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Assessing Soil Compaction on Forest Inventory & Analysis Phase 3 Field Plots Using a Pocket Penetrometer

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Abstract

Soil compaction is an important indicator of soil quality, yet few practical methods are available to quantitatively measure this variable. Although an assessment of the areal extent of soil compaction is included as part of the soil indicator portion of the Forest Inventory & Analysis (FIA) program, no quantitative measurement of the degree of soil compaction is made. We tested a small, lightweight pocket penetrometer that measures soil compression strength as a simple, quantitative measure of the degree of compaction of mineral soils under forested conditions. Soil compression strengths were significantly higher in compacted trails and areas than in adjacent undisturbed locations. In contrast, no significant difference in soil compression strength was found between rutted trails and adjacent undisturbed areas. A protocol is suggested for further pilot testing of this device as part of the soil indicator assessment. The main disadvantage of this device is that many of the compacted soils had compression strengths higher than the maximum measurable value of 4.5 tons/ft^2. Despite this limitation, this device can rapidly and easily distinguish between compacted and uncompacted areas in the field. Time previously spent by field crews trying to identify qualitative evidences of compaction can instead be used to provide a quantitative measure of the degree of compaction, which would strengthen the analysis and interpretation of the soil quality indicator.

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Introduction

The Forest Inventory and Analysis (FIA) program of the USDA Forest Service is responsible for conducting inventories to determine the extent and condition of the nation's forest resource (http://fia.fs.fed.us). The sample design consists of a three phase systematic sample of sites located across all forested lands in the United States (U.S.). In Phase 1 (P1), approximately 3,000,000 points are evaluated by aerial photography and digital orthoquads to determine the location of forested lands. To meet national precision standards, these data are then stratified into land cover classifications using satellite imagery and other remotely sensed data. During Phase 2 (P2), crews visit plot locations identified as accessible forest land in P1 and collect data on land ownership, forest type, tree species, tree size, tree condition, and site attributes (e.g., slope, aspect, disturbance, land use). Plot intensity for P2 measurements is approximately one plot for every 6,000 acres of forested land (125,000 plots nationally).

Phase 3 (P3) plots represent a subset of P2 sample plots (about 7,800 plots), which are measured for a broader suite of forest health attributes including tree crown conditions, lichen community composition, vegetation diversity and structure, down woody material, and soil attributes. These attributes are used as indicators of forest health. Because each P3 is also a P2 plot, all forest mensuration and ownership measurements are collected in concert with forest health data.

Each FIA plot consists of three 24-ft (7.31-m) radius subplots arranged in a triangular pattern around a central subplot (figure 1). Subplot centers are located 120 ft apart with subplots 2, 3, and 4 oriented at 120° angles around the plot center. Each subplot is surrounded by a 58.9-ft radius annular plot that is used for destructive sampling, including the collection of soil samples for chemical analysis. Field variables for the erosion and compaction parts of the soil indicator are collected within the subplot (erosion and compaction) and within the annular plot (soil physical and chemical properties).

Compaction can have a variety of effects on soil productivity resulting from changes in both physical and chemical properties. Reduction in pore space resulting from soil compaction can constrain the size and extent of root systems, reduce infiltration rates (Greacen and Sands 1980) and alter the flow of air and gases through the soil (Cannell 1977), all of which can limit the ability of roots to absorb water, nutrients, and oxygen. Because of the potential negative implications for stand productivity and forest health, soil compaction was selected as one of the 67 indicators of the Montreal Process Criteria and Indicators for Sustainable Forest Management (Montreal Process 1995). However, reporting under the Montreal Process is complicated by the fact that soil

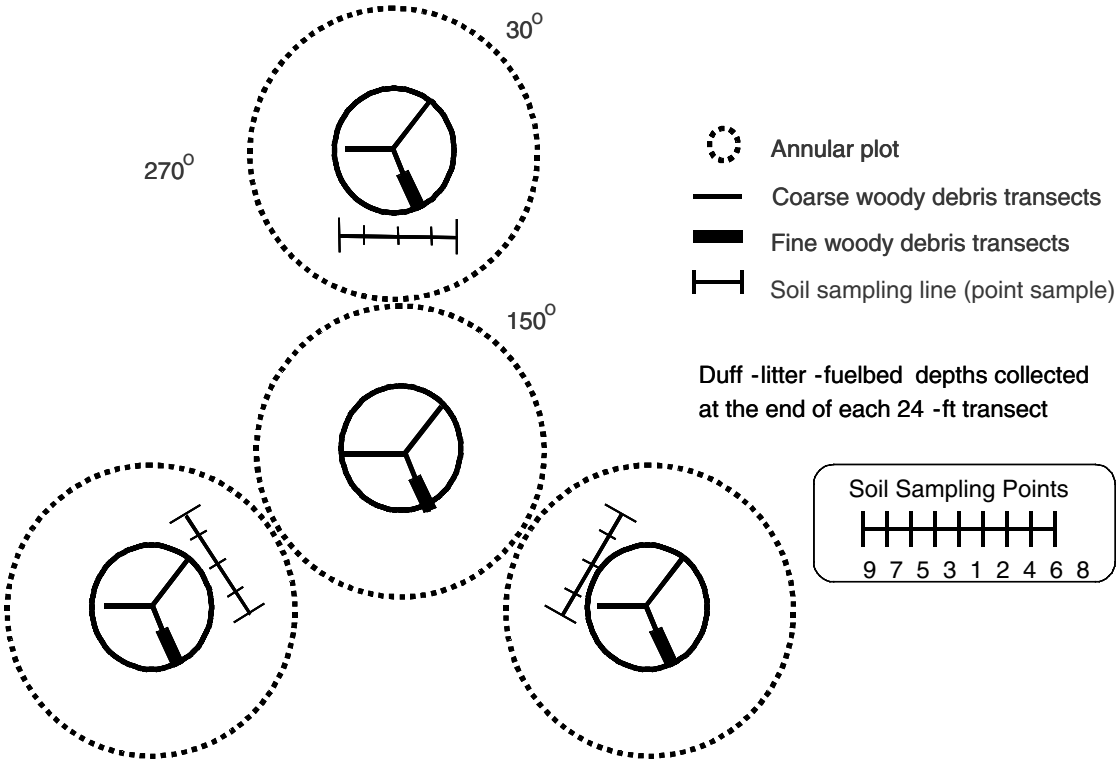

Figure 1. Diagram of the FIA phase 3 plots.

physical properties are not conventionally monitored in a way that facilitates national reporting. To address this limitation, the collection of soil compaction data has been added to FIA Phase 3 plots to help assess "the area and percent of forest land with significant compaction or change in soil physical properties resulting from human activities" (Criteria 4, Indicator 22).

To make this assessment, FIA field crews visually estimate the percent of area within each P3 subplot that shows evidence of compaction. This is the only quantitative measurement of compaction that is collected and it is a measurement of area, not degree of compaction. To help identify compacted areas, crews are taught to identify five evidences of compaction including (1) increased soil density compared to undisturbed areas; (2) platy soil structure caused by compressing soil aggregates; (3) impressions or ruts in the soil (at least 5 cm into the mineral soil); (4) loss of soil structure (e.g., puddling); and (5) mottling (specks of orange and/or green color indicating a recent change in soil aeration). Prior to 2002, crews recorded the presence or absence of these evidences as part of the compaction data. In 2002, these variables were dropped from the indicator because they were not quantitative and data from the subplots could not be aggregated at the plot level.

Beginning with the year 2000 field season, bulk density was added to the list of P3 soil indicator variables. Because soil aggregates get compressed during soil compaction and the volume of any voids in the soil matrix is reduced, compacted mineral soils generally have a higher bulk density than similar uncompacted soils. If a trend of increasing bulk density on a particular FIA P3 plot is observed with time, then soil compaction is strongly suspected, particularly if visual evidence of compaction is also observed. However, analysis of these data between plots for a single sampling period is complicated by the fact that bulk density is influenced by a number of soil properties including coarse fragment content, texture, and organic matter content. For example, bulk density generally increases as coarse fragment content increases and decreases as organic matter content increases. Because coarse fragment and organic carbon contents of soil cores collected in the FIA P3 program are also measured, the influence of these variables on bulk density can be quantified for various soil and forest types. An additional complication is that bulk density is determined by destructive sampling, and assessing temporal trends requires that the inherent variability within a given plot is low enough to be able to detect changes in bulk density over time.

Because the effects of soil compaction on forest health vary depending upon the degree of compaction, it would be desirable to add another quantitative measure of soil compaction to the FIA program. Penetrability is a physical property of soils that is frequently used as a measure of the degree of soil compaction. Soil penetrability is a measure of the ease with which a measuring device can be pushed or driven into a soil surface (Bradford 1986). There are two principal methods for measuring soil penetrability or penetration resistance: (1) dynamic methods in which the measuring device is driven into the soil by a hammer or falling weight and (2) static methods in which the measuring device is pushed steadily into the soil without impact (Bradford 1986). Many factors influence penetration resistance in soils including water content and potential, bulk density, soil compressibility, soil strength, and soil structure. For example, Taylor and Gardner (1962) showed that soil strength increased as bulk density and water potential increased.

Because of time and resource constraints in collecting all the P3 data, any method selected to measure the degree of soil compaction must be fast and easy to implement. Furthermore, any equipment used must be small, lightweight, and cost-effective. Herrick and Jones (2002) developed a new dynamic cone penetrometer with a sliding hammer for measuring soil penetration resistance. Unfortunately, this device is too large to be used by FIA field crews. Similarly, the U.S. Army Corps of Engineers' cone penetrometer, and other commercially available cone penetrometers, are also too large and heavy for routine use by FIA field crews.

The only commercially available penetrometer that meets the necessary size and cost requirements is the pocket penetrometer, which is typically used to measure soil compression strength for soil engineering and construction applications. This small (6.25 inches long), lightweight (5 oz) device can fit into a field vest pocket and is easily transported and used. Accordingly, we decided to test the suitability of this device for measuring soil compression strength as a quantitative indicator of soil compaction. Our objectives were to (1) determine if there are detectable differences in soil compression strength on compacted and rutted trails and in compacted areas as compared to adjacent or nearby undisturbed areas, (2) develop a protocol for using this device to measure soil compaction on FIA P3 plots, and (3) provide an overall evaluation of whether continued pilot testing by FIA field crews is warranted.

Methods

We selected a pocket penetrometer available from Forestry Suppliers (Jackson, MS) to measure soil

compression strength (figure 2). The penetrometer has a ground and polished ¼-in diameter spring-loaded piston, which is pushed into the ground to a depth of ¼ in. A calibration mark on the piston indicates the depth of penetration. The area of the piston end is 0.05 in^2. Compression strength in tons/ft^2 is read on a scale attached to the piston barrel. For soft soils that have a compression strength of 0 using the ¼-in diameter piston, a 1-in diameter adapter foot is recommended. The compression strength reading must be divided by 16 if the adapter foot is used.

We elected to conduct this pilot study in the Logan Canyon portion of the Cache National Forest in northern Utah because this area has heavy recreational use and locating obviously compacted trails and areas (e.g., campsites) is easy. To determine whether there is a significant difference in soil compression strength between compacted and undisturbed areas, it is necessary to first test the device in areas where there is obvious visual evidence of soil compaction.

A two-person field crew was sent into the Logan Canyon part of the Cache National Forest to locate obviously compacted trails and disturbed areas having no vegetation cover or less vegetation cover than nearby undisturbed areas. The crew first identified the type of compaction using the following criteria from the FIA program:

- Rutted trail – Ruts must be two inches deep from the top of the mineral soil surface.
- Compacted trail – Any linear feature on the landscape for foot, horse, or mountain bike travel and generally distinguished by an absence of vegetation or forest floor. Generally, a trail has a somewhat sunken appearance when compared with adjacent undisturbed soil.
- Compacted area – May have any regular (e.g., circular or rectangular) or irregular shape. Generally, marked by an absence of vegetation and often the soil appears compressed in comparison to nearby undisturbed areas. Examples include skid trail confluences, campsites, grazing areas, etc.

The primary difference between trails and areas for purposes of measuring soil compaction is that trails are linear features on the landscape, whereas compacted areas can be any regularly or irregularly shaped polygon that can be visually distinguished from undisturbed areas.

To measure soil compression strength along compacted or rutted trails, the field crew selected an arbitrary starting point along a trail and recorded a

Figure 2. Photograph of the pocket penetrometer and adapter foot.

GPS location for the start point. The crew next selected a direction of travel along the trail and recorded the compass reading of the direction of travel. The crew measured soil compression strength at the center of a compacted trail or the bottom of a rut if it was a rutted trail at points 4.8, 12, 24, 36, and 43.2 ft along the trail from the starting point. These points correspond to 10, 25, 50, 75, and 90 percent of the distance along a 48-ft section of trail. This design ensures that, regardless of the length of a trail within a given subplot, the same relative spacing along the trail length is used for making the measurements. Since a P3 subplot is 48-ft in diameter, this represents the maximum length of a straight section of trail that could be contained within a P3 subplot if the trail passed through the center of the subplot. The crew also measured soil compression strength of undisturbed mineral soil under vegetation and/or forest floor just off the trail but adjacent to each measuring point on the trail.

To measure soil compression strength of a compacted area, the crew first located the approximate center of the area to be measured and recorded the GPS location of the area center. The crew measured soil compression strength at the center and at points two-thirds of the distances (up to a maximum of 24 ft – radius of P3 subplot) between the center and the north, south, east, and west edges of the compacted area. The crew also recorded these distances since many of the areas were irregularly shaped. The crew also measured soil compression strength in a nearby similarly-sized area of undisturbed soil with vegetation cover. All measurements were made on June 26 and 28, 2001.

At each sampling point, the following protocol was used to measure soil compression strength using the pocket penetrometer. The white slide ring was first pushed up against the stop so that it was at the zero point on the compression strength scale as shown in figure 2. Holding the penetrometer vertically and using a steady pressure, the piston was slowly pushed into the soil up to the calibration groove ¼ inch from the end of the piston. After removing the penetrometer from the soil, the soil compression strength was read directly in tons/ft^2 on the low side of the white slide ring (away from the end of the piston).

If the soil was too soft to give a reading on the scale (white ring did not move above zero), the 1-in diameter adapter foot was attached and the measurement re-made by slowly pushing the piston into the soil to the full thickness of the adapter foot. The scale reading was divided by 16 to obtain a corrected value because the adapter foot has 16 times the area of the end of the piston.

Soil compression strengths of > 4.5 tons/ft^2 were truncated to the maximum measurable value of 4.5 tons/ft^2 prior to statistical analysis. Because of this truncation, a Wilcoxon signed rank test was run to compare compacted and undisturbed locations within each compaction type (compacted area, compacted trail, rutted trail). To estimate the mean and standard error of the truncated (censored) data set from compacted areas, procedures given by Cohen (1991) were used.

Results

Locations of sites where the soil compression strength measurements were made are shown in table 1. Since these sites were selected for this study and are not FIA P3 plots, actual site coordinates are listed in table 1. A total of 26 sites were evaluated including 16 compacted trails, two rutted trails, and eight compacted areas. Each site included a paired set of measurements – compacted trail or area and adjacent or nearby undisturbed area. Although not P3 plots, these sites are representative of the types of compaction routinely encountered on FIA plots.

Soil compression strengths ranged from the minimum measurable value of 0.1 tons/ft^2 to the maximum measurable value of 4.5 tons/ft^2 on the pocket penetrometer (table 2 and figure 3). Mean soil compression strength of compacted trails was significantly greater than that of undisturbed soil adjacent to the compacted trails (table 2). Similarly, mean soil compression strength of compacted areas was significantly greater than nearby undisturbed areas (table 2). In contrast, no significant difference in mean soil compression strength was found between rutted trails and undisturbed soil adjacent to the rutted trails (table 2).

Although no significant differences in soil compression strength were found among compacted trails, rutted trails, or compacted areas (type of compaction did not influence soil compression strength), soil compression strength of undisturbed soil adjacent to the two rutted trails included in this study was significantly higher than soil compression strength of undisturbed soil adjacent to compacted trails or in undisturbed reference areas near compacted areas.

Discussion

Although there is overlap in measured soil compression strength between compacted and undisturbed

Table 1. Locations of the study sites

Site number	General location	GPS location N 41°	GPS location W 111°	Trail bearing degrees	Area of compaction ft²
Compacted trails[1]					
1	Riverside	44.811’	48.201’	226	
3	Riverside	44.866’	43.984’	88	
7	Willow Creek	46.891’	36.643’	118	
9	Amazon Mine	56.790’	29.949’	180	
11	Limberpine	44.847’	48.179’	72	
12	Wind Cave	45.714’	42.320’	268	
14	Fucoidal Quartzite	46.830’	38.642’	210	
15	Jardine Juniper	47.856’	38.873’	308	
17	Beta Graph	48.294’	37.862’	170	
18	Cottonwood Canyon	48.864’	37.251’	76	
20	Blind Hollow	50.150’	35.958’	300	
21	Bear Hollow	51.163’	35.193’	165	
22	White Pine	53.753’	38.505’	320	
24	Tony Grove	53.902’	38.678’	140	
25	Steammill Hollow	55.975’	34.206’	194	
26	Sink Hollow	58.659’	31.847’	335	
Rutted trails[1]					
5	Card Canyon	45.521’	39.246’	152	
19	Dugway	49.882’	36.239’	340	
Compacted areas					
2	Bridger Campground	44.892’	44.112’		120
4	DeWitt Spring	45.438’	42.591’		538
6	Camp Lomia	46.277’	36.440’		1123
8	China Row	47.600’	38.729’		427
10	Sinks Road	53.179’	29.133’		2304
13	Fucoidal Quartzite	46.706’	38.344’		172
16	Wood Camp	47.827’	38.707’		669
23	Tony Grove	53.459’	38.534’		2304

[1]A randomly selected 48-ft section of each trail was selected for the soil compression strength measurements.

Table 2. Mean ± standard error (se) and range of observed soil compression strengths for compacted and rutted trails, compacted areas, and undisturbed reference areas. Because the data set for compacted trails and areas was truncated by the maximum measurable value of 4.5 tons/ ft², procedures given by Cohen (1991) were used to derive estimated means and standard errors. Means within each type of compaction not followed by the same letter are significantly different ($p<0.01$).

Type of compaction		Soil compression strength tons/ft² mean ± se	Range of observed soil compression strengths tons/ft²
Compacted trail			
	Compacted	4.4 ± 0.4 a	0.1 – 4.5
	Undisturbed	1.0 ± 0.2 b	0.1 – 3.5
Rutted trail			
	Compacted	4.4 ± 1.2 a	1.0 – 4.5
	Undisturbed	2.8 ± 0.6 a	1.5 – 4.0
Compacted area			
	Compacted	4.5 ± 0.4 a	0.5 – 4.5
	Undisturbed	1.2 ± 0.3 b	0.1 – 3.0

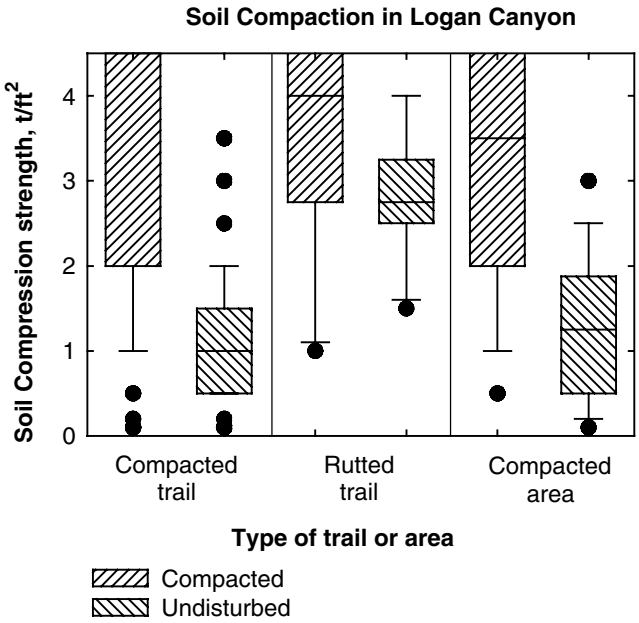

Figure 3. Box plots of measured soil compression strengths of compacted trails, rutted trails, compacted areas, and adjacent or nearby undisturbed areas. The 25th and 75th percentiles are shown as a box centered about the 50th percentile (median); the 10th and 90th percentiles are shown as error bars; and the 5th and 95th percentiles and outliers are shown as points.

points, soil compression strengths along compacted trails and in compacted areas tended to be measurably higher than in adjacent or nearby undisturbed soils (figure 3). Reasons for the lack of a significant difference in soil compression strength between rutted trails and adjacent undisturbed soil are unknown. The measurements along the rutted trails were made at the bottom of the ruts, where compaction was expected to be highest, but since measurements in adjacent undisturbed soil were high, no significant differences in soil compression strengths between ruts and undisturbed soil were found.

Since compaction type is initially determined visually in the FIA protocol rather than by some quantitative measure, this finding suggests a potential problem with the current field protocol -- i.e., an area that visually met the definition of compaction was demonstrated not to meet a quantitative definition of compaction. This inconsistency between visual and quantitative assessments of compaction indicates the need to further investigate adding a quantitative measurement of soil compaction to the FIA soil indicator program.

It is not known why soil compression strength in undisturbed soil adjacent to the rutted trails was significantly higher than soil compression strength measured in undisturbed soil adjacent to compacted trails or nearby compacted areas. Perhaps the soils in the area of the rutted trails have a soil compression strength that is naturally higher than soils measured elsewhere in this study. Also, only two rutted trails were included in this study, so a larger sample size might reveal some significant differences. The number of compacted trails, rutted trails, and compacted area sites selected for measurement in this study was proportional to the frequency occurrence of these compaction types found in this part of the Cache National Forest based on a brief visual survey of compaction types.

The differences in the ratio of compacted:uncompacted soils for the three compaction types indicates that the type of compaction may have influenced the degree of compaction, even though there was no statistical difference between the absolute values of soil strength for the compacted soils. For example, the ratio of compacted to uncompacted soils for the three types of compaction were compacted trail = 3.3, compacted area = 2.7, and rutted trail = 1.3.

Thus, visual assessments of compaction based on surface characteristics may not necessarily correspond to the degree of compaction. For example, rutted trails may be easier for crews to identify as "compacted" than compacted trails based on surface characteristics. But in this case, a quantitative assessment indicated that rutted trails demonstrated a lower degree of compaction relative to the uncompacted areas adjacent to the trail. For this reason, the utility of FIA soil compaction assessments would benefit from the addition of quantitative measurements of soil compaction. Furthermore, with additional testing, we may be able to develop a rating scale for assessing the degree of relative compaction on a plot that would improve comparison across different temporal and spatial scales. For example, a compacted:uncompacted ratio of <2.0 may indicate little to no compaction, a ratio of >2.0, but <3.0 would indicate moderate compaction, and a ratio of >3.0 would indicate severe compaction. Further pilot testing may confirm the usefulness of this approach.

Because measurements of soil compression strength using the pocket penetrometer can distinguish between compacted and uncompacted areas, this method holds promise for providing a quantitative measure of soil compaction for the FIA soil indicator program. The device is relatively low-cost (about $50, adapter foot adds another $20 to the cost), easily portable because of its small size (6.25 inches in length), lightweight (5 oz), and is easily used. Taking a series of five measurements along a trail or in a compacted area typically takes less than 15 min. The adapter foot is easy to install and remove and normally would only need to be used in

undisturbed soils that have relatively low soil compression strengths.

The main disadvantage of the pocket penetrometer is that many compacted soils have soil compression strengths that exceed the upper measuring limit of the device, which is 4.5 tons/ft^2. Thus, datasets are truncated by the upper measuring limit of the device.

Soil compression strength is dependent on soil moisture content. However, by measuring both compacted and adjacent or nearby undisturbed areas on the same plot visit, relative differences in soil compression strength between compacted areas and undisturbed sites can be detected since soil moisture contents of compacted and undisturbed sites that are spatially close are unlikely to differ significantly. Because soil moisture content is one of the soil physical properties collected as part of the P3 program, associations between soil compression strength and soil moisture content can be explored.

The ability of the pocket penetrometer to distinguish between compacted and undisturbed soils indicates that this device should receive further testing by FIA pilot field crews. Measurements on a wide range of soil types in several regions of the country need to be evaluated before including this method in the soil indicator program.

For a testing protocol, we recommend taking five measurements of soil compression strength at 10, 25, 50, 75, and 90 percent of the distance of the length of any trail that falls within a FIA P3 subplot. Thus, regardless of the length of a trail within a given subplot, the same relative spacing along the trail length is used for making the measurements. To save time, these distances can be paced or visually estimated. To sample undisturbed points adjacent to each measurement point on the trail, we recommend alternating measurements on each side of the trail. Each undisturbed measurement point should be located one perpendicular trail width from the center of the trail.

For a compacted area within a subplot, we recommend taking measurements at the center and two-thirds of the distances (up to a maximum of 24 ft) between the center and the north, south, east, and west edges of the compacted area. This corresponds to a spatially uniform distribution of measurements within the compacted area regardless of its areal extent or shape. An adjacent or nearby undisturbed area of approximate size and shape to the disturbed area should be used for uncompacted area measurements. This design provides a comparable starting point for pilot studies of technical utility as well as for time-motion studies across a range of soil and forest conditions.

References

Bradford, J.M. 1986. Penetrability. p. 463-478. In: A. Klute (ed.) Methods of soil analysis. Part 1. Physical and mineralogical methods. 2nd ed. Madison, WI: American Society of Agronomy.

Cannell, R.Q. 1977. Soil aeration and compaction in relation to root growth and management. Applied Biology 2:1-86.

Cohen, A.C. 1991. Truncated and censored samples, theory and applications. New York: Marcel Dekker. pp. 18-30.

Graecen, E.L.; Sands, R. 1980. Compaction of forest soils: A review. Australian Journal of Soil Research 18:163-189.

Herrick, J.E.; Jones, T.L. 2002. A dynamic cone penetrometer for measuring soil penetration resistance. Soil Science Society Of America Journal 66:1320-1324.

Montreal Process. 1995. Criteria and indicators for the conservation and sustainable management of temporal and boreal forests. Catalogue Fo42-238/1995E. Hull, Quebec: Canadian Forest Service.

Taylor, H.M.; Gardner, H.B. 1962. Penetration of cotton seedling taproots as influenced by bulk density, moisture content, and strength of soil. Soil Science 96:153-156.

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