Soil Disturbances from Horse/Mule Logging Operations Coupled with Machines in the Southern United States

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ABSTRACT

Forest harvesting with animals is a labor-intensive operation. While mechanized logging is very efficient for large tracts of timber, it is often disruptive to the soil. Small logging operations using animals may be less environmentally disruptive. To better understand horse/mule logging performances for soil disturbance, five different horse/mule harvesting operations were investigated. About 75 percent of the soil was undisturbed and 22 percent of the remaining soil disturbance was judged to be slight. Only 3 percent of the soil examinations were classified as deeply disturbed and rutted – a condition considered to be prone to soil erosion. This study suggests that horse and mule logging has low soil disturbance in a partial cut of mixed pine/hardwood forests.

Keywords: *animal logging, horse/mule, soil disturbance*

Introduction

For many years, animals were the only source of power for skidding and the primary power for hauling in timber harvesting (Wackerman et al. 1966). Creighton (1997) mentioned that logging was carried out by men and animals long before the introduction of the modern crawler tractor, mechanized wheel loaders, and tractor-trailers. Heinrich (1985) identified three levels of logging operations:

1. labor intensive,
2. intermediate technology, and
3. fully mechanized.

Logging operations with animals is a labor-intensive type of logging.

Soil disturbance in logging operations depends on many factors, such as tree species, size of tree harvested, intensity and number of trees cut, tract size, harvesting season, types of machines used, soil type, soil moisture, and slope. Several logging studies on soil disturbance are summarized in **Table 1**. These six studies used the same soil disturbance codes as reported in this study (**Table 2**). The study carried out by Miller and Sirois (1986) was in a clearcut, but the rest were either for thinning, group selection felling, patch cut, single-tree selection felling, a shelterwood system, or partial cuts.

Miller and Sirois (1986) conducted a study comparing soil disturbance for cable logging in a clearcut with ground skidding in southern loamy hills of the Gulf Coastal Plain in southwestern Mississippi during June to October with slopes ranging from 10 to 45 percent. Harvested stands were mature southern pine from 30.2 to 76.2 cm (12 to 30 in.) diameter at breast height (DBH) with a hardwood component. Rubber-tired skidders were used for ground skidding.

Stokes et al. (1995) conducted a soil disturbance study in the Ouachita National Forest in Arkansas for single-tree selection, group selection, shelterwood, seed tree, and clearcut harvesting in mixed shortleaf pine, loblolly pine, and various southern hardwood species using skidders. All of the pines and hardwoods were greater than 8.9 cm (3.5 in.) DBH.

Klepac et al. (1999) conducted a soil disturbance study for tracked skidders in south-central Washington with slopes from 10 to 30 percent. Harvested stands were 60 to 70 years old, second growth with a mean DBH of 44 cm (17.3 in.). Harvesting was done from April to September in 1998. Residual trees were 74, 59, and 78 percent of pre-harvest basal area for thinning, group selection cuts, and patch cut, respectively.

In thinning of an 18-year-old loblolly pine stand in Baldwin County, Alabama, using a grapple skidder, Lanford and Stokes (1995) found that 39 percent of the ground was deeply disturbed and rutted. This study was conducted during wet logging conditions. Using a Valmet 546 Wood Star harvester and a Valmet 546 Wood Star forwarder, however, they found that only 29 percent of the ground was rutted.

Seixas et al. (1995) examined soil disturbance in partial cuts of 32-year-old slash pine and 33-year-old loblolly pine stands in Tuskegee National Forest in Alabama. Different ground-based systems were compared. Manual felling, feller-buncher, drive- to-tree harvester, harvester, and forwarder were used as well as manual felling with horse prebunching and a forwarder. Hamilton (1998) studied a partial cut with horses in riparian

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International Journal of Forest Engineering 19(1): 17-23.

Table 1. ~ *Soil disturbance percent for harvesting systems with codes.*

Studies	Harvesting systems	Silvicultural operation	Soil disturbance in percent: Undisturbed (1 and 6)	Slightly disturbed (2)	Deeply disturbed (3)	Rutted (4)	Total soil disturbance codes 2+3+4
							(%)
Lanford and Stokes (1995)	Skidder	Thinning	48.0	13.0	1.0	38.0	52.0
	Forwarder	Thinning	62.0	9.0	0.0	29.0	38.0
Klepac et al. (1999)	Skidder	Thinning	59.6	28.9	10.5	1.0	40.4
	Skidder	Group selection	53.9	31.9	13.1	1.1	46.1
	Skidder	Patch cut	44.8	34.6	19.4	1.2	55.2
Stokes et al. (1995)	Skidder	Single-tree selection	40.6	41.0	11.8	6.6	59.4
	Skidder	Group selection	29.0	49.0	13.4	8.6	71.0
	Skidder	Shelterwood	17.7	59.9	13.3	9.1	82.3
	Skidder	Seed tree	12.3	63.9	12.7	11.1	87.7
Miller and Sirois (1986)	Skyline	Clear cut	63.6	25.3	4.6	6.5	36.4
	Skyline	Clear cut	57.9	25.3	4.3	12.5	42.1
Seixas et al. (1995)	Harvester and forwarder	Partial cut	37.5	62.5	0.0	0.0	62.5
	Manual felling and horse with forwarder	Partial cut	46.0	54.0	0.0	0.0	54.0
	Feller buncher and forwarder	Partial cut	34.0	66.0	0.0	0.0	66.0
Hamilton (1998)	Horse with forwarder	Partial cut	91.0	6.0	3.0	0.0	9.0

Table 2. ~ *Soil disturbance codes.*

Code	Description
1	Undisturbed
2	Slightly disturbed: Litter in the place to litter and mineral soil mixed
3	Deeply disturbed with surface soil deposited on top of litter
4	Rutted by log and/or machine
6	Downed wood, stumps, standing trees (undisturbed)

zones with over-mature balsam fir and scattered spruce and fir in Canada using three single-horse crews and one 20-year-old 5-ton forwarder.

Available literature reports very little information on the soil impact from animal logging operations, particularly when machines are combined with horses/mules. The goal of this study was to assess soil disturbance from horse/mule logging operations when horses/mules are combined with loading or forwarding machines. Forest managers and participating foresters need to know what level of soil disturbances to expect from horse/mule logging operations.

Study Methods

Field data were collected from five horse/mule logging operations in Alabama during the summer and autumn of 1999 and the spring of 2001. Only a few rainstorms were experienced during the field data collection period. Most horse and mule operations were located in the northern half of the state, where hilly areas with oak-hickory and mixed pine-hardwood forests are typically owned by non-industrial private forest landowners in small tracts (Toms et al. 1998). The results of this study were compared with previous studies and are shown in **Table 1**.

Horse/mule logging operations were used in selective logging in mixed pine-hardwood forests taking larger trees and leaving smaller ones. It was estimated that the number of residual trees, about 172 to 198 per hectare above 10 cm DBH (about 70 to 80 trees/acre above 4 in. DBH), were similar among the five operations.

Operations were chosen to represent the range of all of the possible horse/mule logging systems identified in Alabama. Conditions that were found for all of the systems included partial cuts for saw logs and pulpwood and operations on almost flat ground (less than 10% slope). The harvesting systems included horses with a forwarder, mules with a forwarder, horses with a side loading truck, and horses with a knuckleboom loader. The logging operations were conducted on red clay loams of hornblende origin of piedmont plateau. In addition an operation with a horse with a long-stick cable loader truck carried out logging on a site with gray cherty silt loam soils on rolling to hilly relief soil.

Animal Logging Operations Details

Five types of animal logging operations identified in Alabama during this study are described below. Animals were used singly for the skidding of logs for all five animal logging operation studied for soil disturbances.

1. Horses with a forwarder (H/FWD): This crew had two horses with harnesses and tongs, a forwarder, two chainsaws, a van to transport horses, and a pickup truck. A chainsaw operator, a horse operator, and a forwarder operator comprised the crew.
2. Mules with a forwarder (M/FWD): This crew had four mules with harnesses and accessories, a forwarder, two chainsaws, and a van to transport the crew to work. Only

two mules were used for logging each day. The crew was comprised of a chainsaw operator, assistant chainsaw operator, two mule operators, and a forwarder operator. Mules were left in the woods in a fenced area overnight.

3. Horses with a side loading truck (H/SLT): This crew had two horses with harnesses and tongs, a side loading truck (**Fig. 1**), two chainsaws, and a van to transport the horses. A chainsaw operator and two horse operators comprised the crew. Horse operators loaded the logs onto the side loading truck when two to five logs were skidded near the arms of truck. One of the horse operators also drove the truck.
4. Horses with a knuckleboom loader (H/KBL) (**Fig. 2**): This crew had two horses with harnesses and tongs, a knuckleboom loader, two chainsaws, and a van to transport the horses. This crew was one man who did all of the felling and processing of trees and skidding and loading of logs.
5. Horses with a long-stick cable loader trucks (H/LSCLT): This crew had two horses although only one horse was used each day, two long-stick cable loader trucks, two chainsaws, and a pickup truck with cage to transport a horse (**Fig. 3**). This crew had a chainsaw operator, a long-stick cable loader operator, and an assistant to the loader operator.

Due to the low number of horse/mule logging operations working in Alabama during the study period and the fact that most were working in similar conditions regarding stand type, diameter class, number of residual trees above 10 cm DBH (4 in. DBH), and terrain, one set of similar conditions was selected for all horse/mule logging operations.

Systematic grids, 48.8 by 36.6 m (160 by 120 ft), were laid out in each harvested area within a week after harvesting but before any rain event (**Fig. 4**). Beginning at one side of a permanent road where logging had been completed, a random starting point was selected for the corner of a study area. The grid covered both horse/mule skidding and machine travel areas. North-south base lines were installed every 12.2 m (40 ft)

Figure 1. ~ *A side loading truck.*

Figure 2. ~ *Horses with knuckleboom loader.*

Figure 3. ~ *Horse and a long stick cable loader truck.*

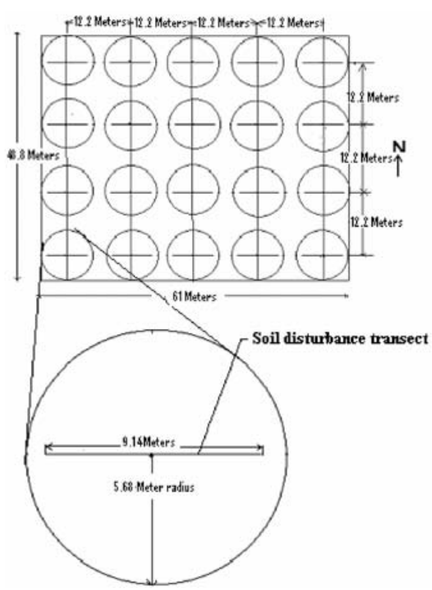

Figure 4. ~ *Layout of sample plots for the measurement of soil disturbances.*

with plots placed every 12.2 m (40 ft) along the lines. Circular 1/99th hectare (1/40th acre) plots with 5.68-m (18.62 ft) radius were installed. Twenty sample plots were taken for each animal logging operation totaling 100 sample plots for five animal logging operations. Sample plots with transect lines are shown in **Figure 4**.

The amount of area required for truck loading varied among crews. Both the forwarder crews and the knuckleboom loader crew used setout trailer landings that were approximately 1/25 hectare (1/10 acre). The horses with side-loading trucks and LSCL truck crew did not need landings because the logs were loaded in the woods and hauled directly to mills or log yards. The sampling grids for soil disturbance excluded the loading areas for setout trailers but included in-woods loading for side-loading trucks and LSCL trucks. Roads used for forwarding were not excluded from the sampling grids.

A 9.14-m (30-ft) transect centered on and perpendicular to the north-south baseline was installed at each sample plot for measurement of soil disturbance (**Fig. 4**). Lengths of undisturbed (code 1 and 6), slightly disturbed (code 2), deeply disturbed (code 3), and rutting (code 4) soil disturbance as used by Lanford and Stokes (1995) (**Table 2**) were recorded along the transect.

Least squares regression with dummy variables for the five animal harvesting operations was used to compare ground disturbances (Cunia 1973, Lanford 1975). The dummy variable technique allows qualitative independent variables to be analyzed in a quantitative fashion. In the case of this paper, the five different harvesting operations were quantified using dummy variables. By assigning a binary value (1 or 0, i.e., yes or no) to an observation of each harvesting operation in combination with a length of transect line (the dependent variable) separated into the various soil disturbance categories, the amount of disturbance could be statistically compared among harvesting systems. The dummy variable technique allowed the different disturbance amounts from the various harvesting systems to be compared for statistical significance.

The dummy variables for horse/mule logging operations were used as the independent variables whereas percent of length measurements corresponding soil disturbance codes were dependent variables. The percent of soil disturbance for each code Y_i was calculated as:

$$Y_i = \frac{L_i}{9.14 \text{ m}}$$

where:

L_i = lengths of soil disturbance codes 1 and 6, 2, 3, and 4 in m along the transects.

A statistical model for comparison is:

$$H_0: R1 = R2$$

where regression R1 is a model that accounts for the different animal logging crews expressed as dummy variables for each of the ground disturbance codes expressed in percent of length.

Total of ground disturbance codes =

$$Y_1 + Y_2 + Y_3 + Y_4 = 100\%$$

Y_1 = undisturbed,

Y_2 = slightly disturbed,

Y_3 = deeply disturbed, and

Y_4 = rutted.

A linear regression model with dummy variables was used:

$$R1: Y_i = b_0x_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4$$

where:

Y_i = ground disturbance of interest as percent of the total transect length

x_0 = 1.

x_1 = 1 for the mules with forwarder crews; otherwise 0.

x_2 = 1 for the horses with side loading truck crews; otherwise 0.

x_3 = 1 for the horses with knuckleboom loader crews; otherwise 0.

x_4 = 1 for the horse with long stick cable loader truck crews; otherwise 0.

b_0, b_1, b_2, b_3, and b_4 = regression coefficients, and

x_1, x_2, x_3, and x_4 = dummy variables.

The horses with forwarder crew effect was represented by the intercept b_0; b_1, b_2, b_3, and b_4 are interpreted as adjustments to b_0.

$$R2: Y_i = b_0x_0$$

Results and Discussion

Field collections from the 100 sample plots are shown in **Table 3**. Amounts of each disturbance code are displayed as percentages of the transect length – 9.14 m (30 ft). For example, Plot 1 taken from a horse with forwarder operation had 8.53 m (28 ft) or 93.33 percent of undisturbed length (Code 1 and 6) and 0.61 m (2 ft) or 6.67 percent of slightly disturbed length (Code 2). These percentages served as the "Y_i" or dependent variable values used in the regression analysis. Means, standard deviations, minimums, and maximums are shown for each type of animal operation and for all of the plots combined.

From **Table 3**, rutting occurred a maximum of 10 percent for the H/FWD and M/FWD crews, 20 percent for the H/SLT crew, 3.33 percent for the H/KBL crew, and 1.67 percent for the H/LSCLT crew. While deep soil disturbance was not observed for the H/FWD and H/KBL crews, maximum values of 60 percent, 53.33 percent, and 5 percent were observed for M/FWD, H/SLT, and H/LSCLT crews, respectively. For all five animal logging crews, plots were found with 100 percent undisturbed areas. Maximum observations of slightly disturbed soil was 63.33 percent, 40.83 percent, 66.67 percent, 100 percent,

Table 3. ~ *Measurement of ground disturbance codes in percent for sample plots for five animal logging operations.*

Plot number	Percent of ground disturbances with codes 1 and 6	2	3	4	Plot number	Percent of ground disturbances with codes 1 and 6	2	3	4	Plot number	Percent of ground disturbances with codes 1 and 6	2	3	4
	- - - - - - - - H/FWD - - - - - - - -					- - - - - - - - M/FWD - - - - - - - -					- - - - - - - - H/SLT - - - - - - - -			
1	93.33	6.67	0.00	0.00	21	95.00	5.00	0.00	0.00	41	53.33	46.67	0.00	0.00
2	66.67	33.33	0.00	0.00	22	91.67	8.33	0.00	0.00	42	33.33	66.67	0.00	0.00
3	56.67	43.33	0.00	0.00	23	100.00	0.00	0.00	0.00	43	56.67	43.33	0.00	0.00
4	81.67	18.33	0.00	0.00	24	96.67	3.33	0.00	0.00	44	76.67	23.33	0.00	0.00
5	85.00	15.00	0.00	0.00	25	26.67	6.67	60.00	6.67	45	76.67	23.33	0.00	0.00
6	80.00	20.00	0.00	0.00	26	100.00	0.00	0.00	0.00	46	73.33	26.67	0.00	0.00
7	100.00	0.00	0.00	0.00	27	100.00	0.00	0.00	0.00	47	36.67	63.33	0.00	0.00
8	83.33	16.67	0.00	0.00	28	90.00	10.00	0.00	0.00	48	66.67	33.33	0.00	0.00
9	26.67	63.33	0.00	10.00	29	59.17	40.83	0.00	0.00	49	90.00	10.00	0.00	0.00
10	78.33	21.67	0.00	0.00	30	63.33	26.67	0.00	10.00	50	53.33	46.67	0.00	0.00
11	100.00	0.00	0.00	0.00	31	100.00	0.00	0.00	0.00	51	83.33	16.67	0.00	0.00
12	100.00	0.00	0.00	0.00	32	80.00	20.00	0.00	0.00	52	46.67	16.67	36.67	0.00
13	100.00	0.00	0.00	0.00	33	88.33	11.67	0.00	0.00	53	100.00	0.00	0.00	0.00
14	26.67	63.33	0.00	10.00	34	100.00	0.00	0.00	0.00	54	83.33	10.00	0.00	6.67
15	31.67	68.33	0.00	0.00	35	50.00	0.00	40.00	10.00	55	43.33	56.67	0.00	0.00
16	96.67	3.33	0.00	0.00	36	100.00	0.00	0.00	0.00	56	16.67	10.00	53.33	20.00
17	100.00	0.00	0.00	0.00	37	96.67	3.33	0.00	0.00	57	100.00	0.00	0.00	0.00
18	80.00	10.00	0.00	10.00	38	90.00	10.00	0.00	0.00	58	83.33	6.67	0.00	10.00
19	83.33	8.33	0.00	8.33	39	100.00	0.00	0.00	0.00	59	83.33	16.67	0.00	0.00
20	100.00	0.00	0.00	0.00	40	60.00	33.33	0.00	6.67	60	0.00	100.00	0.00	0.00
Mean	**78.50**	**19.58**	**0.00**	**1.92**		**84.36**	**8.96**	**5.00**	**1.67**		**62.83**	**30.83**	**4.50**	**1.83**
SD[a]	**24.72**	**22.88**	**0.00**	**3.95**		**21.10**	**12.10**	**15.73**	**3.50**		**27.32**	**26.13**	**14.11**	**5.04**
Min.	**26.67**	**0.00**	**0.00**	**0.00**		**26.67**	**0.00**	**0.00**	**0.00**		**0.00**	**0.00**	**0.00**	**0.00**
Max.	**100.00**	**63.33**	**0.00**	**10.00**		**100.00**	**40.83**	**60.00**	**10.00**		**100.00**	**66.67**	**53.33**	**20.00**

Plot number	1 and 6	2	3	4	Plot number	1 and 6	2	3	4
	- - - - - - - - H/KBL - - - - - - - -					- - - - - - - - H/LSCLT - - - - - - - -			
61	100.00	0.00	0.00	0.00	81	53.33	46.67	0.00	0.00
62	30.00	66.67	0.00	3.33	82	56.67	43.33	0.00	0.00
63	50.00	50.00	0.00	0.00	83	46.67	53.33	0.00	0.00
64	0.00	100.00	0.00	0.00	84	66.67	33.33	0.00	0.00
65	50.00	46.67	0.00	3.33	85	95.00	0.00	5.00	0.00
66	85.00	15.00	0.00	0.00	86	46.67	53.33	0.00	0.00
67	83.33	16.67	0.00	0.00	87	50.00	50.00	0.00	0.00
68	56.67	43.33	0.00	0.00	88	78.33	21.67	0.00	0.00
69	76.67	23.33	0.00	0.00	89	80.00	20.00	0.00	0.00
70	63.33	36.67	0.00	0.00	90	61.67	36.67	0.00	1.67
71	83.33	16.67	0.00	0.00	91	76.67	23.33	0.00	0.00
72	86.67	13.33	0.00	0.00	92	56.67	43.33	0.00	0.00
73	100.00	0.00	0.00	0.00	93	100.00	0.00	0.00	0.00
74	86.67	13.33	0.00	0.00	94	100.00	0.00	0.00	0.00
75	100.00	0.00	0.00	0.00	95	90.00	10.00	0.00	0.00
76	66.67	33.33	0.00	0.00	96	93.33	6.67	0.00	0.00
77	90.00	10.00	0.00	0.00	97	66.67	33.33	0.00	0.00
78	83.33	16.67	0.00	0.00	98	96.67	3.33	0.00	0.00
79	100.00	0.00	0.00	0.00	99	86.67	13.33	0.00	0.00
80	90.00	10.00	0.00	0.00	100	66.67	33.33	0.00	0.00
Mean	**74.08**	**25.58**	**0.00**	**0.33**		**73.24**	**26.25**	**0.26**	**0.08**
SD[a]	**26.12**	**25.67**	**0.00**	**1.03**		**18.59**	**18.87**	**1.12**	**0.37**
Min.	**0.00**	**0.00**	**0.00**	**0.00**		**46.67**	**0.00**	**0.00**	**0.00**
Max.	**100.00**	**100.00**	**0.00**	**3.33**		**100.00**	**53.33**	**5.00**	**1.67**

All plots	1&6	2	3	4
Mean	74.64	22.24	1.95	1.16
SD[a]	24.37	22.62	9.55	3.32
Maximum	100.00	100.00	60.00	20.00
Minimum	0.00	0.00	0.00	0.00

Notes:

Codes for soil disturbance:

- 1 and 6 = Undisturbed
- 2 = Slight disturbance
- 3 = Deeply disturbed and
- 4 = Ruts

Animal logging operations (LOP):

- H/FWD = Horses with forwarder.
- M/FWD = Mules with forwarder.
- H/SLT = Horses with side loading truck.
- H/KBL = Horses with knuckleboom loader.
- H/LSCLT = Horses with long stick cable loader truck.

[a] SD = standard deviation.

and 53.33 percent for H/FWD, M/FWD, H/SLT, H/KBL, and H/LSCLT crews, respectively.

A summary of results for soil disturbance obtained from regression analysis for the five operations studied is given in **Table 4**. Within the horse/mule logging operations, horses with a side loading truck showed the most soil disturbance (Codes 2+ 3+4). Mules with the forwarder showed the least. There were no significant differences among the five horse/mule logging operations in the amount of deeply disturbed soil (Code 3) or in soil rutting (Code 4) with a 95 percent confidence level. Slightly disturbed soil for horses with the forwarder was also not significantly different from the other four animal logging systems at the 95 percent confidence level. The amount of undisturbed soil (Codes 1 and 6), however, was significantly less for the horses with the side loading truck operation compared to the other four horse/mule logging operations at the 95 percent confidence level. The reason for this may be that the side loading truck was parked along the side of a forest road or other open place and did not travel into the forest as required for the other operations. This forced the horses to skid logs numerous times along the same skid trail and longer skid distances causing more area to be disturbed.

Overall, rutting by horse/mule logging averaged 1.2 percent with the highest percent from horses with the forwarder and horses with the side loading truck. An average over the five horse/mule logging operations showed that approximately 75 percent of the ground was undisturbed (Codes 1 and 6) and only 22 percent of the soil was slightly disturbed. The ground disturbance, which was distinctly noticeable, was found to be only 3.2 percent (Code 3 and 4) (**Table 4**).

It was observed that forwarders were operated more in the woods followed by the long-stick cable loader trucks, and least by side loading trucks. The knuckleboom loader truck, however, was stationary outside the woods for loading logs onto setout trailers.

Horses with the knuckleboom loader and the long-stick cable loader truck showed a high level of undisturbed soil and a high level of slightly disturbed soil. This may be due to limited movement of loading or forwarding equipment and numerous times skidding of logs along the same trail. A high percent of slightly disturbed soil was noticed in those horse/mule logging operations where horse/mules had to skid the logs numerous times to the same skid trail. The least disturbance was observed when horse/mule extraction was combined with a forwarder (**Table 4**).

From the previous studies (**Table 1**) and this study (**Table 4**), all horse/mule logging operations resulted in 2 percent or less of the ground being rutting, and deeply disturbed ground was found to be 5 percent or less. More than 90 percent of soils from all horse/mule logging operations were either undisturbed or slightly disturbed.

Horse logging operations had 31 percent or less of ground classified as having slight soil disturbance except in the case of the study done by Seixas et al. (1995), which had 54 percent slightly disturbed. The average from seven horse/mule logging operations gave 73 percent of soil undisturbed, 24 percent slightly disturbed, and 2 percent and 1 percent deeply disturbed and rutted, respectively (**Tables 1 and 4**).

Table 4. ~ *Summary of soil disturbance by horse/mule logging operations in percent.*

	Disturbance percent with codes				
System	1 and 6	2	3	4	Total (codes 2+3+4)
H/FWD	78.5	19.6	0.0	1.9	21.5
M/FWD	84.3	9.0	5.0	1.7	15.7
H/SLT	62.8[b]	30.8	4.5	1.9	37.2
H/KBL	74.1	25.6	0.0	0.3	25.9
H/LSCLT	73.4	26.2	0.3	0.1	26.6
SD[a]	24.37	22.62	9.55	3.32	--
Mean	74.64	22.24	1.95	1.16	25.35

[a] SD = standard deviation.
[b] Significantly different at 95% confidence level.

Logging operations with mechanical forwarding had 38 to 66 percent disturbed ground. Harvesting with mechanical skidding had 40 to 88 percent in disturbed ground. Except for horses with a side loading truck and horses with forwarder in Seixas et al. (1995), the remaining five horse/mule logging operations had less soil disturbance compared to mechanical skidding and mechanical forwarding (**Tables 1 and 4**). Horse/mule logging operations produced from 9 to 54 percent total soil disturbances. Most disturbances from horses with side loading trucks and the results of Seixas et al. (1995), however, were classified in the slightly disturbed category (**Tables 1 and 4**).

Conclusion

This study showed that a range of horse/mule logging operations produce similar soil disturbance in mixed pine-hardwood forests with partial cuts on less than 10 percent slopes when horses/mules are paired with loading and forwarding equipment. Undisturbed, slightly disturbed, deeply disturbed, and rutted soil conditions were similar except in the case of horses used with a side loading truck, which had significantly less undisturbed soil compared to the other four horse/mule logging operations at 95 percent confidence level.

Data comparing undisturbed and highly disturbed soil conditions from 13 mechanized harvesting operations and seven horse/mule logging operations found that horse/mule logging operations had the least total soil disturbance. In addition, horse/mule logging operations had less deeply disturbed and rutted soil conditions combined as compared to mechanized logging observed by Lanford and Stokes (1995), Klepac et al. (1999), Stokes et al. (1995), and Miller and Sirois (1986) (**Table 1**). The horse/mule logging operations studied (**Table 4**) and two other previous horse logging studies (**Table 1**) support its applicability in those forest areas where low soil disturbance is desired in a mixed pine-hardwood forest with less than 10 percent slope. The results of this study support the perception that horse/mule logging has lower soil disturbance than other logging operations.

More studies on soil disturbance from horse/mule logging operations in conditions such as hardwood forests, pure pine forests, small and large tree sizes, range of slopes, clear cutting, and dry and wet conditions are required to determine the appropriate horse/mule logging applications for those conditions. Side by side studies with horse/mule logging operations, logging with mechanical skidding, logging with mechanical forwarding and cable yarding will contribute additional information concerning soil disturbances.

Funding Acknowledgment

Funding for this project was provided by the USDA Forest Service, Forest Engineering Unit, Southern Research Station, Auburn, AL.

Literature Cited

Creighton, J. 1997. Logging trucks, tractors and crawlers. Motorbooks International, WI. 128 p.

Cunia, T. 1973. Dummy variables and some of its uses in regression analysis. A paper presented at IUFRO, Nancy, France. 106 p.

Hamilton, P.S. 1998. Logging with horses in riparian zones. Forest Engineering Research Institute of Canada (FERIC). Field note Partial cutting-21. 2 p.

Heinrich, R. 1985. Medium technology in wood harvesting: Logging and transport in steep terrain. Food and Agricultural Organization, Rome. 333 p.

Klepac, J., S.E. Reutebuch, and B. Rummer. 1999. An assessment of soil disturbance from five harvesting intensities. I*n*: Proc. of ASAE Annual International Meeting, Toronto, Canada. pp. 1-16.

Lanford, B.L. 1975. Projection of forest stand tables based on successive measurements of permanent plots. Ph.D. Dissertation, State Univ. of New York, College of Environmental Science and Forestry, Syracuse, NY. 438 p.

Lanford, B.L. and B. J. Stokes. 1995. Comparison of two thinning systems. Part 1. Stand and site impacts. Forest Prod. J. 45(5): 74-79.

Miller, J.H. and D.L. Sirois. 1986. Soil disturbance by skyline yarding vs. skidding in loamy hill forest. USDA Forest Service, Southern Experiment Station, New Orleans, LA. 83 p.

Seixas, F., B. Stokes, B. Rummer, and T. McDonald. 1995. Harvesting soil impacts for selected silvicultural prescriptions. *In*: Proc. of the International Union of Forestry Research Organization XX World Congress, Tampere, Finland. pp. 230-238.

Stokes, B.J., R.A. Kluender, J.F. Klepac, and D.A. Lortz. 1995. Harvesting impacts as a function of removal intensity. *In*: Proc. of the XX IUFRO World Congress, Tampere, Finland. pp. 207-216.

Toms, C., J. Wilhoit, M. Dubois, J. Bliss, and B. Rummer. 1998. Animal logging fills important timber harvesting niche in Alabama. Alabama Agricultural Experiment Station. Highlights of Agricultural Research. 45(1): 7-8.

Wackerman, A.E., W.D. Hasgestein, and A.S. Michell. 1966. Harvesting Timber Crop. McGraw-Hill. NY. 540 p.