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Influence of vehicular traffic on air permeability and groundnut production in a semi-arid sandy loam soil

J.O. Ohu, E. Mamman and U.B. Muni*

Department of Agricultural and Environmental Resources Engineering, University of Maiduguri, Maiduguri, Nigeria

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A b s t r a c t. The effect of vehicular traffic on the production of groundnut (*Arachis hypogea*) was investigated in a sandy loam soil. A randomized complete block design with treatments of 0, 5, 10, 15 and 20 passes of a tractor with 31 kPa contact pressure was used. The gravimetric soil moisture content, soil dry bulk density, penetration resistance and air permeability for each applied load were measured from the soil surface up to a depth of 10 cm. Seed moisture content, haulms and seed yield were determined at harvest for each treatment.

Soil dry bulk density and penetration resistance increased with increase in the number of tractor passes while air permeability decreased with increase in the number of tractor passes. The haulms yield and seed yield increased with increase in the number of tractor passes up to 5 passes, and thereafter decreased with further increases in tractor passes. The soil physical properties and the product of the number of tractor passes and contact pressure were used to generate a groundnut yield model. The yield model that contained the interactions of the product of the number of tractor passes and contact pressure, penetration resistance and air permeability had the greatest influence on the yield of the crop. It can be concluded that in groundnut production in a sandy loam soil in a semi-arid environment, a moderate amount of soil compaction could improve the yield of groundnut.

K e y w o r d s: semi-arid, tillage, vehicular traffic, compaction, air permeability, groundnut.

INTRODUCTION

Although mechanization of agriculture has increased the efficiency of crop production, cumulative effect of vehicular traffic on agricultural soils has been observed by several researchers to cause soil compaction (Alblas *et al*., 1994; Carman, 2002). The physical properties of the soil affected by compaction that may have adverse effect on crop emergence, growth and consequently yields, include increased soil bulk density, soil strength, reduced infiltration, and reduced water movement within the root zone of plants (Lipiec *et al*., 1991; Lowery and Schuller, 1994; Mamman and Ohu, 1997). The degree of soil compaction depends upon the soil type, soil moisture content, the contact pressure and the number of repeated passes of agricultural vehicles (Håkansson and Reeder, 1994; Al-Adawi and Reeder, 1996; Wiermann *et al*., 1999). Soil compaction affects the physical, mechanical and hydraulic properties of the soil (Ohu *et al*., 1985; Shafiq *et al*., 1994; O'Sullivan and Simota, 1995; Carman, 2002). Compaction could lead to soil deterioration indirectly, by considerably reducing the water infiltration rate, thus increasing surface water runoff and soil erosion (Soane and Ouwerkerk, 1995).

Boone *et al*. (1994) reported dry matter yield of peas after heavy soil loading to be considerably reduced in a simulated wet growing season. The reduction was significantly greater on heavily loaded wet soil than on heavily loaded moderately wet soil. The reduction in crop yield was attributed to insufficient aeration. Lipiec and Stępniewski (1995) stated that soil compaction resulting from vehicular traffic or tillage systems could lead to soil deformation which will in turn affect nutrient transformations and uptake through changes in soil hydraulic, aeration and diffusive properties, as well as by its effect on root growth and configuration. Alakuku and Elonen (1995) determined the long-term effects of soil compaction by heavy traffic on crop growth in field experiments on a heavy clay (Vertic Cambisol) and an organic soil (Mollic Gleysol). It was reported that for several years after the loading, compaction decreased yields and nitrogen uptake of crops, and lowered seed moisture content at harvest.

*Corresponding author's e-mail: mamman2002ng@yahoo.com

Even though soil compaction is generally believed to have adverse effects on crops, some researchers have observed some beneficial effects of moderate soil compaction on crop production (Gupta, 1981; Gulati *et al*., 1985; Kayombo, 1989). Mamman and Ohu (1998) evaluated the performance and yield of millet in a compacted sandy loam soil. The highest head weight was obtained at 15 tractor passes while the least was in zero traffic. Regression equations developed, relating head weight to soil physical properties, showed that the number of passes, contact pressure and air permeability had the greatest effect on the crop. Ohu *et al*. (1991) obtained the highest yield of sorghum at 15 tractor passes while, 5 tractor passes gave the highest yield of groundnut, even though both experiments were conducted in the same sandy loam soil and the treatments were imposed at the same soil moisture content. The authors could not make conclusive statements on the effects of compaction on groundnut yield because air permeability, which is an important soil physical property in soil-plant-water interaction, was not determined.

Air permeability refers to the ability of a soil to allow air to pass through its horizon. Air permeability is an index of soil structure and therefore can provide a meaningful description of the state of soil compaction (Evans and Kirkham, 1949). Soil air has been recognized as a source of energy for soil microbial activities and crop development (Bowen *et al*., 1983). The knowledge of the extent of air availability in cropped field, which is linked to crop growth and development, is of particular importance in regions where large-scale agricultural production is practiced using tractors and implements. Therefore, the measurement of available air in agricultural soil is highly essential for the determination and amelioration of excessive compaction and water logging. The knowledge of the amount of air available to crops after different tillage practices will help farmers and researchers to plan effectively the tillage requirements for the production of a given crop. This is generally true in many developing nations, like Nigeria where tractors are mostly employed for land preparation in order to improve agricultural productivity. In Nigeria, studies on the effects of soil compaction on different food crops are limited. Studies available are so few that recommendations cannot be made to farmers in general terms on the care, correct choice and efficient use of machines for improved crop production.

In northern Nigeria, and especially in the semi-arid region, groundnut is one of the cash/food crops consumed by more than 85% of the populace. Unlike sorghum and millet, which is usually planted before weeds germinate, groundnut is always planted into a well-prepared seedbed. Seedbed preparation is usually done by hand hoe or animal and tractor drawn ploughs. The availability of commercial tractors made about 90% of commercial farmers in the region adopt tractors for seedbed preparation for seeding different crops. The farmers, however, have limited or no knowledge of the effects of vehicular traffic on the physical properties of the soils considered suitable for groundnut cultivation. The tractor operators also use the tillage implements indiscriminately, thus destroying the soil structure and consequently the productivity of the soil. Since tractorization is the mode of soil preparation mostly practiced in this region, understanding the effect of machinery traffic on the production of groundnut will help in improving its production.

The objective of this study was therefore to determine the effects of vehicular traffic on air permeability and groundnut production in a semi-arid sandy loam soil.

MATERIALS AND METHODS

The experiment was conducted on the Agricultural and Environmental Resources Engineering Research Farm of the University of Maiduguri (11°50’ N, 13°05’ E). The mean rainfall and temperature during the growing period of about three months (July-September) at this location was 170 mm and 30.6°C respectively. The soil is sandy loam and is classified as Typic Ustipsamment (Rayar, 1984). It is made up of 6% silt, 17% clay and 77% sand. At this location, reasonable amount of rainfall usually starts in the middle of July, but in 1998, rain started in the second week of June and by the first week of July the field was overgrown with weeds. This condition was contrary to the one encountered during the 1997 growing season. To avoid the cushioning effect of weeds during seedbed preparation (load application), the field was harrowed with an offset disc harrow attached to a Fiat Tractor (model 780) because it is the most common tractor used for tillage operations at the study area.

A 20-plot experiment consisting of five treatments and four replicates was set up using a randomized complete block design. The plot size used was 10 m x 10 m with 4 m spacing between adjacent plots. The treatments were applied on 10th July, 1998. The treatments applied were 0, 5, 10, 15 and 20 passes of a tractor which had a tyre contact pressure of 31 kPa (the ratio of load to contact area). The use of 31.0 kPa contact pressure was to avoid changes in the pore system below normal tillage depth (Eriksson *et al*., 1974; Håkansson and Danfors, 1981). Ohu *et al*. (1991) and Mamman and Ohu (1997) also used 31 kPa contact pressure for groundnut and millet experiments, respectively. The compaction was done at average soil moisture content of 8.3% on dry basis. This is the moisture content at which the soil deformation is minimum and is less than the Proctor optimum compaction moisture content for the soil, which is 12.5% on dry basis (Ohu and Folorunso, 1989). After the treatment application, groundnut (*Arachis hypogea*) was planted manually (by hoe) on 12th July, 1998, by placing two seeds per hole (2-3 cm depth) at 25 cm intervals along the row, having 33 rows spaced 30 cm apart within a plot. Basal fertilizer application of mono super phosphate of 60 kg ha^{-1} was applied to each plot immediately after planting.

The plots were weeded manually (with hoe) throughout the growth period. The soil physical properties measured at different growth stages of the crop included air permeability, moisture content, dry bulk density and penetration resistance. Air permeability was measured because aeration was considered very important for groundnut germination and growth. The air permeameter used was designed, constructed and calibrated by Ohu *et al*. (1994) following the air permeameter of Grover (1955). The core sampler method was used to measure dry bulk density (Blake and Hartge, 1986). Penetration resistance readings (20 cm depth) were obtained using a hand pushed cone penetrometer following the American Society of Agricultural Engineers (1982) standard procedure. The penetrometer had a cone base diameter of 15 mm and cone angle of 30° and was operated at a penetration speed of about 1829 mm min^{-1}. Soil moisture content was determined using the method described by Gardner (1986). Haulms and seed yields, and seed moisture content were measured at harvest. The soil physical properties and crop parameters were subjected to statistical analysis. The mean values of the soil and crop parameters were used for analyses to generate a growth prediction equation for the crop.

RESULTS AND DISCUSSION

Soil bulk density

The relationship between compaction levels and soil bulk density is presented in Fig. 1. For all moisture levels, soil bulk density increased with increases in treatment levels. Soil bulk density increased with increase in moisture content up to a point and then decreased with further increases in soil moisture content. Soil moisture content of 11% recorded the highest values of soil bulk density, while 13% soil moisture content gave the least. The increases in soil bulk density with increase in treatment levels was attributed to the packing together of soil particles, thus increasing cohesion and reducing the pore space of the sandy loam soil. The decrease in soil bulk density with further increases in soil moisture content could be attributed to increase in pore water pres- sures which made the soil less compactable. This result was similar to that reported by Ohu and Folorunso (1989) who stated that changes in soil bulk density is a function of both the compactive effort and the water content of the soils.

Penetration resistance

Figure 2 shows the relationship between compaction levels and penetration resistance. For all levels of soil moisture content, penetration resistance increased with increase in compaction level. For each level of compaction, penetration resistance decreased with increases in soil moisture content. The maximum penetration resistance was obtained at the lowest moisture content level, which was 8% on dry basis. This was because at the lowest moisture content level the cohesive forces of soil particles were greater than at the highest moisture content level and therefore more resisting forces were developed by the soil particles. Like bulk density results, higher penetration resistance values were obtained with increases in compaction level. Higher compaction increased soil cohesion, hence the more energy needed for the probe to penetrate into the soil.

Air permeability

For all levels of soil moisture content, air permeability decreased with increase in treatment levels (Fig. 3). For each compaction level, air permeability decreased with increase in soil moisture content. The decrease in air permeability with increase in compaction level was more drastic between zero and 5 tractor passes than between other treatment

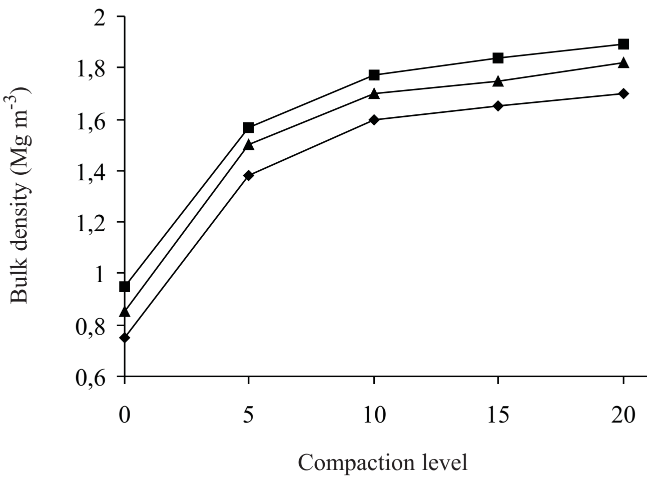

Fig. 1. Variation of soil bulk density with compaction level (passes of a tractor) at different soil moisture content (◆ 8%, ▲ 11%, ■ 13%).

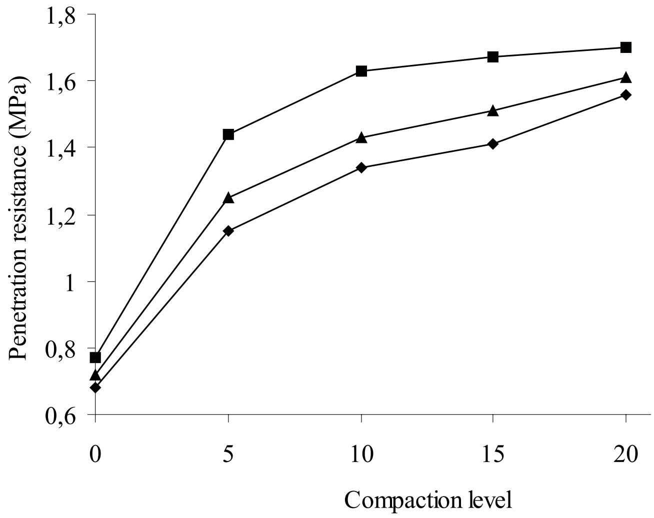

Fig. 2. Variation of penetration resistance with compaction level (passes of a tractor) at different soil moisture contents. Explanations as in Fig. 1.

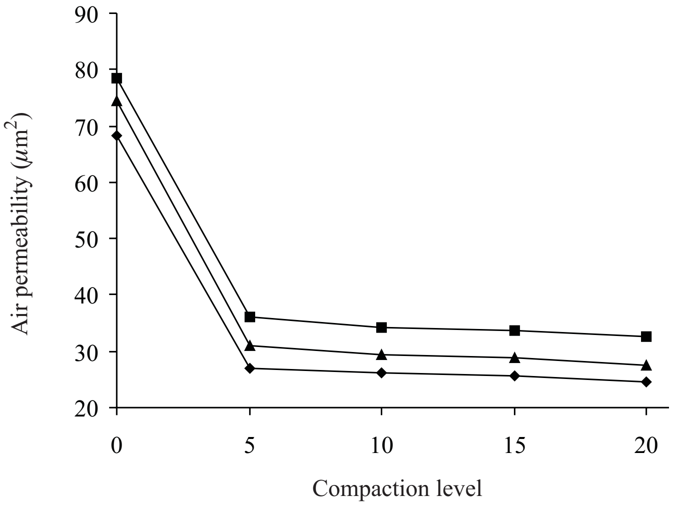

Fig. 3. Variation of air permeability with compaction level (passes of a tractor) at different soil moisture contents. Explanations as in Fig. 1.

levels. The decrease in air permeability with increase in traffic intensity could be attributed to the adverse effect of compaction on the sandy loam soil which resulted in decreased pore spaces and consequently restricted free flow of air in the soil. The decrease in air permeability with increase in moisture could be due to the filling of the soil pores with water, which restricted air movement in the soil.

Seed moisture

Figure 4 presents the relationship between compaction level and seed moisture. Seed moisture increased with increase in traffic intensity. The seed moisture varied from 1.48% at zero tractor traffic to a maximum of 1.79% at 20 passes. The increase in seed moisture was more pronounced between 15 and 20 tractor passes. The steady increase in seed moisture with compaction level could be explained by the fact that at 15 and 20 passes of the tractor more moisture was trapped in the soil, which could neither percolate nor evaporate. The roots of the crop in these treatments did not go deep because of the high density of the soil. More water was therefore stored in the stem, which eventually translocated into the seeds.

Haulms yield

The variation of haulms yield with compaction levels is shown in Fig. 5. Haulms yield varied from 2640 kg ha^{-1} at zero traffic to a maximum of 3760 kg h^{-1} at 5 tractor passes and then decreased with further increases in tractor passes. The maximum yield obtained at 5 passes could be due to more available water in the soil to the crop and the difficulty of roots going deeper into the soil at higher compaction levels (Ohu *et al*., 1994).

Seed yield

Figure 6 shows the relationship between seed yield and compaction level. The seed yield varied from 37680 kg ha^{-1} at zero traffic to a maximum of 41120 kg ha^{-1} at 5 tractor passes, and thereafter decreased. The 5 tractor passes, which gave the highest yield, was considered to be suitable for groundnut production in a sandy loam soil. The decrease in the yield parameters with further increase in compaction level may be due to little movement of water and nutrients required by the crop for its growth. From the yield and yield parameters of groundnut obtained in this study, it appears that moderate compaction is needed for the production of the crop in a sandy loam soil. Ohu and Folorunso (1989), and Mamman and Ohu (1998) also reported similar findings for some other crops grown in the region. However, the number of tractor passes that produced the highest yield of the crop considered by the authors varied from one crop to the other and it was only groundnut that had the highest yield at 5 tractor passes.

Growth prediction model

Different prediction models were tried to relate soil bulk density, penetration resistance, traffic intensity and air permeability to yield of groundnuts. Regression equations were used to obtain the relationships as follows:

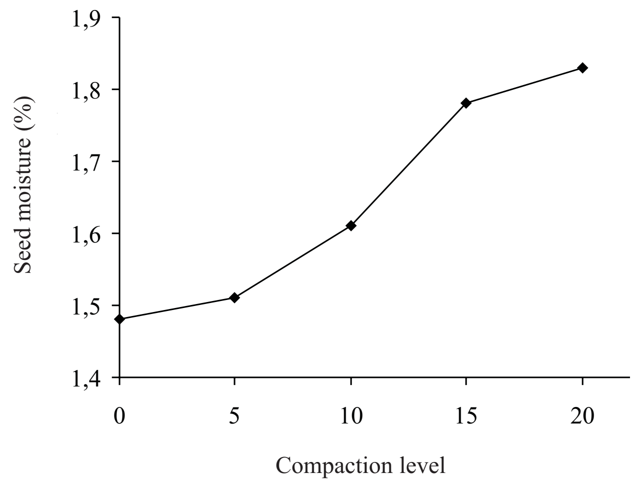

Fig. 4. Variation of seed moisture with compaction level (passes of a tractor).

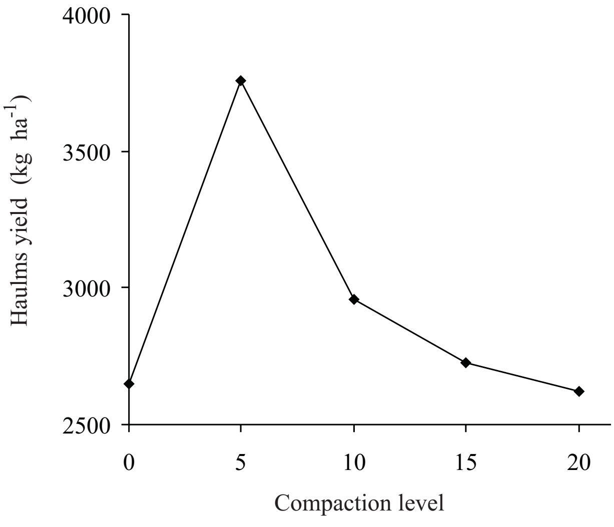

Fig. 5. Variation of haulms yield with compaction level (passes of a tractor).

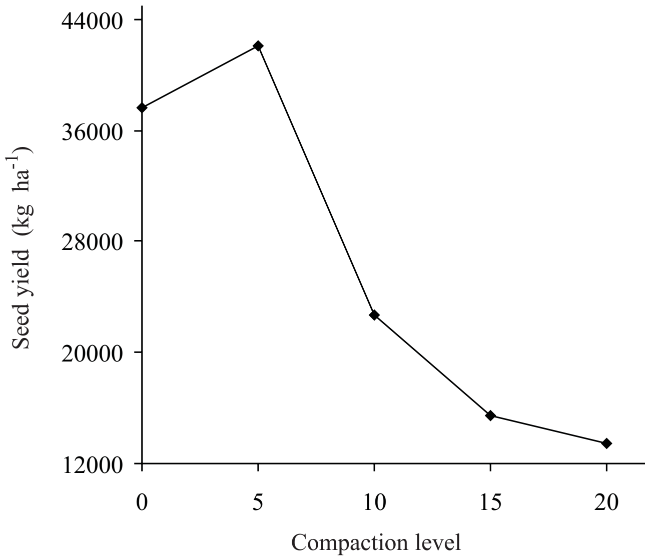

Fig. 6. Variation of seed yield with compaction level (passes of a tractor).

$$G_{sw} = 7778.6 - 2101.6\ P_r - 91.622\ A_p \quad (1)$$

$$(R^2 = 67\%),$$

$$G_{sw} = 7059.35 - 1757.75\ B_d - 78.65\ A_p \quad (2)$$

$$(R^2 = 79\%),$$

$$G_{sw} = 3126.77 - 25.58\ (nP) - 25.33\ A_p \quad (3)$$

$$(R^2 = 93\%),$$

$$G_{sw} = 5875.28 + 1946.67\ P_r - 3181.66 B_d - 59.09\ A_p \quad (4)$$

$$(R^2 = 83\%),$$

$$G_{sw} = 5040.77 - 13.24\ (nP) - 845.53\ B_d - 51.52\ A_p \quad (5)$$

$$(R^2 = 97\%),$$

$$G_{sw} = 5209.06 - 15.56\ (nP) - 915.87\ P_r - 55.5\ A_p \quad (6)$$

$$(R^2 = 99\%),$$

where: G_{sw} – groundnut seed weight (kg ha^{-1}), B_d – bulk density (Mg m^{-3}), P_r – penetration resistance (MPa), A_p – air permeability (μm^2), nP – product of the number of tractor passes and contact pressure. Equation (6) gave the highest coefficient of determination (R^2 = 99%). The equation shows that the product of the number of tractor passes and contact pressure, penetration resistance and air permeability best described the yield of groundnut in this compact soil. The interaction among the three soil physical parameters considered gave a higher correlation than the one described by Ohu *et al.* (1991) when groundnut yield was not correlated with the number of tractor passes and air permeability. This implies that, for groundnut production, the ability of the roots to penetrate the soil for moisture and nutrient absorption is more important than how densely the soil is packed. It is therefore evident that in a growth experiment, air permeability is an important parameter that affects yield. This reveals that to achieve maximum yield, this sandy loam soil needs a moderate level of compaction. It has also shown that the choice of tractor, tyre size and traffic intensity should depend on soil and the type of crop to be planted.

CONCLUSIONS

1. In the investigated sandy loam soil, groundnut yield was affected by the soil physical properties and the number of tractor passes considered. Five tractor passes gave the highest values of the yield parameters.

2. This implies that in groundnut production in a sandy loam soil, a moderate amount of soil compaction is needed for optimum yield.

3. The study confirms that in a growth experiment air permeability is an important parameter in describing the yield of groundnut.

4. The importance of air permeability for the growth and yield of other crops apart from grains needs to be verified. This will definitely help in the choice of the right machine and equipment for obtaining maximum yield of crops grown in the light soils in the region.

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