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Effects of Soil Properties, Water Content, and Compactive Effort on the Compaction of Selected California Forest and Range Soils[1]

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ABSTRACT

Soil compaction reduces plant growth in a variety of settings. In forest and range sites, amelioration of a compacted soil is usually impractical, therefore, emphasis has been given to minimizing and preventing compaction. To provide information on inherent soil compactibility, important factors related to susceptibility to compaction were identified by multiple linear regression of soil physical and chemical properties on Proctor maximum dry bulk densities. The following equation was derived:

$$D_b = 1.91 - 0.0596\ \mathrm{C} - 0.0076\ W_l + 0.0019\ S + 0.0058\ \mathrm{Fe},$$

where D_b = maximum dry bulk density in g/cm^3, C = organic C content, W_l = water content at liquid limit, S = total sand, and Fe = dithionite Fe. The equation has an adjusted R^2 of 98.6% and $S_{y.x} = 0.0356$.

With the use of organic C content, Proctor densities, and normalized change in porosity after compaction as criteria, the 14 soils were ranked by relative susceptibility to compaction. The three criteria produced virtually the same groupings of soils, with the four range soils in the study being most compactible.

Moisture content and compactive effort, which can be controlled, are important factors influencing soil compaction. To further understand the compaction behavior of these forest and range soils, six representative soils of different textural characteristics were subjected to Proctor compaction, with 30, 50, and 100 blows at three to four moisture contents ranging from field capacity to 15% less than field capacity. Density increased significantly with each increase in compactive effort, and maximum values were reached near the optimum moisture content of the standard compaction treatment.

Analysis of moisture characteristic curves for 14 forest and range soils suggests that two range soils would occur in the field at water contents making them susceptible to puddling. About half the soils would remain at near optimum water contents for compaction for a long period of time under field conditions.

Additional Index Words: soil interpretations, soil management, bulk density, Proctor test, puddling.

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SOIL COMPACTION reduces the survival and growth of plants (Rosenberg, 1964; Liddle, 1975). Trampling of grasses and herbs (Liddle and Greig-Smith, 1975) and compaction from logging vehicles affect both established plants (Moehring and Rawls, 1970) and tree regeneration (Foil and Ralston, 1967).

Ripping dense soil layers decreases compaction effects on field crops (Bishop and Grimes, 1978), and some foresters have recommended cultivation to improve seedling growth on newly planted logging sites (Sokolovskaya et al., 1977). Froehlich (1973) points out that such efforts give highly variable results and emphasizes the need to minimize the impact of compaction due to intensive forest management from the start.

Successful planning to minimize compaction depends on a knowledge of the distribution of soils in the area to be managed (i.e., a soil survey), coupled with a knowledge of the behavior of each soil in response to compactive effort. Although many national forests in California and elsewhere have extensive soil resource inventories, work on the compactibility of the various soils has just begun.

The many factors that affect compaction of a given soil can be divided into external and internal factors. The primary external factor is the compactive effort applied to the soil, i.e., the packing energy imparted to a given area of soil. Internal factors include but are not limited to particle-size distribution, particle density, organic matter content, and mineralogy.

Several studies have linked soil properties to bulk density. Qualitative relationships of organic matter to compactibility were described by Free et al. (1947). Curtis and Post (1964) and Jeffrey (1970) found organic matter content to be the best parameter for estimating the bulk density of uncultivated soils. Bod-

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Table 1—Family classification, particle-size distribution, and some chemical properties of surface soils from 14 national forest sites.

		Particle-size analysis					Organic C				
Soil series and textural phase	Subgroup classification†	Gravel, 4–2 mm‡	Fine, plus very fine sand, 0.25–0.05 mm	Total sand, 2–0.05 mm	Total silt, 0.05–0.002 mm	Total clay, <0.002 mm	Walkley-Black	Induction furnace	Dithionite Fe	pH 1:1 H_2O	CEC
		%									meq/100 g
Ahwahnee loamy sand§	Coarse-loamy, mixed, thermic Mollic Haploxeralfs	4	31.0	78.0	15.9	6.1	0.9	1.2	0.66	6.2	6.5
Aiken clay loam	Clayey, kaolinitic, mesic Xeric Haplohumults	11	17.8	31.3	38.1	30.6	7.4	7.0	7.54	6.0	32.9
Auberry sandy loam	Fine-loamy, mixed, thermic Ultic Haploxeralfs	4	31.7	76.2	16.2	7.6	1.3	1.5	0.67	6.3	7.4
Chawanakee sandy loam§	Loamy, mixed, mesic, shallow Dystric Xerochrepts	5	21.8	73.6	17.8	8.6	3.0	3.3	0.71	5.8	14.2
Corbett loamy sand	Mixed, frigid Typic Xeropsamments	28	28.6	83.2	12.9	3.9	4.3	4.2	0.77	5.8	10.8
Ditchcamp loam	Fine-loamy, mixed, mesic Xerollic Durargids	6	37.9	50.4	33.0	16.6	1.6	1.8	1.59	6.6	13.3
Holland sandy loam§	Fine-loamy, mixed, mesic Ultic Haploxeralfs	7	22.7	53.0	30.4	16.6	4.7	4.5	1.58	5.9	22.9
Hurlbut sandy loam§	Fine-loamy, mixed, mesic Dystric Xerochrepts	15	28.4	53.1	36.6	10.3	6.0	6.0	2.51	5.3	14.7
Idonno loam¶	Mollic Haploxeralfs	21	11.8	32.2	41.8	26.0	6.3	5.1	21.00	5.9	18.5
Josephine silt loam§	Fine-loamy, mixed, mesic Typic Haploxerults	4	16.1	29.9	51.8	18.3	5.6	5.5	4.06	5.8	22.9
McCarthy sandy loam	Medial-skeletal, mesic Andic Xerumbrepts	11	17.2	55.7	33.1	11.2	12.2	12.8	3.61	5.5	31.6
Musick sandy loam	Fine-loamy, mixed, mesic Ultic Haploxeralfs	3	19.9	57.5	27.9	14.6	4.3	5.0	1.23	5.8	21.5
Packwood loam§	Loamy, mixed, mesic, shallow Xerollic Durargids	6	31.9	37.5	44.4	18.1	0.4	1.0	1.37	6.5	15.6
Windy loam	Cindery, frigid Typic Dystrandepts	10	20.5	49.6	39.3	11.1	9.4	9.6	2.79	5.6	27.7

† In some cases the classifications are tentative.
‡ Gravel content is expressed as percent of < 4-mm material; all others are expressed as percent of < 2-mm fraction.
§ Soils used for study of moisture content and compactive effort.
¶ Proposed series name.

man and Constantin (1965) explored the effects of particle-size distribution and found that soils with a wide range of particle sizes reach the highest densities. Heinonen (1977) used silt and clay as independent variables in a regression equation developed for soils low in organic matter. Density increased as fine silt content rose and decreased as clay content rose. Faure (1976) showed that density rose with clay content up to 20% clay in clay-sand mixes subjected to Proctor compaction. For Scottish agricultural soils, optimum water content and organic matter were the parameters most highly correlated with maximum dry bulk density ($r = -0.944$ and -0.811, respectively). Particle-size parameters were less well correlated with density (Soane et al., 1972). Alexander (1980) found organic carbon (OC) and 15-bar water content (W15) to be most important variables in regression of the properties of 386 California upland soils on their field bulk density (DB) ($\mathrm{DB} = 1.57 - 0.287\,\mathrm{OC}^{0.5} + 5.004\,\mathrm{W15} - 41.866\,\mathrm{W15}^2 + 74.689\,\mathrm{W15}^3$; $r^2 = 0.656$; $\mathrm{SE} = 0.1521$.

For a given soil and a given compactive effort, water content influences the ease with which a soil is brought to its maximum density. As water content increases up to a critical level, the compactive effort required to change soil bulk density decreases (Free et al., 1947; Steinbrenner, 1955). This critical water content at which a soil reaches maximum density in laboratory tests is called the *optimum water content.*

This study had several objectives: (i) to measure susceptibility of various forest and range soils to compaction in the laboratory, (ii) to identify soil properties that are associated with high susceptibility to compaction, (iii) to assess the influence of water content and compactive effort on the laboratory-compacted densities of selected soils, and (iv) to interpret the water content data in light of the water holding characteristics of those soils.

MATERIALS AND METHODS

The surface 15 cm of soil material from 14 soils was collected from modal sites in the Sierra, Tahoe, and Modoc national forests in California (Table 1). The samples were dried and passed through a no. 4 sieve in preparation for compaction. Compaction was done by the standard method (ASTM, 1977). Optimum water content and maximum dry density are the average of two replicates.

Separate subsamples were passed through a no. 10 sieve for laboratory analysis. The 2- to 4-mm material retained on the no. 10 sieve represents the gravel content of the soil samples used for the compaction studies. Particle-size distribution of the fine earth fraction was determined by the sieving and pipette methods (SCS, 1967). Organic C was determined by dry combustion in an induction furnace and by the Walkley-Black method (SCS, 1967). Iron was removed by Na citrate-bicarbonate-dithionite (CBD) extraction (Jackson, 1975) and analyzed by atomic absorption. Cation exchange capacity was determined by the $BaCl_2$-TEA method (SCS, 1967). Water contents over a range of potentials were measured with a standard pressure plate apparatus (Richards, 1965). Particle density was determined as described by Blake (1965a) using 100-ml volumetric flasks. Liquid limit was done by the standard method (ASTM, 1977). Field bulk density was determined on paraffin-coated clods (Blake, 1965b). The average of three clods of about 50 to 250 cm^3 volume was taken. We calculated porosities (n_{field}) of undisturbed clods and cores of maximum compaction (n_{lab}) based on particle density (G_s) and dry bulk density (D_b)

$$n = 1 - (D_b/G_s).$$

The "normalized change in porosity" reported in Table 2 was

Table 2—Compaction characteristics and various water contents of the 14 soils arranged in order of decreasing compactibility.

	Bulk density			Water contents						
Soil series	Undisturbed field	Maximum proctor	Normalized change in porosity	Compaction optimum	liquid limit	−0.1 atm	−0.33 atm	−1 atm	−15 atm
	g/cm^3		%	% by weight					
Packwood	1.50	1.81	−27.0 (1)†	15.1	19.4	30.7	23.4	15.9	9.4
Ahwahnee	1.48	1.79	−26.0 (4)	14.5	21.3	19.3	13.1	7.9	3.3
Auberry	1.45	1.78	−26.8 (2)	14.5	25.5	22.8	15.9	9.5	4.1
Ditchcamp	1.49	1.76	−23.5 (5)	15.4	22.6	28.4	20.0	14.5	9.1
Chawanakee	1.44	1.67	−20.3 (8)	16.4	31.6	25.6	17.3	13.2	5.3
Musick	1.18	1.53	−26.7 (3)	21.3	37.9	34.6	30.4	20.8	9.0
Corbett	ND‡	1.52	ND	19.2	36.2	30.8	16.2	11.4	6.2
Holland	1.15	1.46	−21.8 (7)	24.2	40.4	41.6	34.3	22.5	11.2
Josephine	0.90	1.27	−22.6 (6)	32.1	46.5	41.2	34.2	31.6	16.3
Hurlbut	1.12	1.41	−19.6 (9)	24.8	34.3	45.0	30.7	18.1	9.5
Idonno	1.05	1.36	−17.6 (10)	31.8	47.5	53.1	37.7	34.8	19.9
Aiken	0.84	1.10	−14.4 (12)	45.1	59.8	49.7	45.2	42.8	27.7
Windy	0.84	1.03	−11.6 (13)	45.3	50.9	62.3	46.1	29.8	21.5
McCarthy	0.64	0.87	−14.7 (11)	52.5	59.1	67.6	55.7	40.9	33.6

† Numbers in parentheses are rankings of compactibility based on normalized change in porosity; 1 = most susceptible.
‡ Undisturbed clods were not collected for Corbett, and change in porosity could not be determined (ND).

calculated by subtracting field from compacted porosity and expressing the result as a percentage of original field porosity:

$$[(n_{lab} - n_{field})/n_{field}] \times 100.$$

Particle-size analysis showed that all the soils fell into three particle-size families with approximately 35, 55, and 75% sand. Two soils from each of these families were chosen for the moisture content–compactive effort experiments. These six soils are marked with the symbol § in Table 1.

Water content at −0.33 atm potential was taken to approximate field capacity. The six selected soils were moistened to approximately field capacity, 5 and 10% less than field capacity. Additional tests were conducted on the Holland and Packwood soil material at water contents roughly 15% lower than field capacity. The soils were cured overnight and compacted using standard Proctor equipment (ASTM, 1977), with compactive efforts of 30, 50, and 100 30.5-cm drops of the 2.5-kg rammer instead of the standard 75 blows for these experiments. The compactive efforts delivered energies of 221, 368, and 737 joules (166, 275, and 550 foot/pounds, respectively), compared with 553 joules (412 foot/pounds) by standard compaction. Two replicates were compared at each compactive effort × moisture level.

RESULTS AND DISCUSSION

Factors Influencing Maximum Dry Density

Classification and variation in selected physical and chemical properties of the soils used in this study are shown in Table 1. The maximum dry densities by Proctor compaction cover a wide range, with the value for the Packwood soil being twice as high as that for the McCarthy soil (Table 2).

Maximum dry density by Proctor compaction was used as the dependent variable in the study. Correlations between dry density and soil properties suggested that organic C and water content might be the most important independent variables related to maximum dry density (Table 3).

By multiple linear regression and comparison of the values of R^2 and $S_{y\cdot x}$, three equations were derived using Walkley-Black organic C, water content at liquid limit, sand content, and dithionite Fe as independent variables (Table 4).

Table 3—Correlations between dry density and soil properties.

Independent variable (% unless noted otherwise)	r†
Organic C (Walkley-Black)	−0.981
Optimum water content	−0.979
Liquid limit	−0.956
−0.33-atm water content	−0.933
−15-atm water content	−0.910
CEC, meq/100 g	−0.876
Fine + very fine sand	0.727
Total sand	0.428
Total silt	−0.452
Total clay	−0.306
Dithionite Fe	−0.337
Gravel content	−0.280

† All coefficients > ±0.532 are significant at $p = 0.05$.

Table 4—Multiple linear regression equations relating maximum dry density (D_b, g/cm^3) to organic C content (C), liquid limit (W_l), optimum water content (W_o), sand (S), and dithionite Fe (Fe).

Equation	R^2	$S_{y\cdot x}$
[1] $D_b = 1.91 - 0.596C - 0.076\ W_l + 0.0019S + 0.0058\ Fe$	0.986	0.0356
[2] $D_b = 1.93 - 0.0628C - 0.0063\ W_l + 0.0012S$	0.979	0.0437
[3] $D_b = 3.27 - 0.0231C - 0.528 \log_e W_o - 0.0008S + 0.0039\ Fe$	0.997	0.0178

All coefficients significant at $p = 0.05$ or less, except sand in Eq. [2] ($0.10 < p < 0.20$).

We attempted to use variables that are routinely measured and that have a reasonable physical relationship to compaction in our equations. Percent organic C by the Walkley-Black method had higher correlation with maximum dry density than did percent C determined by the dry combustion method. Although the natural logarithm of optimum water content in conjunction with organic C gave the regression line with highest R^2 and lowest $S_{y\cdot x}$ (Eq. [3], Table 4), we felt that an equation using liquid limit would be more useful since determination of optimum moisture involves simultaneous measurement of maximum density.

We chose to use CBD-extractable Fe in one equation because it has been used to improve prediction of soil erodibility (Singer et al., 1978). When used in conjunction with the other parameters, dithionite Fe also improved the corrected R^2 and lowered the standard error of our predictive equation for density despite its low simple correlation coefficient ($r = -0.337$). Since Fe data is often not available, we have also included an equation using only organic C, liquid limit, and sand (Eq. [2], Table 4).

We elected not to use several of the variables in

Table 3 in our multiple regression for two reasons. First, some were not independent. Cation exchange capacity (CEC), for example, is closely related to organic C and clay content. Second, C content is easier to measure than CEC and has a physical role in soil density, whereas CEC does not. Similarly, fine plus very fine sand (250 to 50 um) was not used in combination with sand because they are closely correlated. Sand was selected as an independent variable rather than fine plus very fine sand because sand data is generally more available than fine plus very fine sand data.

Relative Susceptibility to Compaction

Various measures of relative susceptibility to compactive effort have been used as an aid to land managers who wish to protect soils from compaction. We interpret relative susceptibility to mean that under a uniform compactive effort, soils that reach a high density are more susceptible to compaction than those soils that do not reach as high a density. We ranked the relative susceptibility of our soils in three ways: (i) organic C content (Table 2, column 1), (ii) standard Proctor compaction test of 75 blows (Table 2, column 3), and (iii) normalized change in porosity (Table 2, column 4). In this method, the difference between porosity based on maximum Proctor dry density and undisturbed field bulk density is used to rank the soils.

Since organic C is a routinely measured soil property, we tested it as a predictor of relative susceptibility to compaction. The soil series in Table 2 are listed from lowest to highest organic C content. Soils that have the least organic C (Table 1), such as Packwood and Ahwahnee, are most susceptible to compaction.

Except for the Josephine series, the soils were ranked in the same order by organic C content as by maximum Proctor density. Normalized change in porosity did change the rankings. Ahwahnee and Chawanakee ranked somewhat less compactible, whereas Musick and Josephine were ranked as somewhat more compactible based on the change in porosity. Aiken and McCarthy change positions in the ranking by this method compared with maximum Proctor density ranking.

All three systems place soils in more or less the same order of relative compactibility. Based on organic C content and Proctor density, the top four soils in Table 2 appear to be clearly most susceptible to compaction. It is interesting that these are the four range soils included in the study. With widely ranging textures from basaltic and granitic parent materials, they have in common a relatively dry climate and open savannah vegetation. The low organic matter in the soil surface under these conditions allows high densities to be reached despite differences in texture and mineralogy.

Conversely, the bottom three soils in Table 2 form a grouping of soils clearly less susceptible to compaction than the rest. Also varying widely in texture, they are all forest soils from volcanic parent materials formed under higher rainfall. They may be affected by a component of volcanic ash, but high organic matter is the most obvious factor in their low field and laboratory densities.

Table 5—Bulk density as a function of water content and compactive effort.

Soil series	Water content, wt. %	Compactive effort (no. of blows) 30	50	100	$\bar{D}_b$†
Ahwahnee	4.1	1.53‡	1.62	1.70	1.62a
	8.8	1.58	1.66	1.76	1.67b
	13.9	1.63	1.74	1.80	1.72c
$\bar{D}_b$§		1.58a¶	1.67b	1.76c	
Chawanakee	10.7	1.46	1.52	1.63	1.54a
	15.5	1.51	1.62	1.73	1.62c
	20.7	1.55	1.59	1.60	1.58b
$\bar{D}_b$		1.51a	1.58b	1.65c	
Holland	20.2	1.31	1.38	1.47	1.39b
	25.8	1.25	1.38	1.46	1.37b
	31.2	1.35	1.36	1.38	1.36b
	36.2	1.25	1.28	1.26	1.26a
$\bar{D}_b$		1.29a	1.35b	1.39c	
Hurlbut	22.1	1.32	1.41	1.51	1.41c
	28.1	1.26	1.35	1.36	1.32b
	33.5	1.26	1.28	1.29	1.28a
$\bar{D}_b$		1.28a	1.34b	1.39c	
Josephine	21.4	0.98	1.04	1.10	1.04a
	27.0	0.98	1.04	1.16	1.06a
	32.0	1.01	1.09	1.20	1.10b
$\bar{D}_b$		0.99a	1.06b	1.15c	
Packwood	9.5	1.52	1.59	1.68	1.60ab
	14.9	1.64	1.72	1.82	1.72c
	20.6	1.64	1.65	1.66	1.65b
	25.5	1.52	1.54	1.56	1.54a
$\bar{D}_b$		1.58a	1.63b	1.68c	

† Mean bulk density, dry wt. basis, in g/cm^3, for each water content.

‡ Bulk density values, in g/cm^3, are means of two replicates.

§ Mean bulk density for each compactive effort.

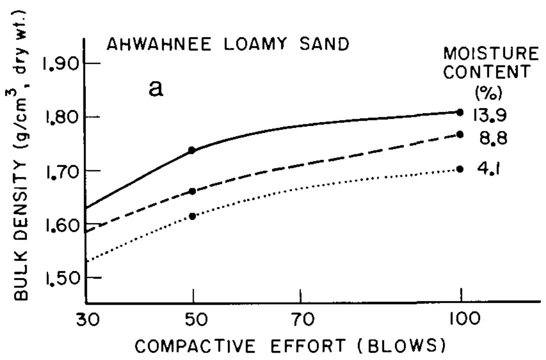
¶ Mean values not followed by the same letter are significantly different by Duncan's Multiple Range Test at 0.05 probability. Means for compactive effort are not compared with means for water content.

Water Content and Maximum Dry Density

It is useful to know optimum water content and liquid limit of a soil. Interpretations cannot be made for the soil until those water contents are related to field conditions. Will optimum water content ever be reached in the field during the wet spring or late fall parts of the timber harvest season? Will a soil in the field ever reach the liquid limit? To get answers to these questions we compared optimum water content and liquid limit with water contents in the wet end of the moisture-characteristic curves for these soils (Table 2). We interpreted these measures of disturbed soils in light of the soil's profile characteristics in the field.

The two coarsest soils in the study, Ahwahnee and Corbett would drain to below optimum moisture content under −0.33 atm potential. The other two sandy soils, Auberry and Chawanakee, would also quickly drain after a rainstorm or snowmelt to water contents below optimum. All four soils are well drained with moderately rapid or better infiltration. These soils would therefore have a low probability of compaction because they should not remain at a critical water content for a long time.

Two of the coarse-loamy soils, McCarthy and Windy reach optimum water content near, but above, field capacity. It appears that Windy, a very deep, well-drained soil, would quickly drain to water contents below which it would have a low probability of compaction. McCarthy, which has field capacity 3% above optimum, may be wetter for longer periods and may



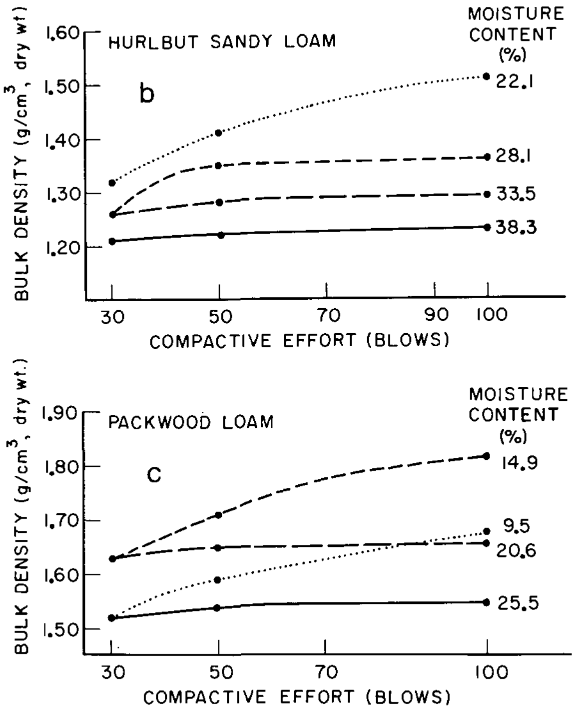


Fig. 1—Bulk density as a function of compactive effort at various water contents for a sandy *(a)*, coarse-loamy *(b)*, and fine-loamy *(c)* soil.

therefore have a higher compaction probability. It is well drained and skeletal but only moderately deep to weathered volcanic mud flow.

The other coarse-loamy soils, as well as Idonno and and Packwood of the fine-loamy soils, require potentials of about −1 atm to have moisture contents below optimum water content. These soils would be susceptible to compaction for the longest time based on water content. All are well drained and occur in areas with low summer rainfall, thus they should dry out by late summer. Aiken and Josephine resemble coarser soils in having optimum water contents in the lower range of field capacity (−0.10 to −0.33 atm). Because they have fine-textured subsoils, they would drain slowly to "safe" water contents.

Two soil series, Ditchcamp and Packwood, both range soils from the Modoc Plateau in northeastern California, have field capacities above optimum. They will be wet and susceptible to compaction through winter and spring. In addition, Packwood, with a shallow duripan, is susceptible to puddling because the liquid limit is below field capacity (−0.33 atm). Ditchcamp may also be susceptible to puddling because the −0.33 atm water content and liquid limit are close, and it has a duripan at about 70 cm. Field studies showed that cattle traffic in the wet season caused a dense, sealed surface on both soils.

All soils were near or above optimum water content for compaction at −0.33 atm, but about half of them would drain to drier moistures fairly rapidly. The others would be at water contents where they would have a high probability of compaction until they drained to a potential of about −1 atm.

Bulk densities for the six soils selected for water content-compactive effort experiments are shown in Table 5. For all six soils, average bulk density for a given water content was significantly different as compactive effort increased from 30 to 50 to 100 blows. Optimum water content is the water content at which maximum density is reached for a given compactive effort. For 30, 50, and 100 blows, this was near the optimum moisture from the standard 75-blow treatment for most soils.

For a soil low in both clay and organic matter, such as Ahwahnee (Fig. 1a), two-way analysis of variance shows that compactive effort and water content do not interact, and density rises as much from one water content to the next with 30 blows as with 100 blows. There were significant interactions between compactive effort, water content, and soil properties for the other five soils. An increase in either organic matter (Hurlbut, Fig. 1b) or clay (Packwood, Fig. 1c) causes smaller increases in density as water content increases above or drops below optimum. Hurlbut sandy loam shows that above the optimum water content for compaction (24.2%) there is little or no change in density with increasing compactive effort. As expected, at any compactive effort, density decreases with increased water content above the optimum water content (Fig. 1b). A similar relationship is shown for the Packwood loam (Fig. 1c). When the soil is compacted at water contents of 9.5 and 14.9% (below the 15.1% optimum), increasing compactive effort causes increased density. At water contents above optimum, smaller density increases were obtained. The lubricating effect of water on larger soil particles is masked at lower energies by organic matter and clay, which absorb water. At higher compactive efforts, density increases in drier soils but remains constant in soils moistened to near the liquid limit, since free water in the pores resists any increase in dry density.

The other three soils, Chawanakee, Holland, and Josephine, behaved similarly to Hurlbut and Packwood. Chawanakee has almost the same sand content as Ahwahnee (74 vs. 78%), but three times as much organic C (3.0 vs. 0.9%). Chawanakee showed an interaction between compactive effort and moisture content. That is, its density increased more (0.10 g/cm³) at high compactive effort than it did (0.05 g/cm³) at low compactive effort with the same 4.8% increase in moisture content. This interaction suggests again that organic matter content may have a greater effect than sand content on soil compactibility.

SUMMARY

We found that organic C content, normalized change in porosity, and maximum Proctor dry density could be used to rank soils according to their relative susceptibility to compaction. Higher relative susceptibility is defined here as the tendency for one soil to reach a higher density than another under equal compactive effort. Through multiple linear regression techniques we found that Walkley-Black organic C, water content at the liquid limit, sand content, and CBD extractable Fe explained 98.6% of the variability in maximum dry density. Organic C and -15 atm water content were inversely related to maximum density for these soils and for those studied by Alexander (1980) although the final regression equations are different. We did not find that density was positively correlated with either silt or clay content as was found by Heinonen (1977) or Faure (1976).

Our data confirm the importance of water content in compaction. We show that water content and compactive effort interact for some soils and that this interaction must be considered when predicting how soils will react to compactive effort. We assumed that certain soils, because of their texture, structure, and profile characteristics, would quickly drain to field capacity but that others would not. Those that have field capacities near or above liquid limits and optimum moisture contents are more likely to be compacted than those soils that have field capacities below their liquid limits or optimum moisture contents.

This information and these relationships should be useful to forest and range managers who are attempting to manage soils to reduce the chances for compaction.

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