Soil Physical Property Changes After Skidder Traffic With Varying Tire Widths

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ABSTRACT

Eight combinations of skidder tires, ranging in total width from 0.7 m to 2.2 m, were evaluated for rut formation potential on two soils in south-central Alabama. One was a mixed pine-hardwood bottomland; the other was an upland, predominantly pine stand. Each soil/tire combination was replicated twice. Changes in soil profile after one, three, seven, and nine loaded passes were used as indices of soil disturbance. The number of skidder passes was the most significant factor influencing rut formation. The effect was linear up to nine passes on both test sites. The first pass on the upland site accounted for half the average rut depth and area. The magnitude of the displacement after one pass was related to tire width. Each subsequent pass caused a uniform smaller increment in depth and area. The magnitude of the increase was independent of tire width. On the bottomland site, however, each pass resulted in an increment in both depth and area the magnitude of which was a function of tire width. Average rut cross-sectional area on the bottomland site ranged from 0.13 m^2 to 0.75 m^2 for nine passes. Depth of ruts ranged from 1.7 cm to 3.6 cm for nine passes on the upland soil, and from 1.4 cm to 21.2 cm for nine passes on the bottomland soils. Soil physical properties were not affected by skidder traffic regardless of tire width.

INTRODUCTION

Increasing numbers of Southern loggers are using wide tires on their equipment, especially on skidders. The increased popularity of wider tires has arisen because of the flexibility they provide for operation under wet conditions, which can more than compensate for their higher investment cost. Because ground pressure is reduced using wide tires, they are perceived as lessening the potential for traffic-related changes in soil physical properties. With ever shorter rotations, managers are seeking methods of reducing the impact of more frequent harvests. Consequently, there is growing interest in using wide tires even in conditions where they may not be necessary for traction.

Other studies have demonstrated benefits of wide tires in minimizing soil impacts from skidders. Burger and others [3] compared tires 86 cm and 112 cm in width for their effect on rut formation on Coastal Plain soils at two moisture contents: one near the proctor limit, the other the liquid limit. The wider tires caused smaller ruts on the wetter soil, and neither tire caused much damage in the drier conditions. No justification was found based on performance for use of the wide tires, although the wider tires might have been appropriate to minimize site disturbance. They noted that management considerations, such as scheduling of operations and experience of the skidder operators, had a much greater effect on site disturbance than tire size. Aust and others [1] compared site disturbance of areas logged using skidders with 71-cm- and 173-cm-wide tires on a wetland Coastal Plain site. Areas harvested using both skidder systems showed significant increases in soil bulk density, cone penetration resistance, and macropore space. The magnitude of the changes was comparable for both tire sizes. Murosky and Hassan [4] found lower levels of soil compaction resulting from skidder traffic with wider tires (127 cm vs 86 cm) on a Coastal Plain river bottom site. Rollerson [5] evaluated the impacts of skidder traffic on coastal soils in British Columbia. The skidder had tires 112 cm wide and was run on five sites at two moisture levels for up to 80 loaded and unloaded passes. Increases in soil bulk density were reported to be greater in moist soil conditions, but still somewhat less than values reported in the literature. Rollerson concluded that the wide tires were beneficial in reducing detrimental changes in soil properties, but that the expected increases due to traffic, even with the wider tires, would decrease seedling growth.

Published reports indicated potential benefits of using wide tires in skidding, especially on moist soils. The diversity of the studies, however, made it

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Table 1. Summary of tires used in the tests.

Tire	Size	Manufacturer	Tire Width (cm)	Inflation Pressure (kPa)
28	single 28L-26	Firestone	71	172
28+23	dual 28L-26/23.1-26	Firestone	130	76
30+30	dual 30.5L-32	Firestone	155	76
43-25	single 66x43-25	Firestone	109	172
43-15	single 66x43-25	Firestone	109	83
43+43	dual 66x43-25	Firestone	218	76
50	single 68x50-32	Firestone	127	76
68	single 68x68-25	Rubber Applicators	173	89

difficult to establish the magnitude of expected soil impacts as a function of tire width. No one study tested, under the same conditions, the effects of a range of tire widths representative of those available on the market. This information would be useful in specifying a minimum width of tire for a given set of conditions.

This study was done to evaluate the relative performance of several commercial tires in side-by-side comparisons of rut formation and soil physical property changes following skidder traffic. Specific objectives were to:

1. Examine the rut formation potential of a range of skidder tires in wet and dry soil types, and

2. Determine the changes in soil physical properties associated with rut formation.

EXPERIMENTAL METHODS

In conjunction with several cooperators (including Bridgestone-Firestone Tire Inc., Rubber Applicators Inc., International Paper Co., Union Camp Corp., Webco Tire and Rim, and Auburn University), eight tire combinations (Table 1) were tested during March 1992 for their rut formation potential. The tires were a mixture of singles and duals ranging in overall width from 0.7 to 2.2 m. Seven of the tires were of bias-ply construction typical of skidder tires used at present. The 68x68-25 tires were of radial-ply construction and designed primarily for flotation on very wet sites. Their lugs were both smaller and spaced further apart than is typical of tires used widely in forestry operations. The dual 66x43-25 tires are not used operationally because of the resulting extreme width of the skidder, but were included in the study for comparison. Single 66x43-25 tires were tested at inflation pressures of 172 kPa and 83 kPa. In this report, tire combinations are referred to using the nomenclature of Table 1 based on tire width and, where appropriate, inflation pressure.

Tests were conducted in two soil conditions typically encountered in the Coastal Plain region of the Southeast. One, a minor stream bottom, was a mixed pine-bottomland hardwood stand on the floodplain of the Pigeon River. Its soils were classified as Bethera series, clayey, mixed, thermic Typic Paleaquults. These poorly drained soils are generally formed of marine or fluvial sediments, and consist of a deep loam surface layer with a grayish clay subsoil. The other site was situated above the floodplain on the surrounding hillsides and was composed primarily of soils in the Luverne series, clayey, mixed, thermic Typic Hapludults. Typically, these soils are well drained with a surface layer of fine sandy loam about 18 cm thick, underlaid by a red clay subsoil. The sites were adjacent to each other and located on a tract owned by Union Camp Corporation in Butler County of south-central Alabama.

Two test plots for each tire combination and each soil type (total of four plots per tire) were established in previously untrafficked areas of the sites. There was essentially no vegetative cover on the bottomland site plots, and a surface covering of grass on the upland site. Plots were cleared of slash and saplings and two posts were set on either side to establish a transect for profile measurements. Tire treatments were assigned randomly to the test plots. The tests were usually run on successive days, one

Table 2. Initial soil moisture, bulk density, and cone penetrometer readings for both sites. Values are averages for two plots. Numerical column headings represent the depth of the measurement, in cm.

Site	Tire	Bulk Density ($Mg\ m^{-3}$)			Moisture Content			Cone Penetrometer (MPa)	
		0-5	10-15	20-25	0-5	10-15	20-25	0-25	25-50
Upland	28	1.15	1.16	1.14	0.36	0.36	0.39	1.40	1.87
	50	1.19	1.29	1.26	0.26	0.31	0.34	0.97	1.67
	6	1.07	1.16	1.13	0.34	0.37	0.39	1.38	1.94
	28+23	1.07	1.20	1.26	0.36	0.34	0.35	1.28	1.86
	30+30	1.09	1.15	1.17	0.38	0.35	0.37	1.21	1.84
	43-15	1.01	1.31	1.16	0.38	0.30	0.35	1.02	1.46
	43-25	1.09	1.21	1.12	0.34	0.37	0.41	0.90	1.58
	43+43	1.20	1.41	1.46	0.29	0.26	0.28	1.53	1.57
Bottom-land	28	1.09	1.37	1.34	0.43	0.33	0.34	0.71	1.16
	50	0.95	1.27	1.31	0.47	0.33	0.37	0.77	1.37
	68	1.09	1.37	1.42	0.37	0.30	0.29	0.77	1.18
	28+23	1.05	1.26	1.31	0.41	0.33	0.35	0.81	1.15
	30+30	1.05	1.29	1.33	0.41	0.33	0.35	0.53	1.13
	43-15	1.03	1.34	1.39	0.40	0.32	0.33	0.84	1.07
	43-25	1.08	1.33	1.33	0.45	0.34	0.35	0.41	0.74
	43+43	1.00	1.31	1.39	0.48	0.34	0.34	0.73	1.06

tire combination per day. Weather was generally dry during the tests, but there was significant rainfall just prior to the start of the study, and during the tests of the 28+23 tires.

Tests consisted of recording surface profiles following one, three, and nine passes of a loaded skidder. On the bottomland site, an additional measurement after seven passes was made. The skidder load was two loblolly pine logs with total volume of 2.5 m^3. A third log was added on the upland site to simulate a realistic full load, raising the total pull volume to 3.7 m^3. Profiles were established using a gauge constructed from a 6.1-m-long aluminum I-beam suspended at a fixed height across a plot between the two posts. One end of the beam was hinged, allowing it to be swung out of the way between skidder passes. A 1.5-m-wide carriage attached to the I-beam held a series of suspended yardsticks spaced 3.5 cm apart on centre. At any location along the length of the I-beam, the sticks could be lowered independently to the ground and the height to a reference point on the carriage measured.

Before each test, an undisturbed surface profile was measured and soil core samples were taken for physical property analysis. Three cores were removed at five uniformly spaced locations along the width of the plot, one each at depths of 0-5, 10-15, and 20-25 cm. This sampling arrangement gave a two-dimensional picture of initial soil conditions both across the plot width and below the ground surface.

After each of one, three, and nine skidder passes (seven also on the bottomland site), one additional core was taken at the lowest point within each rut (both inside and outside tires for duals). All initial and post-traffic cores were subsequently analysed for bulk density, moisture content, and macropore space [2].

Penetrometer readings were recorded at the five transect locations. A 1.29 cm diameter cone was used, and measurements were taken over two depth ranges: 0-25 and 25-50 cm. Each measurement was the average of five individual readings. Average initial moisture contents, bulk densities, and cone penetrometer resistances are summarized in Table 2.

Soil displacement was quantified using measures of rut depth and total cross-sectional area. Depth was defined as the largest average negative displacement across the width of one tire occurring on any portion of the profile after a given number of

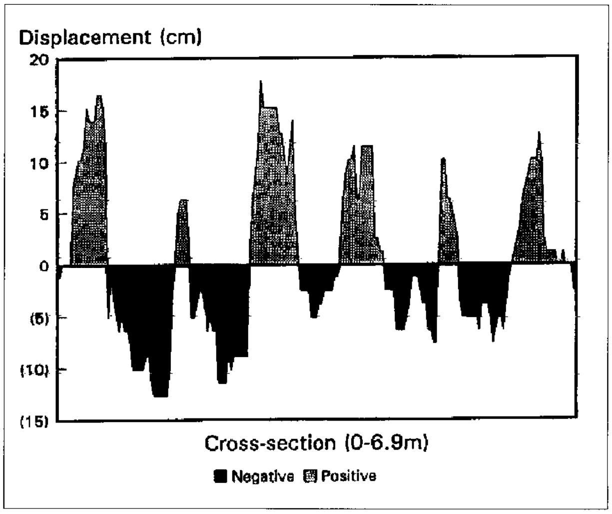

Figure 1. Example of rut cross-section, dual 66x43.00-25 tires on the bottomland soil.

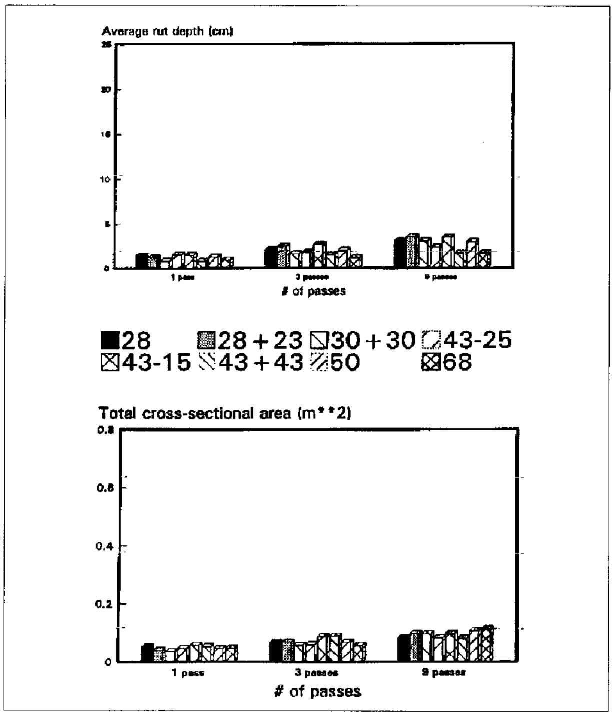

Figure 2. Rut depth and area on the upland site as a function of number of passes. Values are averages for two plots.

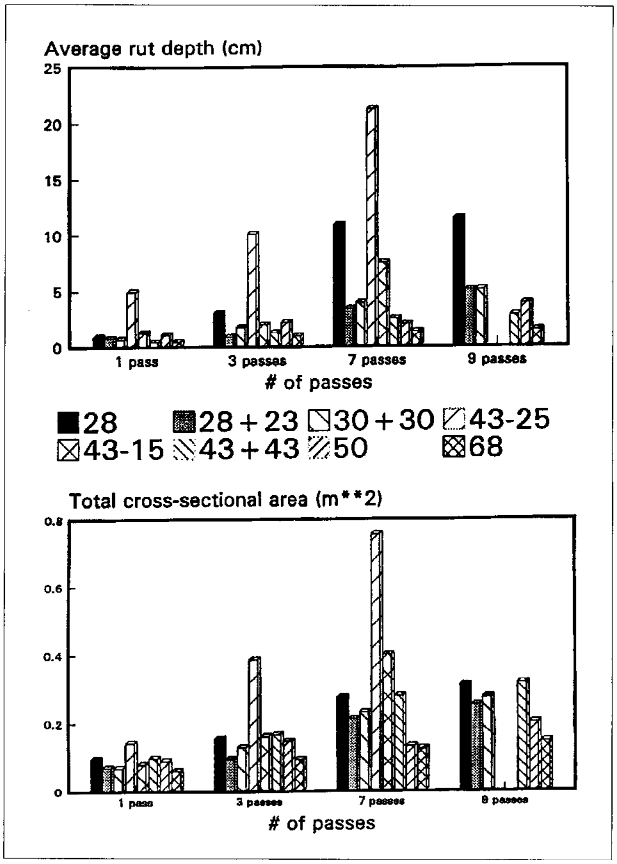

Figure 3. Rut depth and area on the bottomland site as a function of number of passes. Values are averages for two plots.

passes. Only negative displacement of soil relative to the original profile was counted in the averaging process, so the depth, as defined, did not account for berm height. Cross-sectional area was defined as the sum of all negative and positive displacements times the horizontal measurement interval (3.5 cm). Figure 1 shows an example of a measured rut cross-sectional area of displacement (43+43's on the bottomland soil, nine passes). The curve shows the change in surface profile relative to the original. The shaded regions show the displacement cross-section. Analysis of covariance was used to develop models of rut depth and cross-sectional area, with type of tire as the main effect and number of passes and initial soil conditions as covariates.

Soil physical property changes were measured as differences in pre- and post-traffic bulk density and macropore space at a given rut depth. In other words, the post-traffic value taken from the rut surface was compared to the initital soil property at that depth. Originally, pre-traffic properties were to be interpolated from the two-dimensional grid of initial soil samples. But because of the large amount of variability in the data this idea was abandoned. Instead, values within the three sampling depths

Table 3. Regression equations for the rut depth and area disturbance measures. Values in parentheses are R^2.

Regression Model Site	Depth	Area
Upland	$\tau_i + \alpha n + \beta C$ (0.76)	$\tau_i + \alpha n + \beta C$ (0.51)
Bottomland	$\alpha_i n$ (0.82)	$\alpha_i n + \beta B_{15}$ (0.71)

τ_i - Tire effect
α - increase in rut depth or area with number of passes, n
β - coefficient of covariate, C or B
α_i - expected increase in rut depth or area per pass for tire, i
C - average initial cone penetration resistance, 0-12 cm
B_{15} - average initial bulk density at depth of 15 cm

were pooled across the transect width and linear regression was used to develop an equation for soil properties as a function of depth for each plot. The equations (one each for bulk density and macropore space) were used to estimate initial soil property values at a given depth for comparison to post-traffic measurements. Changes in physical properties as a result of traffic were tested using the Student's t-distribution under the null hypothesis that the pre- and post-traffic values were the same.

RESULTS AND DISCUSSION

Other than in rut size, there were essentially no differences between pre- and post-traffic soil physical properties noted in this study. The main reason for this was the large amount of variability in measured soil properties. The analysis was also hindered by the low number of replicates, making any differences very difficult to detect.

Changes in rut profile were found to be a function of number of passes, soil type (upland or bottomland), tire size, and, in some instances, microsite (plot) pre-traffic soil properties. Graphs of the increase in rut depth and cross-sectional area as a function of the number of skidder passes are shown in Figures 2 and 3, respectively. On the upland site, rut depths for the eight tire combinations averaged from 1.7 to 3.6 cm after nine passes, and cross-sectional areas from 0.080 to 0.112 m^2. On the bottomland site, average depths ranged from 1.4 cm to 21.2 cm and areas from 0.134 to 0.754 m^2 after nine passes.

Results of the analysis of covariance for the rut profile data are summarized in Table 3. The equations represent the best estimate, in terms of highest R^2, of the expected change in rut depth or cross-sectional area as a function of the type of tire (τ_i), the number of passes (αn or α_in), and, in some cases, either the initial cone penetrometer resistance reading (C) or the initial bulk density at a depth of 10-15 cm (B_{15}). Higher order models, and greater numbers of covariates, were tested, but did not improve the model fit. The models differed in form depending on soil type.

Upland Soil

In general, rut profiles changed uniformly with the number of passes within a given site. On the upland soil, rut depth and area both increased at a uniform rate (α) regardless of the tire size. The intercept (τ_i), however, was related to tire width. This indicated that, for both the change in rut depth and cross-sectional area, the displacement due to the

Table 4. Regression coefficients for rut disturbance models, upland site. Regression equations are in Table 3. Values in parentheses are standard errors of the estimates.

Coefficient	Units	Depth Value	i	Area Units	Value	i
α	$\frac{m}{pass}$	0.0018 (0.00022)		$\frac{m^2}{pass}$	0.00538 (0.0011)	
β	$\frac{m}{MPa}$	-0.023 (0.0048)		$\frac{m^2}{MPa}$	-0.085 (0.024)	
τ_i	m	0.0469 (0.0071)	28^{a}	m^2	0.181 (0.038)	43+43^{a}
		0.0463 (0.0066)	28+23^{a}		0.166 (0.035)	68^{ab}
		0.0416 (0.0054)	43-15^{ab}		0.162 (0.035)	28^{ab}
		0.0412 (0.0078)	43+43^{ab}		0.154 (0.033)	28+23^{ab}
		0.0389 (0.0063)	30+30^{bc}		0.143 (0.027)	43-15^{abc}
		0.0371 (0.0071)	68^{bc}		0.142 (0.031)	30+30^{bc}
		0.0358 (0.0052)	50^{bc}		0.132 (0.026)	50^{bc}
		0.0324 (0.0049)	43-25^{c}		0.116 (0.024)	43-25^{c}

[a] - Coefficients with the same letter are not significantly different.

first pass was the only difference between the tires. Table 4 is a summary of the model coefficients for the upland site. The tire effects (τ_i) are ordered from largest to smallest in the table. The comparisons between the tires were based on least squares means. There were no clear trends in the effect of the tire on rut depth on the upland site. The four tires that exhibited the greatest expected rut depth included both the narrowest and widest combinations tested. The same two tires at different inflation pressures (43-25 and 43-15) ranked both third and eighth in expected depth, and, contrary to what is normally expected, the tire with the lower inflation pressure caused deeper ruts.

Examination of the change in rankings of the tires for rut depth versus cross-section indicated that the wider tires tended to cause somewhat shallower, but also somewhat larger, ruts. The two widest tire combinations, the 43+43 and 68, had the largest ruts in terms of volume of soil displaced, but were both intermediate in depth. Conversely, ruts caused by the 28 tires were deepest, but intermediate in volume of displaced soil. Based strictly on these results, it

Table 5. Changes in bulk density and soil macropore space following skidder taffic. Differences are relative to the estimated pre-traffic value. Values are averages for two plots.

		Δ Bulk Density (Mg m^{3})			Δ Macropore Space (%)		
Site	**Tire**	**Pass 1**	**Pass 3**	**Pass 9**	**Pass 1**	**Pass 3**	**Pass 9**
Upland	28	-0.10	-0.12	-0.03	2.0	2.0	0.6*
	50	0.11	0.13	0.13	-4.2	-4.5	-4.4
	68	0.03	-0.06	-0.05	-0.7	1.2	0.2
	28+23	-0.11	-0.15	-0.14	2.3	1.7*	1.4
	30+30	0.04	0.03	-0.05	-0.1	-0.4	0.5
	43-15	-0.01	-0.08	-0.04	0.5	1.9	2.3
	43-25	-0.02	-0.05	-0.17	1.1	1.8	3.3
	43+43	0.04	0.09*	0.11	-2.1	-3.3	-3.0*
Bottom-land	28	-0.08	-0.09	-0.08	1.9	2.0	2.2
	50	-0.04	-0.05	-0.03	-2.1	-1.9	-2.3
	68	0.14	0.11*	0.19	-3.8	-3.7	-4.8
	28+23	0.04	0.04	-0.03	-1.1	-1.6	0.1
	30+30	0.04	-0.02	-0.06	-3.3	-2.5	-1.6
	43-45	-0.01	0.04	-0.01	-0.2	-0.4	0.5
	43-25	0.15	0.01	-0.02	0.4	1.7	1.1
	43+43	0.06	-0.12	-0.09	-1.5	0.6	1.8

* - Significantly different from zero, α - 0.05.

seemed that tires of intermediate width were preferable from the standpoint of minimizing soil displacement. Although undoubtedly microsite differences were responsible for some of the advantage of the 43-25 and 50 tires, the changes in rank between depth and area measures of rut size for the other tires indicated clearly that the widest tires caused the largest amount of disturbance.

The observed post-traffic changes in bulk density and macropore space are summarized in Table 5. There were very few changes in soil physical properties as a result of traffic. Of those changes that were statistically different from zero, only the 43+43 tires showed a detrimental change in both bulk density and macropore space. The 43+43 tires also created the largest cross-sectional soil displacement. It is unlikely, however, that the two results were related since neither of the changes, although different from zero, were the largest observed. It is more likely that sampling error happened to be lower on those plots. Still, the result is a further incentive not to use the wider tire combinations on upland type soils.

The ratio of the α term to the τ_i terms indicated that most of the rutting occurred on the first pass. Assuming an initial soil penetrometer reading of 1.2 MPa and the average value for τ_i (0.04), rut depth after the initial pass was half of the total after nine passes. This result tends to support the use of designated skid trails if total site disturbance is to be minimized.

Bottomland Soil

Coefficients for the rut depth and cross-sectional area prediction models for the bottomland site are summarized in Table 6. The coefficients in the table (α_i) are the slopes of a regression line indicating either the increase in rut depth or area as a function of the number of passes. The bulk density covariate was not significant in the rut depth model. For the cross-sectional area regression, bulk density at 10-15 cm depth was a covariate. Tire comparisons were based on linear contrasts of the slopes (α_i's).

Table 6. Regression coefficients for rut disturbance models, bottomland site. Regression equations are in Table 3. Values in parentheses are standard errors of the estimates.

Coefficient	Depth Units	Depth Value	Depth *i*	Area Units	Area Value	Area *i*
β				$\frac{m^2}{Mg\ m^{-3}}$	0.0374 (0.018)	
α_i	$\frac{m}{pass}$	0.0312 (0.0022)	43-25a	$\frac{m^2}{pass}$	0.102 (0.0099)	43-25^{a}
		0.0146 (0.0022)	28^{b}		0.0474 (0.0099)	43-15^{b}
		0.0101 (0.0022)	43-15^{bc}		0.0314 (0.0066)	43+43^{bc}
		0.00563 (0.0022)	30+30^{cd}		0.0303 (0.0067)	28^{bcd}
		0.00460 (0.00218)	28+23^{cd}		0.0255 (0.0066)	30+30^{cd}
		0.00424 (0.0029)	50^{cd}		0.0225 (0.0066)	28+23^{cd}
		0.00369 (0.0022)	43+43^{d}		0.0174 (0.0071)	50^{cd}
		0.00217 (0.0022)	68^{d}		0.0106 (0.0067)	68^{d}

^{a} - Coefficients with the same superscript are not significantly different.

The wider tires tended to minimize rut depth, somewhat in order of ascending width. The 68 tires caused the minimum penetration per pass of all combinations tested, only 20% greater than the increase per pass found on the upland site. The 43-25 tires caused the greatest penetration per pass, over twice that of the next highest tire combination. Figure 4 is a plot of the predicted increment in rut depth and cross-sectional area per pass versus tire width. Except for the 43-25's, the τ_i's decreased rapidly to a width of about 1.3 m. Beyond that, the values continued to decrease but at a slower rate.

Cross-sectional area response was very similar to the depth results. The range of the response, however, was more limited and there were fewer pairwise differences between the tires. This suggested that although wider tires tended to minimize rut depth, width was not as effective in minimizing total displacement of soil. In fact, the two tires at the extremes in width, the 43+43's and 28's, were nearly equal in cross-sectional area response, despite the fact that they differed in rut depth by a factor of about four, nearly the same as the ratio of their widths.

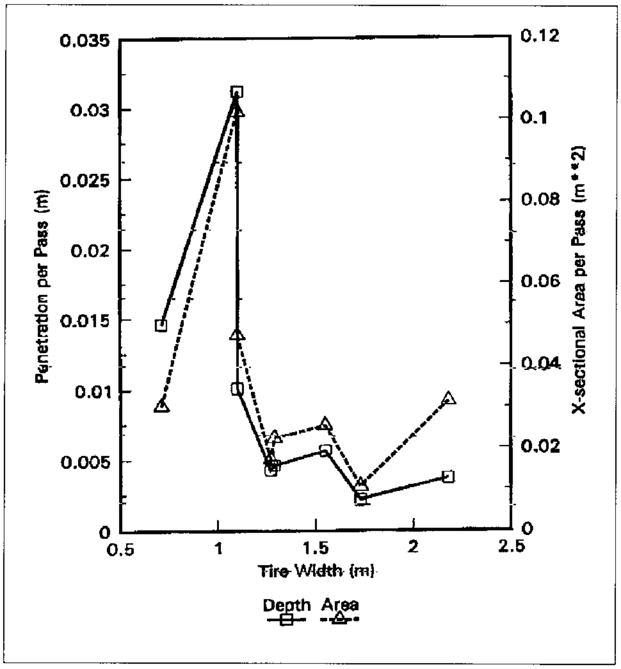

Figure 4. Plot of rut depth and area increment per pass as a function of tire width.

These results suggested that wider tires tended to minimize rut depth, but not total displacement of soil, on wet sites. This was probably because soil displacement behaviour on the wet site was plastic in nature and was more related to the applied load than the ground pressure distribution. The criterion for choosing tires for this site then should not necessarily be to minimize rutting since that depends on how the rut size is measured. If depth of ruts was of primary concern, for example to minimize the visual impact of harvesting, shearing of roots, or extending the operational range of the skidder during the wet season, wider tires could have been justified. If the objective were to minimize total soil movement, no particular advantage was gained using wide tires.

The intercept terms of the equations for rut depth and cross-sectional area on the bottomland site were not statistically significant. This implied that, unlike the upland site, soil displacement increased uniformly with each pass. From an operational standpoint, this result would indicate that designated skid trails would be inappropriate under these conditions and that traffic should be dispersed to maintain a minimum acceptable level of disturbance across the entire area.

There was also no advantage for the wide tires in minimizing adverse soil physical property changes on the wet site. The only significant change in bulk density observed (Table 5) was due to traffic from the 68 tires, which had the lowest impact in terms of soil displacement. Although the significance of the increase in bulk density could have been due to chance, the fact that the loss in macropore space for the 68's, although not significant, was the largest observed among all tires also suggested that they did cause some compaction. The average surface moisture content of the two plots the 68 tires were tested on was 37%, the lowest observed among all bottomland plots. Perhaps the moisture content was nearer the optimum for compaction on those plots, resulting in the larger detrimental changes.

The rut formation of the 43-25 tires on the bottomland site was much larger than expected. These particular tires were tested first, and the tests followed two days of rain. Average moisture content and bulk densities of the 43-25 test plots were only slightly higher and lower, respectively, than the mean for all plots on the bottomland site. Average cone penetrometer readings for the 43-25 plots, however, were only about 60% of the site average at both depths and were the lowest observed. This suggested that cone penetrometer readings might be useful in predicting trafficability of skidders on this site.

It was interesting that the coefficient for the cross-sectional area covariate, B_{15}, or bulk density measured in the 10-15 cm depth range, was positive. This was surprising in that higher bulk density generally indicates greater bearing strength and, therefore, less rutting, suggesting a negative coefficient for the B_{15} term. Bulk density was not, however, significant in the depth equation. Perhaps a firmer subsurface caused greater upward displacement of soil. Berms accounted for about 50% of the total amount of displaced soil. Depth, however, was defined as negative displacement only.

SUMMARY

Eight forestry tire combinations were tested for their rut formation potential on two soils typical of the lower Coastal Plain of Alabama. On an upland site, wider tires tended to spread the same total rut disturbance across a shallower, wider corridor. All tires created their greatest increment in rut depth and cross-sectional area on the first pass. The magnitude of the increment in depth after one pass was dependent on tire width. Subsequent passes increased rut depth a small amount that was uniform among all tires.

On a bottomland site, the increment in both depth and cross-sectional area increased uniformly with increasing numbers of passes. The magnitude of the increase in depth and area per pass was a function of tire width. The increment in cross-sectional area per pass was influenced somewhat less by tire width.

Soil bulk density and macropore space were relatively unaffected by traffic on either site.

LITERATURE CITED

[1] Aust, W.M., Reisinger, T.W., Burger, J.A., and Stokes, B.J. 1991. Site impacts associated with three timber harvesting systems operating on wet pine flats—preliminary results. Pp. 342-350. In: Coleman, S. and Neary, D. (eds.). Proceedings of the Sixth Southern Silvicultural Research Conference. USDA Forest Service General Technical Report SE-70. Southeastern Forest Experiment Station, Asheville, NC. 868 pp.

[2] Aust, W.M., Reisinger, T.W., Stokes, B.J., and Burger, J.A. 1993. Tire performance as a function of width and number of passes on soil bulk density and porosity in a minor stream bottom. Pp. 131-136. In: Brissette, John C. (ed.). Proceedings of the Seventh Southern Silvicultural Research Conference. USDA Forest Service General Technical Report SO-93. Southern Forest Experiment Station, New Orleans, LA. 665 pp.

[3] Burger, J.A., Wimme, K.J., Stuart, W.B., and Walbridge, T.A. Jr. 1989. Site disturbance and machine performance from tree-length skidding with a rubber-tired skidder. Pp. 521-525. In: Miller, J.H. (ed.). Proceedings of the Fifth Southern Silvicultural Research Conference. USDA Forest Service General Technical Report SO-74. Southern Forest Experiment Station, New Orleans, LA. 618 pp.

[4] Murosky, D.L., and Hassan, A.E. 1991. Impact of tracked and rubber-tired skidders traffic on a wetland site in Mississippi. Transaction ASAE. 34(1):322-327.

[5] Rollerson, T.P. 1990. Influence of wide-tire skidder operations on soils. Journal of Forest Engineering. 2(1):23-29.

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