Assessing the Effectiveness of Forest Soil Tillage Practices

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ABSTRACT

Numerous ground-engaging teeth, disks, and shanks of forestry equipment are used to till forest soils. The effectiveness of these practices to loosen soil has less frequently been reported, and the methods used are often time consuming and expensive. Methods of measuring soil to assess tillage effectiveness will be briefly reviewed and a new method that is easy to use in the field will be presented. Effective soil tillage loosens soil and increases the elevation of the soil surface; the new method measures the change in soil elevation before and after tillage using a rotating laser level, permanent reference points, and temporary transects. The method was used while testing equipment options for tilling temporary forest soils and oil and gas wellsites in Alberta. Plowing soil to depths of between 0.7 and 0.9 m consistently produced gains of soil elevation that averaged 0.15 m immediately following tillage, and was more effective than rippers. After four years, about 30 percent of the gain in elevation was still measureable, which produces 4 to 5 cm of increased air-filled porosity and/or increased water holding capacity. Soil cores confirmed that the tillage increased soil water content and increased air-filled porosity. Measuring the gain in soil elevation is a practical method of assessing the effectiveness of tillage in the field and reinforces the need for tillage practices to produce large increased in soil elevation if tillage practices are to be effective.

INTRODUCTION

The effects that equipment used to harvest forests and transport logs has on soil and future forest productivity have been a concern for several decades (Froehlich and McNabb 1984). Reducing the ground pressure of skidding equipment with wider tires and tracks have been one method used with some success (Froehlich et al. 1981), but these machines can still cause significant compaction when the soil is wet (McNabb et al. 2001). Limiting machines to dedicated skid trails is also an effective option to limit the areal extent of the soil impact but is a less useful practice on wet soils of low strength that are more easily rutted.

The soil in temporary roads needed to access logs within cutblocks or a series of cutblocks are more severely impacted by truck traffic than the soil impacted by skidding logs. In western Alberta, logging trucks can compact soils to soil densities equal to the maximum densities measured in laboratory compaction (Proctor) tests (McNabb 1994). Furthermore, the impact to soil can change soil porosity and water retention properties of the soil to a depth of at least 0.6 m (McNabb 1997). Within this layer of soil the impact is severe enough to destroy soil structure and create massive soil. This damage of soil structure causes numerous changes to soil physical properties that can affect the growth of the trees (Froehlich and McNabb 1984), as well as severely mpair the hydrologic function of the soil profile and adjacent area.

When soil impacts can not be avoided or minimized, the soil is commonly tilled. Most tillage is done with dozers and excavators using conventional ground-engaging attachments, or their modifications. As a result a wide range of teeth, shank spacing, and tooth modifications are used by companies to till soil. As an alternative, site preparation equipment is sometimes used but the depth of tillage is generally shallow (Gent et al. 1984). Only three-shank, winged-subsoiler has been specifically developed for tillage of forest soils (Davies 1990), but is less effective in soils of higher clay content (McNabb 1994). The effectiveness of many of these implements used in forests for restoring the soil physical environment has not been reported (Sutherland and Gillies, 2001). Measuring the effectiveness requires access to expensive equipment and is generally time consuming (Andrus and Froehlich 1983, McNabb and Hobbs 1989, Davies 1990, McNabb 1994). Furthermore, some of the commonly used methods of measuring soil may not be as reliable when used in tilled soil. There remains a need for simple and effective methods for assessing the effectiveness of tillage quickly in the field (Bulmer 1998).

The objective of this paper are two-fold: briefly review the methods that have been used to measure the effectiveness of tilled soil; and report on a new field method of assessing the effectiveness of soil tillage that is simple and fast. The field method has been used for several years in Alberta to evaluate deep tillage of oil and gas wellsites and forest roads in Alberta. The method will also be used to confirm the sustained benefits of the deep tillage after 4 years, and was verified with the measurement of soil density, water retention, and air-filled porosity on soil cores.

COMMON MEASURES OF TILLAGE EFFECTIVENESS

Assessing the effectiveness of a tillage operation is difficult. Tillage loosens the soil, but some of the increased porosity is lost over time by the natural consolidation of the soil. From a loosen state, a soil will consolidate toward a normal, or stable, bulk density (Heinonen 1977). In the absence of vehicle trafficking, how long it takes to achieve this density is unknown, but the number of cycles of freezing and thawing, wetting and drying, and the amount of precipitation are important contributing factors. The normal bulk density of tilled soil is also likely to be less than that of undisturbed soil. Therefore, sampling loose, tilled soil, and disturbances of the soil in the process of collecting a sample, will affect the reliability of most of the methods of measuring tillage effectiveness.

Soil Density and Penetrometers

Soil density can be measured using undisturbed soil cores or soil density gauges; however, the loose soil makes obtaining undisturbed soil cores nearly impossible immediately after tillage. The collection of soil cores with the more commonly used, thick-walled samplers that are hammered into the soil will compact tilled soil and affect the measurement of soil density and porosity. Therefore, a high priority must be placed on verifying the quality of each core collected. The highest quality, soil cores are generally collected in thin-walled rings that have not been hammered into the soil (McNabb and Boersma 1993), but in recently tilled soil this method will not guarantee the soil cores are undisturbed.

Two-probe soil density gauges have been used to measure soil density following ripping of a forest site in southwest Oregon (McNabb and Hobbs 1989); however, these gauges are limited to a depth of 0.3 to 0.6 m. When oriented in the direction of tillage, a two-probe gauge can provide an accurate assessment of the tillage effect around a single tooth or tine (Figure 1).

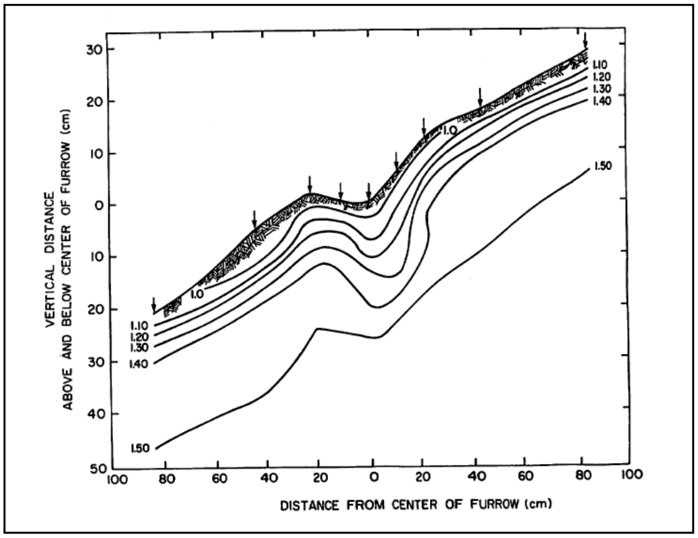

Figure 1. . Cross-sectional profile with isolines of soil bulk density following tillage with a single, tine ripper. The soil is a Typic Haploxeralf and located in southwest Oregon. The arrows mark points were a dual-probe gamma gauge was used to measure soil density parallel to the furrow at 5 cm depth increments (8 replications). (Source: McNabb and Hobbs 1989).

Penetrometers are commonly used to access tillage effectiveness, whether it is simply a rod pushed into the ground or a more sophisticated unit that records penetration resistance according to the depth. These units are compatible with deep tillage operations (Dunker et al. 1995, Baumhardt et al. 2008). As with any application of a soil penetrometer, and in tilled soil maybe more so, soil penetrometers require considerable expertise in their use and interpretation because of the confounding interaction of soil density, soil water content, depth of measurement, and amount of fracturing of the soil by the tillage operation.

Size of Clods

Size of clods produced by a tillage operation can be used as a measure of tillage effectiveness (McNabb 1994, Dexter and Birkas 2007, Kzric et al. 2009). Dexter and Birkas used a portion of clods larger than a certain size to access the effectiveness of seedbed tillage practices, while Kzric et al. use the maximum size of clod produced to establish different tillage treatments in a forest landing restoration project in British Columbia, Canada. McNabb used a clod size distribution curve of a percentage of material passing different screen sizes as a measure of tillage effectiveness in a forest road reclamation project in Alberta, Canada (Figure 2). Clod size distribution can also be used to calculate packing, or gradation, parameters for tilled soil that may have value in assessing seedbed quality. Clod sizes can be determined in the field using a rock screening set, which commonly uses a set of screens with a grid between 0.005 to 0.076 m, and a field scale. Large samples are needed to minimize the risk that the excavation of the sample is not reducing clod size.

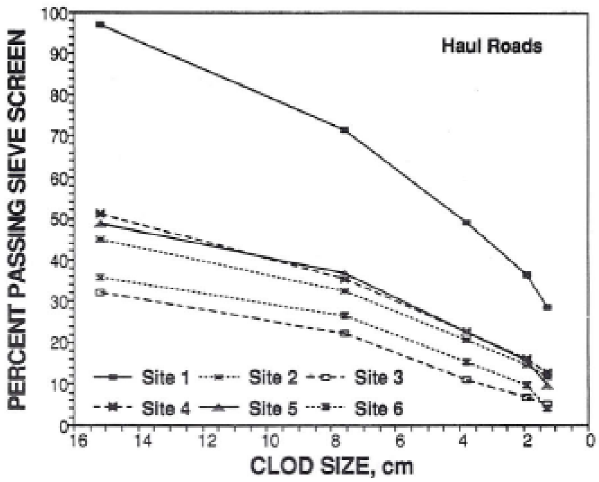

Figure 2. Clod size distribution of soil from the 0-30 cm depth of forestry haul roads and landings tilled with the forestry subsoiler (Figure 2). Soils were the subsoil horizons with mostly clay loam and clay textures, and located in west-central Alberta, Canada. Each point on a line corresponds to the size of the grid used to sieve the sample. (Source: McNabb 1994).

Excavated Profile

Trenches can be excavated across tillage furrows to expose a cross-section of the tilled soil (Andrus and Froehlich 1983, Raper 2005). Careful separation of the loosened soil from the untilled soil will define the boundary between the two materials. It is important to maintain reference points on either side of the furrow so that the original surface of the soil is known, and measured prior to tillage. Measurement of the elevation of the surface and the boundary of the tilled/untilled soil can be graphed to illustrate the area of soil loosened by tillage.

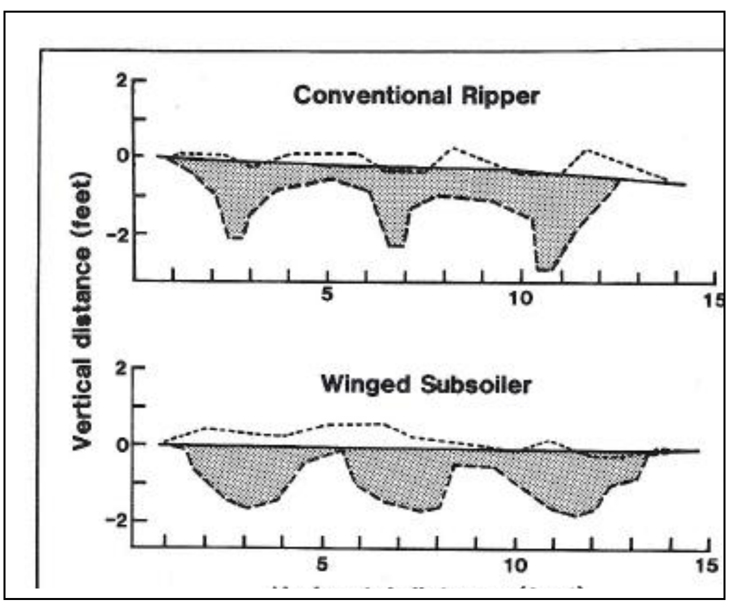

Figure 3. Excavated cross-section of furrows created with three, conventional rippers or winged subsoilers. The research was done in western Oregon but the soil type and wetness were not identified. (Source: Andrus and Froehlich 1983).

NEW FIELD METHOD OF ASSESSING TILLAGE EFFECTIVENESS

Method

A new method of measuring tillage effectiveness, and deep tillage practices in particular, has been used in Alberta for several years. The methods involves measuring soil elevations along transects established across an area prior to tillage and remeasuring the elevations at the same points afterwards. A similar method has been used to measure soil lift from tillage in mined lands in Australia by Croton and Ainsworth (2007).

The method is based on the principle that effective soil tillage fractures and loosens the soil thereby increasing soil porosity. Soil porosity can only increase if the soil volume increases. In the field, lateral confinement of soil limits volume expansion to the vertical axis. Therefore, any tillage induced increase in soil porosity must increase the elevation of the soil surface. Soil elevations can easily be measured in the field before and after tillage to calculate a gain in soil elevation.

Figure 3 is a general example of the relationship between a decrease in soil density as a result of increasing soil porosity and the gain in soil elevation for different average depths of tillage. An important point that this graph illustrates is that for tillage below a depth of depth of about 0.3 m, relatively large differences in the average elevation of the soil surface is required to produce small decreases in soil density. The measurement provides a single value for the increase in soil porosity and decrease in soil density produced by tillage; it does not provide a measure of where in the soil profile the porosity is located. Tilling plots of the same soil at increasing depths could provide some insight as to the effectiveness of a tillage practice at different depths, but would need to be interpreted carefully.

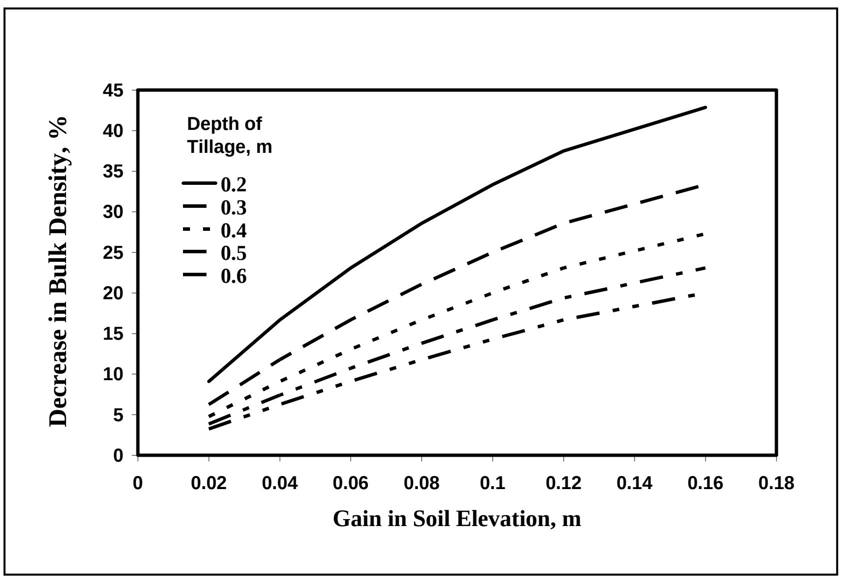

Figure 3. General relationship between the gain in soil elevation as a function of the depth of tillage and the decrease in soil bulk density. The assumptions are the average soil density for the soil profile is 1.30 Mg/m^3, all soil is fractured to the depth listed, and the fracturing is uniform for each depth.

The gain in soil elevation can be measured with a rotating laser level and rod by taking measurements from a permanent reference point and reestablished transects across tilled soil. Two methods of establishing transects for the measured of the gain in soil elevation have been used in Alberta. Both methods require a reference point that can not be disturbed by tillage for measuring all elevations. On narrow linear disturbances such as forest roads, the reference point can be a stump several meters from the road. When used to measure tillage of wellsites, an area was left untilled and the reference point marked with a rebar.

A moderately priced, laser level commonly used in the home construction industry can have an accuracy of ±0.005 m at a distance of 30 m. Reestablishment of transects in this application found the lasers had an average accuracy of about 0.003 m for distances between 4 and 20 m. All the best management practices for using a rod and level apply in this application.

On temporary roads, four transects were installed diagonally across the road with the end points marked off the road so that they would not be damaged by the equipment tilling the road. The angle that the transect made with the road varied but the transects were installed so that there were at least 10 measurements points, 1 m apart, taken along each transect on the section of the road to be tilled. Four transects were installed on each road segment measured for a total of 40 elevations.

On wellsites (approximately a square 110 m on a side), the reference point was a common end point for four transects radiating away from the point in four directions. The opposite end of each transect was in tilled soil about 15 m away. It was located by azimuth of a line between the reference point and a permanent object around the perimeter of the wellsite, such as a single tree, so that it could be more easily and accurately relocated to measure soil elevations after the soil was tilled. Soil close to the reference point was not tilled and 10 measurements, 1 m apart, were taken along each transect with the first measurement taken at between 3 to 5 m.

Results

The gain in soil elevation has been used to assess the effectiveness of different tillage implements on forest roads and wellsites in Alberta. The gain in soil elevation was always measured immediately following tillage, when the soil is most porous. Four wellsites were remeasured four years after tillage and provides a more sustainable measure of the longer term benefits of the tillage.

Temporary summer roads in several cutblocks on Luvic Gleysols in north-central Alberta were tilled with a Caterpillar® D7G with two standard rippers, or a pair of prototype RipPlows specifically designed for deep tillage with dozers (Figure 4). The road was tilled with lapping passes so that the main traffic area was tilled with a shank spacing of approximately 1 m. Rippers operated at a depth of about 0.7 m, and the RipPlows at a depth between 0.4 and 0.5 m; the older dozer was under powered for pulling RipPlows deeper in the compacted, higher clay content soils. For tree replications, rippers produced a gain in soil elevation of 5.8 cm, and the RipPlow a gain in soil elevation of 13.0 cm.

Figure 4. Pair of prototype RipPlows on a Caterpillar® D7R used to till forest roads and wellsites in Alberta. Soil can be tilled to depths up to 0.90 m and produce a gain in soil elevation of 0.15 m.

Numerous wellsites in northwest Alberta have been tilled with the RipPlows pulled with Caterpillar® D7Rs, which are capable of plowing the soil to depths of between 0.8 and 0.9 m (Figure 4). With lapping passes, the RipPlows cover over 65 percent of the area. In this practice, RipPlows consistently achieved a gain in soil elevation of 15 cm; the soils were mostly Orthic Grey Luvisols and Luvic Gleysols. After four years, the transects on four sites were reestablished and the soil elevations remeasured. About 30 percent of the original gain in soil elevation remained. This represents about a 4 to 5 cm increase in soil porosity that is allocated to increasing soil aeration and/or soil water holding capacity. Undisturbed soil cores were collected at one wellsite at a depth of 30 cm and the tillage significantly increased volumetric water content of the soil and air-filled porosity. Natural consolidation of the soil over time causes the decrease soil elevations and an evolution toward a normal soil bulk density (Heinenon 1977). After four years, the improved soil porosity may be sustainable for some time; in the absence of heavy trafficking, the benefits of deep tillage can persist for at least three decades (Baumhardt et al. 2008).

OPERATIONAL CONSIDERATIONS

All effective tillage practices will create a loose, unstable soil that will consolidate over time, and shift the soil toward a normal soil bulk density. The time period could be relatively short for shallow tillage but is generally longer for deeper tillage. Intentional and unintentional trafficking of soil after tillage will also significantly reduce soil porosity. In Alberta, a single pass by a tracked log loader over a recently tilled, logging road reduced the gain in soil elevation in the tracks by over 50 percent, and about 35 percent between the tracks. Therefore, the method chosen to evaluate tillage effectiveness must consider how the date are to be used and whether the method will affect the data.

If the objective is to assess the effect of tillage on soil density, soil water retention, and aeration status of the soil, the sampling of undisturbed soil should be delayed until most of the consolidation is complete. Collection of undisturbed soil cores from recently tilled soil is improbable immediately after tillage. Thick-walled core samples, particularly if hammer driven into the soil will compact the soil in the process. The quality of the cores can be assessed by removing the top of the sampler and comparing the elevation of the soil inside the ring with the soil outside the ring; the elevation of a minimally disturbed sample should be the same. The use of thinned-walled engineering samplers has been found to the best when gently pushed into the soil by hand. Methods of collecting undisturbed soil cores in weak soils have been described in McNabb 1993, McNabb et al. (2001). One- and two-probe soil density gauges cause the least disturbance and the two-probe gauges are more accurate but not very common.

The measurement of clod sizes, which can be readily done in the field with field sieve sets and scales is well suited for assessing the quality of surface soil as a seedbed. Large samples are needed to reduce fracturing clods during excavation (McNabb 1994). Obtaining quality samples from deeper in the soil profile will require more effort to avoid damaging the layer to be measured during excavation. Clod size distributions can also be used to calculate packing coefficients of the material, which should have added value for assessing seedbed quality of nursery soils.

Excavation of furrows is a simple field procedure, and is useful for demonstrating the effectiveness of rippers where the critical depth of tillage is closer to the suface (Figure 3). In this situation, only a small volume of soil may be effectively loosened (Andrus and Froehlich 1983); rippers operating below this depth will compact the soil around the shank (Raper 2005). Excavation assessment of tilled soil requires that the elevation of the original surface be established prior to tillage. Deep tillage will exponentially increase the amount of work required to expose the tillage boundary but excavation also provides information on how well the soil is fracturing.

Measuring the gain in soil elevation to evaluate a tillage treatment is the fastest, least destructive method of measuring tillage effectiveness. Forty pre-tillage and another 40 post-tillage measurements can be taken in as little as three hours and the average gain in elevation can be calculated in the field. A good quality laser level should be used. Establishment of a stable, untilled reference point is critical part of the method, and becomes more so if remeasured over a period of several months or years.

The gain in soil elevation provides an average value of the increase in soil porosity produced by tillage. In practice, the surface soil may be loosened more that soil deeper in the profile. Disks generally produce much larger gains in soil elevation than rippers; disks have been observed to double soil volume. Hence, a gain in soil elevation might average 20 cm, but the depth of soil penetration would only be 10cm, and the looser soil will consolidate more over time.

CONCLUSIONS

The ground-engaging implements of forestry equipment and their modifications have infrequently been evaluated for their effectiveness to till soil because of the cost and suitability for use in tilled soil. However, there are practices that allow the assessment of soil tillage to be done in the field. Measuring the gain in soil elevation is a new method for measuring tillage across larger areas and more complex terrain. The method also confirms that large increases in soil elevation are required (Figure 3) if deeper tillage of soil is to be effective, and that natural consolidation will reduce the gain in soil elevation by more than half. Nevertheless, effective deep tillage has successfully added several centimeters of increased soil porosity and/or water retention to a soil profile that is likely sustainable for several decades in the absence of trafficking.

The practical implications are two. Effective tillage produces large gains in soil elevation. Depth of tillage should not be measure from the surface of the surface of tilled soil but from the original soil surface; otherwise, the estimate of tillage depth is over estimated. These two points should help operations staff better choose and assess the effectiveness of tillage operations in the field when data are not collected.

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