ABSTRACT: Heavy forest machinery used in skidding can influence the physical properties of soils. These may lead to an upsurge in soil disruption and compaction of the soil surface decreases forest soil fertilities. This study assesses the effects of skidding on some soil physical properties such as the soil bulk density and porosity in the Nkrankwanta off-forest reserve in Ghana. The treatments comprised of four traffic intensity levels (0, 1, 5, 10, and 15 passes) of the Mercedes Benz skidder (MB) Trac 1800 and a slope of two levels (less than 20 % and greater than 20 %) in a completely randomized block design. Also, porosity and soil bulk density was assessed at varying distances from the MB Trac 1800. Soil bulk density results showed increasing trends with traffic frequency. Soil bulk density measured in the undisturbed area was 0.64 g cm$^{-3}$ and 0.56 g cm$^{-3}$ at slopes of less than 20% and greater than 20%, respectively. On the skid trail, soil bulk density significantly increased with traffic frequency ($p<0.05$). However, soil porosity declined. Soil porosity estimated in uninterrupted area was 59.10 % and 57.40 % at < 20% and > 20% slope, respectively. Soil porosity was significantly influenced via different skidder passes ($p<0.05$). The soil physical properties were not influenced by the steepness of the slope however acted together in the number of passes to influence soil porosity. The impacts of the skidder on soil physical properties were significantly apparent at distances of 2 m to each sideway of the skidding trail. In conclusion, distinct responsiveness ought to be considered throughout the operations of skidding to curtail unfriendly influences on soil physical properties in ground-based skidding.

Keywords: Porosity, Bulk density, Compaction, Skidding.
Introduction

The usage of heavy equipment to execute forestry undertakings, for example logging, has intensified all over the overworld in the past years. Yet, this equipment could extremely influence the ecosystem of soils by way of inducing the upper soil layers as well as soil compaction (Najafi and Solgi 2010; Ampoorter et al. 2010; Picchio et al. 2019; Sohrabi et al. 2020). Soil compaction is a common consequence of the ground-based skidding systems that always occurred in heavy machinery operation (Binkley and Fisher 2013).

Soltanpour and Jourgholami (2013) detailed that the using heavy machinery and harvesting operation in the forested areas, naturally impact the bulk density of soils, degraded soil particles, decrease the porosity of soils and the porousness capability of soils, and as well as affecting the structure and the stability of soils thus triggering erosion.

The point to which compaction occurs in forest soil as a result of automated logging relies on numerous variables and features of the forest such as the soil texture, soil organic matter content, slope, soil water content, soil temperature, and harvesting activity such as the machine type, machine mass, traffic intensity (Mohieddinne et al. 2019). The number of machine passes is a factor that significantly influences the degree of soil damage.

In this study, the researchers aimed to evaluate the impact of the Mercedes Benz (MB) Trac 1800 skidder on the disruption of soils at altered the number of passes and trail slope in respect to the soil porosity and bulk density of soil. The ultimate goal of the researcher was to make available valuable, technical, and scientific evidence for the progress of best practices of management in the forest areas of Ghana with regards to the protection of forest soils efficiency and the effectiveness of the forest ecosystem.

Materials and Methods

Site description

This work was done throughout March-May 2018 in the Nkrankwanta Off-Forest Reserve in the Dormaa Municipal of Ghana in the Brong-Ahafo Region. The town elevation is about 375 meters above sea level. It is found within longitudes 3° West and 3° 30’ West and latitudes 7° North and 7° 30’ North. The yearly mean temperature is 26.1 °C. The dominant species of trees in the reserves comprise, Milicia excelsa, Terminalia superba and Tectona grandis. The type of soil in the study area was identified as sandy-clay-loam soil.
Machine description

The machine used in the study was the Mercedes Benz (MB) Trac 1800 skidder, which is powered by a 6-liter turbocharged diesel 6-cylinder engine. This machine has a slightly longer wheelbase, meaning more stability (Figure 1 and Table 1).
Figure 2. The MB Trac 1800 skidder used for skidding operations

Table 1. Measurement of skidder MB Trac 1800

| Features                              | Measurement Unit | Value                  |
|---------------------------------------|------------------|------------------------|
| Standard engine                       | L                | Mercedes Benz 6.0      |
| Power                                 | kW               | 134                    |
| Transmission                          | -                | 14 forward; 14 reverse |
| Height                                | Cm               | 293                    |
| Width                                 | Cm               | 468                    |
| Maximum Blade Lift Above Ground       | Mm               | 1204                   |
| Maximum Blade Dig Below Ground        | Mm               | 295                    |
| Front Axle to Front of Machine        | Mm               | 1507                   |
| Front Axle to Blade Cutting-Edge Arc  | Mm               | 2112                   |
| Length                                | Cm               | 468                    |
| Wheelbase                             | Cm               | 265                    |
| Weight                                | Kg               | 6351 kg                |
| Tire size                             | -                | Back 18.4R34, Front 18.4R34 |

Data collection technique and experimental design

Line transect space of 4.5 m wide and 100 m long were used to collect data of disturbed soils. The bulk density and porosity at slopes of different levels (less than 20% and greater than 20%) and different passes of 0, 1, 5, 10, and 15 in a completely randomized design with three replications to make a total of 24 plots. It was related to undisturbed areas and of no skidding influence, by 50 – 60 m from the skid trail, as in similar studies (Jaafari et al. 2014). Samples of soils at the depth of 0 –10 cm were gathered at three varied points sideways of a different transect, the right track (RT), the middle of the tracks (MT), and the left track (LT). Additionally, samples of soils at 10 locations were collected on different sides of the track at an interval of 0.5 m, covering the area of skid trails to undisturbed soils. The samples of soil were collected via a 50 mm high Eijkelkamp steel cylinders (72 mm
diameter), consequently, the samples of soils were free from grits and were put in labeled polyethylene bags. Samples of soils were also analyzed to determine the porosity and bulk density of soils using the bulk density core. Soils were compared before and after the study using a paired t-test. Soil porosity was calculated based on (Solgi and Najafi 2014) as;

\[
AP = \left(1 - \frac{Db}{2.65}\right) / VC
\]

Where:
- \(AP\) – soil porosity
- \(Db\) – soil bulk density
- 2.65 – assumed particle density
- \(VC\) – volume of the soil cores (502.4 cm\(^3\))

Volumes of soil cores were put into a 120 °C oven and dried for at least 48 hours. Bulk density was determined by dividing dry weight by the sample volume (Ezzati et al. 2012). The individual treatment was repeated five times.

Statistical analysis

The influence of the levels of traffic, trail slope, soil porosity, and bulk density plus the interaction of the number of passes and slopes were assessed using a two-way ANOVA which was analyzed with GenStat®. The significant differences of porosity and soil bulked density was among various treatments using Turkey’s test (\(p<0.05\)).

Results and discussion

Soil bulk density measured in the undisturbed area was 0.64 g cm\(^{-3}\) and 0.56 g cm\(^{-3}\) at slopes of less than 20% and greater than 20%, respectively. On the skid trail, soil bulk density significantly increased with traffic frequency (\(p<0.05\)), following previous studies (Labelle and Jaeger 2011). Most of the potential impact occurred after the initial passes, also confirming the results of Solgi and Najafi (2014).

In contrast, slope did not impact soil bulk density (Table 2). This result was different from that found in previous studies (Jaafari et al. 2016), but can likely be explained by the larger tire size of the (MB) Trac 1800 skidder, which can reduce the impact on soil bulk density on different slopes. The effect of the interaction of the number of passes and slope was not found to be significant (Table 2).

Additionally, the force lowers speed intensely and increases the disruption of soils on steep slope trails (Solgi and Najafi 2014). Previous studies by Solgi et al. (2015) have recognized wheel slips on farm trucks triggering compaction significantly as well as wheel slip from forest trucks can consequently add to compaction. Compaction can also be expressed as the increased bulk density, accordingly at the initial passes.

Bulk density increases and porosity decreases on steep slope trails and at different distances from the trail and this could be connected to the lesser speed of the skidder on steep slopes.

An earlier investigation has only evaluated the effects of skidder operations on soil proprieties
within the skid trail (Solgi and Najafi 2014; Naghdi et al. 2018). The researchers measured skidder impacts on soil properties beyond the left and right tracks. The researchers found out that the degree of soil bulk density at the right and left track or between tracks varied at different distances from the track. Indeed, the utmost bulk density of soil was perceived in the sample points along the main track as the researcher moved from the main track, bulk density decreased.

Soil porosity estimated in uninterrupted area was 59.10 and 57.40% at < 20% and > 20% slope, respectively. Soil porosity was significantly influenced via different skidder passes (p<0.05) however the slope did not influence soil porosity (Table 3). Specifically, soil porosity was considered lower in the undisturbed area on skidder trails. This could be due to the consequence of increased soil compaction leading to changes in soil porosity. Our findings showed that compaction led to the decrease in total porosity, probably owing to reduced macro-porosity that was sturdily decreased at > 20% slope in some treatments. This result was partially confirmed by Solgi and Najafi (2014). The collaboration between different skidder passes and the slope was significantly influenced (p>0.05) and the decrease of the soil porosity was further noticeable at > 20% slope (Table 3). At different treatment from the main track increased soil total porosity.

Table 2. Effect of slope and traffic intensity on soil bulk density (g cm⁻³)

| Statistic | Number of Passes (NP) | Slope (S) | Mean Number of Passes |
|-----------|-----------------------|-----------|-----------------------|
| NP 10.12*** | 0                     | < 20      | 0.64c                |
| S 0.119ns  | 1                     | >20       | 0.56c                |
| NPxS 0.61im | 5                      | < 20      | 0.83b                |
|            | 10                    | > 20      | 1.03ab               |
|            | 15                    |           | 1.32a                |
| Mean slope |                        |           | 0.74b                |

Capital letters indicate significant differences among row means. Small letters indicate significant differences among column means.

Table 3. Effect of slope and the traffic intensity on soil total porosity (%)

| Statistic | Number of Passes (NP) | Slope (S) | Mean Number of Passes |
|-----------|-----------------------|-----------|-----------------------|
| NP 54.21*** | 0                     | < 20      | 57.40a               |
| S 4.18ns   | 1                     | > 20      | 59.10b               |
| NPxS 6.76*** | 5                      | < 20      | 42.30b               |
|            | 10                    | > 20      | 49.11b               |
|            | 15                    |           | 41.28b               |
| Mean slope |                        |           | 42.42b               |

Capital letters indicate significant differences among row means. Small letters indicate significant differences among column means.

Conclusion

This study was carried out with the general aim of describing the effects of skidder passes and skid trail slope on the bulk density and porosity of the soil in Ghana. As compaction increased, the rates of total porosity decreased. In particular, the results pointed out that traffic intensity (number of machines passes) plays an important role in forest soil compaction: soil deformation can increase with the number of passes and may lead to excessive soil disturbance. One pass of the skidder is enough to cause ruts classified as medium-heavy disturbance and to induce a significant increase in soil bulk density. Conversely, the two different classes of slope did not show significant effects on soil bulk density and porosity. The impact of the skidder on soil physical proprieties was more noticeable under the main track (right and left track) or log track (between tracks) than at various distances from the track. Successful planning of skidding operations to minimize soil compaction will depend on knowledge of the distribution of soils in the area to be managed, coupled with knowledge on the response of each soil to compaction effort. There is the need to comprehend the connection concerning the soils in the forest and their proneness to soil disruption from harvesting equipment.

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