

EFFECT OF TRACTOR FORWARD SPEED ON SANDY LOAM SOIL PHYSICAL CONDITIONS DURING TILLAGE

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ABSTRACT

Field studies were conducted at the National Centre for Agricultural Mechanization (NCAM), Ilorin on a sandy loam soil to evaluate the effect of the imposition of different levels of tractor forward speed during tillage on some soil physical properties. The forward speed was varied from 1.0 to 10.6km/h: The depth of tillage was maintained constant at 20cm throughout the operations. The soil physical parameters measured were cone penetration resistance (cone index CI), shear strength (SS), bulk density (BD), moisture content (MC), and clod mean weight diameter (MWD).

Results indicate significant differences in soil physical conditions arising from different levels of tractor forward speed. A forward speed of approximately 7km/h resulted in appreciable amelioration of soil structure as reflected in improvements in the soil strength properties and maximum reduction in clod mean weight diameter. Soil strength properties generally decreased with increasing speed but increased with depth of tillage. A predictive model depicting the most vital soil physical parameters affected by tractor speed was developed

Keywords: Forward speed; soil physical conditions; tillage.

INTRODUCTION

Soil physical properties of greatest importance to crop growth and development include water, strength and porosity characteristics, and aeration and temperature regimes. Because of the interactive relationship among the various soil physical properties, a change in one may affect the others. More importantly, these properties are influenced largely by the structural characteristics of the soil in question. Thus, in this respect, the size distribution of the aggregates represented by the mean weight diameter (M.W.D.) of the clods is a very important structural index used in evaluating soil physical condition. Research has shown that aggregate stability is significantly correlated with crop yields when other conditions are equal (Singh, 1982). Furthermore, considering the fact that soil physical parameters are responsible for the ability of the aggregates to maintain a high permeability to water, air and to plant roots and determines the soil's susceptibility to erosion, it becomes necessary to investigate the effect of different operating conditions on soil physical properties.

Several research efforts aimed at quantifying the effects of speed of tillage operation were mainly centred on draft (Singh et al., 1979; Bukhari et al., 1988; Thakur et al., 1988; Shirin et al., 1993 and Ahaneku et al., 2004). Though the work by Thakur et al. (1988) on speed effects on soil physical properties were limited to the bulk density and mean weight diameter, their results showed that speed had significant positive influence on these soil properties.

In Nigeria, similar studies on tillage effect on soil strength properties have been carried out (Oni and Adeoti, 1986; Ojeniyi, 1989; Onwualu and Anazodo, 1989; Anazodo et al., 1991 Ahaneku, 1997 and Ahaneku and Sangodoyin, 2003). Despite the enormity of these studies, limited research information exist in the country on the effect of tractor speed on soil physical conditions.

This study was therefore undertaken to determine the changes in soil physical conditions arising from different tractor speeds during tillage with a view to recommending appropriate speeds for tillage operation of a given soil.

MATERIALS AND METHODS

Experimental Site

The experiment was conducted during the wet season of 1998 at the research farm of the National Centre for Agricultural Mechanization (NCAM), Ilorin ($8^{\circ} 26^1\text{N}, 4^{\circ} 30^1\text{E}$). Ilorin lies within the Southern Guinea Savannah agro-ecological zone of Nigeria (Kowal and Knabe, 1972) and is characterized by a tropical climate with distinct wet and dry seasons and mean annual rainfall of about 1000mm. The soil is deep, porous and darkish brown. It is classified as Typic Haplustalf (Soil Taxonomy, 1975) of Eruwa, and Odo-Owa (Kwara State) series. Mechanical analysis of the top 100cm of the soil showed 22.09, 6.14 and 71.77% clay, silt and sand, respectively indicating a sandy loam texture (Ahaneku, 1997).

Implement Description

The implement used is a mouldboard plough cum clod breaker. It is a 2-furrow mounted implement hitched to the 3 point linkage of a 52kW (70hp) Fiat tractor. The clod breaker is powered by the Power Take-off (P.T.O.) of the tractor. The implement has a vertical clearance of 68cm and width of cut of 90cm. It is equipped with a gear, belt and pulley systems which transmits the vertical rotational motion of the PTO to a horizontal rotational motion of the clod breaker. The plough share width is 58.3cm. The clod breaker consists of three rigid rods with five blades on each rod. The length of each rod is 38cm and has a centre distance of 9cm between blades. The effective cutting width of the blade is 10.5cm. The rigid rods are arranged in an inverted cone shape with included angle of 23° .

Field and Laboratory Measurements

A land area measuring 100m x 50m was used for the experiment. Measurements were made to determine the effect of different levels of tractor forward speed on soil physical conditions. In order to assess the changes arising from the treatment, initial soil conditions were defined by sampling the experimental area randomly to determine the average bulk density, porosity, shear strength,

cone index and mean-weight-diameter of the soil. The soil moisture content was also determined from these samples. After each speed level, samples were collected for analysis in order to define the final states of the soil parameters in relation to the initial conditions. All field experiments were completed within 1 day to minimize the effects of variations in soil moisture. Cone index was determined in the field with the aid of a hand held penetrometer of 3.2cm^2 cross-sectional area with a cone tip having an included angle of 30° . Scale deflections were recorded at 5cm, 10cm and 15cm depth. Five replicates were taken for each speed run. The shear strength for each forward speed was measured with a shear vane at 10cm depth with 4 replications. The bulk density samples were collected at 7cm depth intervals up to 21cm using a 5.6cm diameter and 8.3cm high metal cylinder. Total porosity was evaluated using the relationship between bulk density and particle density. The soil moisture content at the various depths were determined gravimetrically using the samples for the bulk density measurements.

Travel reduction (wheel slip) was assessed by measuring a constant distance of 50m from the plot demarcated with ranging poles. The time taken for the tractor drive wheel marked with chalk to traverse the distance on no-load and on load was recorded. The travel reduction was computed using the following relation:

$$T_R(\%) = \frac{S_1 - S_2}{S_1} \times 100(1)$$

Where

T_R	=	Travel reduction
S_1	=	Operating speed on no-load
S_2	=	Operating speed on load

The clod mean weight diameter (MWD) of the soil was determined after each operating speed. The clod and pulverized soil were collected up to the depth of cut and mixed. From this, a composite sample was taken and air-dried in the laboratory. Subsequently, a sieve analyses was performed with an Endocott sieve shaker for 10 minutes using 2.36, 0.60, 0.425, 0.30 and 0.25mm size sieves. The weight of the soil retained on each sieve was recorded to determine the clod MWD of the soil aggregates, using the relationship:

$$MWD = \frac{\sum_{i=1}^n w_i d_i}{W} \quad (2)$$

Where

MWD = mean-weight- diameter of soil aggregates,
 W_i = weight of soil samples retained over the i^{th} sieve, g
 d_i = class of mean size for i^{th} sieve, and
 W = total weight of soil sample, g.

All data generated from the various soil parameters were subjected to regression analysis (step-wise) to assess the degree of their relationship with the various imposed speed

RESULTS AND DISCUSSION

Effect of Tractor Speed on Bulk Density

Dry bulk density of the soil at different depths for different levels of speed designated as S_1 , S_2 , S_3 , S_4 and S_5 for 1.0, 1.3, 6.8, 8.8 and 10.6km/h, respectively are shown in Fig. 1. Dry density generally increased with depth but decreased with speed of tillage operation within the 15cm top layer. Thereafter, increased speed did not have much impact on bulk density reduction. This is attributable to the fact that at higher speeds of operation, the tractor tractive efficiency became very low leading to skidding. The ultimate effect was the pulverization of the soil top layer by the tillage tool while compacting the lower horizons. These results generally agree with earlier findings elsewhere under varying soil conditions (Soane et al., 1981; Thakur et al., 1988 and Rautaray et al., 1997).

Effect of Speed on Soil Moisture Content and Porosity

The effect of speed on soil moisture content is given in Table 1. There was no definite trend of moisture variation with speed. This may be attributed to the fact that all measurements were taken the same day within the same weather condition.

Porosity measured immediately after tillage at different speeds of operation increased with speed even though the increases were not

significant (Table 1). The improvement in porosity with speed indicate a positive condition for the flow of air and water through the soil profile and minimum resistance to root growth and proliferation.

Effect of Speed on Cone Penetration Resistance

Cone index generally increased with soil depth and the speed of operation but was consistently higher for the upper speeds of 8.8 and 10.6km/h (Fig. 2). Figure 2 shows that mould board ploughing with clod breaker attachment seem to have the greatest potential for relieving soil compaction only within the top 10cm depth of the soil. Beyond this critical depth, speed had no influence whatsoever in alleviating mechanical impedance with the implement. Therefore, crops with root zones beyond 10cm depth will encounter problem with extracting nutrients beyond this soil depth. However, within this critical depth, speed S_3 (6.8km/h) gave the least resistance to penetration. As the maximum depth of cut (20cm) was approached, the differences in cone index between the various levels of speed was not significant. This situation resulted in a compartmented soil structure within the tilled profile, with a loose upper layer and a dense lower layer. Such soil profiles have been reported to have negative impacts to root growth and development (Negi; et al., 1980, and Anazodo et al., 1991). In addition, increased soil cutting forces and energy will be required to alleviate the strength of the densified layer (McKyes, 1985).

Effect of Speed on Clod MWD

The variation in clod MWD with respect to different speeds of operation is presented in Table 1. The regression analysis performed on clod MWD as affected by tool speed showed a highly significant correlation ($P < 0.05$) with R^2 of 0.97 and coefficient of variation (CV) of 11 %. These results were not unexpected as an earlier work have shown that an increase in tool speed can have an effect on MWD (McKyes, 1985). Maximum clod size reduction was obtained for speed range of 6.8 to 8.0km/h with an average value of about 7.0km/h.

Conversely, a greater degree of shearing and shattering of soil clods was obtained with

increase in speed due to larger impact force giving rise to reduced clod size. At the upper speed range of 8.8 to 10.6km/h, the tractor was skidding due to negative travel reduction with consequent low tractive efficiency. The fallout of this phenomenon was the over-pulverization of the top soil profile which resulted in very low values of clod MWD. These results corroborates the findings of Thakur et al (1988) at low and medium speeds but is at variance with their observation at the upper speed range. This may be due to the soil type being investigated (sandy loam) unlike the silty- clay-loam upon which they experimented. Thus, it could be asserted that the structural aggregates of agricultural soils can be modified by the speed of the operating tillage tool. This assertion is substantiated by the over 57% decrease of MWD from its initial state.

Effect of Speed on Shear Strength

The variations in shear strength with different speeds of tillage are presented in Table 1. Results indicate that the shear strength of the soil increased with increases in speed of the operating tool. The reverse was the case for reduced speed of operation. The observed trend may well confirm earlier reports (McKyes, 1985) that aggregates of low inherent cohesion such as the one investigated (sandy loam) may crumble even further when they fall against the furrow bottom or previously deposited material, resulting in low shear strength after tillage. On the other hand, the soil tends to flow over the operating tool at high speeds, virtually retaining its initial strength properties (Table 1). Regression analysis showed that shear strength had a significant correlation with speed of operation ($R= 0.76$). Since this strength property can affect the rate at which plant roots can grow and the flow and availability of water and nutrients for their use, it appears that medium range speeds of 5 to 7km/h should be appropriate for this soil.

Effect of Speed on Travel Reduction

Travel reduction or wheel slip is one of the major parameters affecting the tractive efficiency of a pulling machine. Figure 3 shows the relationship between speed and travel reduction. The regression analysis

performed, show a highly significant ($R^2 = 0.99$) but negative linear correlation between speed and travel reduction. Travel reduction was high at low speeds but decreased with increase in speed. The high value of travel reduction recorded at low speed of operation may be due to deeper penetration of the mould board plough at lower speeds. This is in accord with the observations of Bukhari et al. (1988). However, at the upper speed range of 8.8 to 10.6km/h, negative wheel slip resulted due to skidding of the tractor at very high speeds. From Figure 3, it can be seen that for sandy loam soils, the maximum speed to avoid skidding is about 7.0km/h.

Predictive Equation for the Effect of Speed on Soil Physical Conditions

A step-wise regression analysis was performed to detect the major soil physical parameters affected by speed. The result showed that travel reduction, shear strength and clod mean-weight diameter are the parameters having the greatest correlation with speed. The predictive equation developed using the experimental data generated is of the form:

$$S = 9.20.1TR - 3.3ST - 0.3MWD \quad (3)$$

$$R^2 = 0.99$$

Where

S = Forward speed of tillage

TR = travel Reduction

ST = Shear strength of soil, and

MWD = Mean weight diameter of soil clod.

The predictive model is valid for the test conditions used in this study, but may be applicable to other locations with similar soil type.

The model shows that an increase in travel reduction, shear-strength and clod mean weight diameter will result in a reduction in the forward speed of tillage. Conversely, a decrease in these parameters will give rise to an increase in speed. From equation (3), it follows that when a negative travel reduction occurs, the resultant speed will be too high as to cause the skidding of the tractor. Therefore, for good tractability, the values of the model parameters should be such that S must not exceed 9km/h. This value falls within the

speed range for mouldboard ploughs (Hunt, 1977), thus indicating the reliability of the predictive model. At low speeds, assuming that other parameters are constant, the shear strength will be high. It implies that at low speeds, the tillage tool further compacts the soil rather than pulverizing it. This may lead to difficult traction for the pulling machine and great mechanical impedance to root penetration.

CONCLUSIONS

Based on the results obtained in this study, the following conclusions can be drawn:

1. No definite patterns of moisture variation exist with increases in tractor speed when conducted within a limited time frame under the same climatic condition.
2. The maximum reduction in clod MWD without negative travel reduction was obtained at a speed of 6.8 km/h.
3. Soil strength properties generally decrease with increases in speed of operation.
4. A highly significant linear but negative relationship exists between speed and travel reduction.
5. The operating speed for a given soil and tillage tool can be predicted in order to minimize soil degradation.
6. For a sandy loam soil, an average speed of 7.0 km/h is recommended when using a mouldboard plough.

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Table 1: effect of speed of operation on soil of properties

Speed (km/hr)	Shear strength* (MPa)	MWD (mm)	Moisture Content % (db)	Porosity (%)
1.0	0.03	1.77	9.23	43
1.3	0.02	1.73	11.47	42
6.8	0.03	1.38	9.73	45
8.8	0.5	1.06	10.99	40
10.6	0.5	1.02	10.37	44
Initial soil Condition	0.05	1.75	9.55	37

*Each data is the mean of five replications

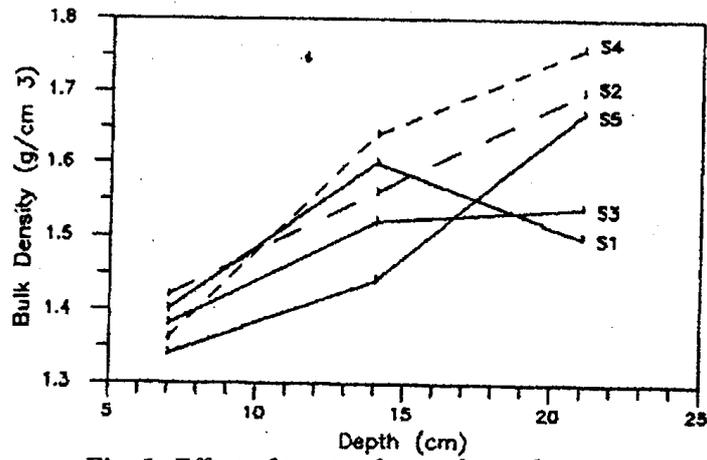


Fig. 1: Effect of tractor forward speed on soil bulk density with depth.

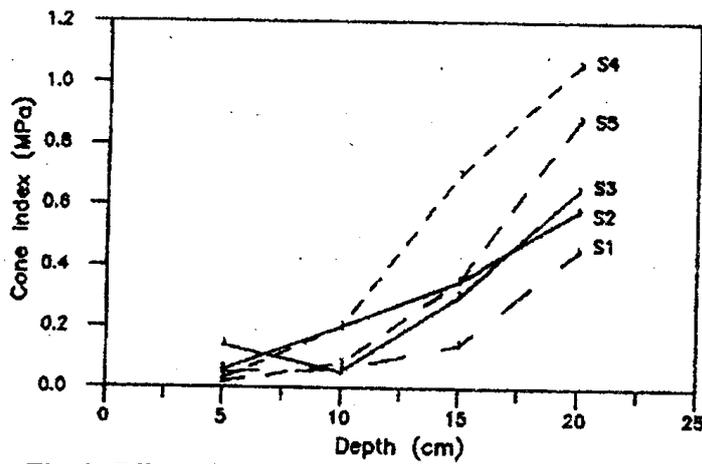


Fig. 2: Effect of tractor forward speed on cone index with depth

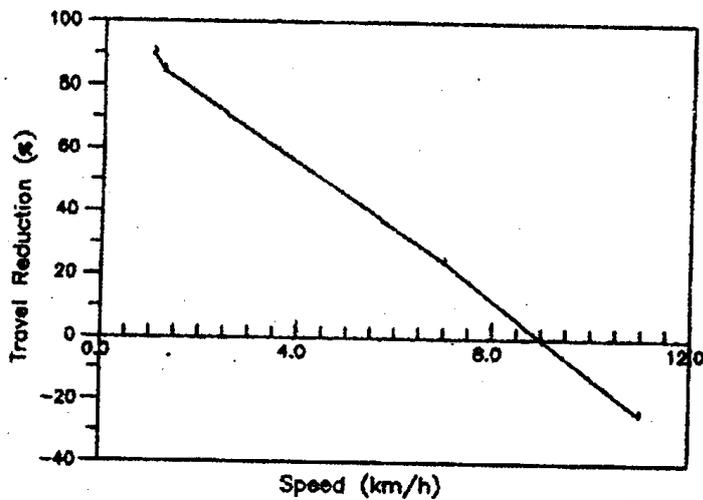


Fig.3: Effect of tractor forward speed on travel reduction