clear trend with traffic intensity and may reflect inherently different soil conditions at the time of trafficking.

The relationship between bulk density and traffic intensity under constant soil moisture conditions resembled results reported by Ayers and Perumpal(1982) for cone index values in which cone index increased with successive compaction efforts at a standard moisture content. Further investigation into this relationship may be warranted to predict maximum bulk density (and soil strength) under standard traffic conditions and soil moisture.

Gravimetric water content declined with successive traffic intensities until a maximum soil moisture content of 26 percent was attained at the maximum traffic intensity (10 to 24). Reductions in the percent of water may be an indication of a toss of capillary pore space in response to trafficking. Hill and Sumner (1967) theorized that differences in soil moisture content after compaction would occur depending on soil texture. They noted sandy loam soils would experience a loss of total porosity at the expense of the capillary pores and as a result, hold less water. The surface soil layer under consideration was classified as a sandy loam which may account for the results obtained in the study. Gravimetric water content increased in response to traffic intensity in subsoil layers and may be indicative of the response of a clay soil to compaction through an increase in capillary pore space and water holding capacity as noted by Hill and Sumner (1967).

Soil strength increased to its highest level in the surface layer after one pass and declined thereafter; four passes elevated soil strength to its highest level in the subsoil layer. Soil strength response may be the resuit of increased compaction effort under a constant soil moisture content at. the time of compaction as demonstrated by Ayers and Perumpal (1982). They noted that minimal changes in soil strength occurred under conditions of elevated soil moisture contents and increasing bulk density. Soil moisture conditions were expected to be elevated within the soil body under consideration as harvesting occurred in winter of 1998 when moisture was plentiful. Soil strength changes might have been minimal under these conditions elucidated by the authors.

SUMMARY

Traffic maps depicting patterns and intensities of harvest traffic were produced through the collection of positional data by a standard GPS. A majority of the site experienced ≤ 10 passes after trafficking by a feller-buncher, multiple skidders, or both. Soil impacts examined by measuring soil physical response at locations correlated to traffic intensity indicated that changes in bulk density, soil strength, and soil moisture would not be expected to significantly impact pine regeneration in surface layers; soil strength levels >2.0 MPa often encountered in subsoil layers may be indicative of limitations to root growth. Further elaboration of soil physical response to trafficking under a range of site conditions would be beneficial in understanding this complex relationship.

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