Arid Zone Journal of Engineering, Technology and Environment. October, 2007; Vol.5, 13-25

Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
www.azojete.com.ng

A CRITICAL EXAMINATION OF MAIZE YIELD RESPONSE TO TILLAGE, TRAFFIC AND SOIL TEMPERATURE ON A FERRUGINOUS SOIL (HAPLUSTALF)

Yusuf, D.D.[1]

Abstract

Compaction of agricultural soils due to multiple passes of heavy power units has been the subject of much concern, in recent years. This paper, through a 3-year on-farm experiment, studied and discussed the resulting effects of tillage, traffic compaction and soil temperature on maize yield. Results showed that soil resistance to cone penetration and crop yield changed rapidly during the period of study and could be related to soil moisture content and tillage. As maize extracts soil moisture, differential soil strengths and crop yields were obtained between shallow and deep tilled plots. Soil temperatures were lower in shallow (15.0 xm) tilled plots than in deep (30.00cm) tilled plots and high soil temperature enhanced maize grain yield. The most rapid seedling emergence and highest crop yield were obtained in soil temperatures that averaged 30^0C at seedling level and within the top soil of 0-15cm zone. Increase in soil resistance to cone penetration reduced maize grain yield. Tillage treatment significantly affected ($P \leq 0.05$) soil temperature, plant height and maize grain yield.

1. Introduction

In Nigeria, technological development in agricultural sector together with economic pressure to reduce production costs and increase crop production for the growing population make it imperative that more vehicles are used on the farm. The unknown traffic set up by these vehicles has been shown to cause soil compaction (Brannack and Dexter, 1979; Soane *et al*., 1981; Spoor, 1982; Wolf and Hadas, 1984). Soil compaction which is also a measure of soil particle bonding and matrix properties have caused reduction in seed germination, retarded root development and reduced crop yields for many soil types and conditions (Soane *et al*., 1982; Soane and van Ouwerkerk, 1994). Modern farming system is a continuing cycle between soil compaction caused by wheel traffic and reduction of this compaction through appropriate tillage. Soil physical investigations and studies on crop yield suggested that crop yields were improved when appropriate tillage was practiced (Rydberg, 1986; Ryderg and Ockerman, 1987; Dexter, 1988; Hakansson *et al*., 1988; Kay, 1990; Domzal and Hodora, 1991; 1992; Domzai *et al*., 1993).

Each implement pass causes a reduction of the mean aggregate size, and weakens the internal structural bonds (Chanclellor *et al*., 1969). Intensive cultivation affects soil aggregate stability with deleterious effect on soil physical properties and subsequent crust formation. These modifications of soil physical properties have a direct effect on soil temperature. Soil temperature models have been used to help predict soil temperatures resulting from different tillage operations (Cruse *et al*., 1989; Gupta *et al*., 1981; 1982). Walker (1969) and Barlow *et al*. (1977) showed that 1^0C change in soil temperature can significantly affect corn growth rates. The objective of this research was to examine the effects of tillage, traffic, compaction and soil temperature on maize yield at the Institute for Agricultural Research Farm.

[1]Department of Agricultural Engineering, Ahmadu Bello University, Zaria. Nigeria

2. Theory

2.1 Soil temperature

Change in soil temperature with time can be expressed as:

$$\delta T / \delta t = k'(\delta T / \delta z^2) \text{ (van Wijik, 1963)} \quad (1)$$

where *k'* is the soil thermal diffusivity, *T* is temperature, *t* is time and *z* is soil depth.

According to van Wijik (1963), one –dimensional soil temperature changes in a homogeneous soil is:

$$T(z,t) = \overline{T} + A_0 e^{-z/D} Sin[\omega t + (\phi_0{}^{-z/D})] \quad (2)$$

where *D* is the damping length. $\overline{T}$ is the average temperature, ω is the radial frequency, A_0 is the surface temperature and ϕ_0 is the phase constant.

2.2 Tillage

Deviations of tillage means (over two plots) from their overall (cropped) mean tillage or mean soil moisture content are defined as relative tillage effects that is expressed as:

$$RTE_{ij} = \overline{x}_{ij} - \overline{x}_{l} \text{ (Radke } et\ al.\text{, 1985)} \quad (3)$$

where RTE_{ij} is the relative effect of tillage, x_i is the mean overall tillage and replications for cropping treatments, i, and x_{ij} is the mean over replications with tillage, j, for cropping treatments, i.

2.3 Soil resistance to penetrometer

The resistance to the penetrometer probe (*Qp*) can be calculated in terms of stress normal to the probe surface (σ), the coefficient of soil – metal friction (μ), the adhesion (*Ca*) and the cone semi-angle (α) as:

$$Qp = \sigma(1 + \mu' Cot\alpha) + CaCot\alpha \text{ (Bengough, 1992)} \quad (4)$$

The adhesion term is simply frictional resistance that is due to the load at the soil-metal interface caused by the soil-water suction. Hence, σ represents the resistance to a 'frictionless' probe (i.e. setting μ and *Ca* to zero in Eqnuation 4).

In Nigeria, the effects of soil penetration resistance on crop yields caused by wheel traffic have been studied by various researchers (Oni *et al*., 1982; Kayombo and Lal, 1986; Ojeniyi, 1986; Ohu and Folorunsho, 1989; Onwualu and Anazodo, 1989; Yusuf, 1996; Yusuf and Asota, 1998; Yusuf, 2001). Ohu and Folorunsho (1989) reported higher bulk density and soil resistance to cone penetrometer pressure with increase in the number of tractor passes. Onwualu and Anazodo (1989), Yusuf (1996) and Yusuf (2001) showed that soil moisture content and porosity decreased with increase in soil penetration resistance. The use of appropriate tillage system and the development of tillage machinery are input thrusts for effective crop production in Nigeria.

3. Materials and methods

3.1 Experimental Treatments

The experiments were conducted at Samaru ($11^0 11^1$N, $07^0 338^{'}$E and 685m above sea level) in Kaduna State, Nigeria. The soil is classified as Ultic Haplustalf (Valette and Ibanga, 1984). It is a reddish-brown soil with an average pH-KCl of 5.5 and 0.6%, w/w of organic carbon. The experimental site was at the Institute for Agricultural Research Farm, Ahmadu Bello University, Zaria. The tillage treatments were; arara ploughing followed by ziz-zag harrowing and arara ridging (*T1*), emcot ploughing followed by ziz-zag harrowing and emcot ridging (*T2*), mouldboard ploughing followed by disc harrowing and mouldboard ridging (*T3*), disc ploughing followed by disc harrowing and disc ridging (*T4*) and manual ridging (*T5*). The nitrogen treatments were: No nitrogen (*No*), 40kg Nha^{-1} (*N1*), 80kg Nha^{-1} (*N2*), and 120 kg Nha^{-1} (*N3*). The nitrogen application was done uniformly after the tillage treatments with a drop-type broadcaster that has spaced openings along the full length of a hopper. Two planting methods, manual and mechanical were used. Manual planting involves dropping seeds into holes made with heels, covering the seeds with soil and compacting the soil surrounding the seeds with the heels. The mechanical planting involves the use of a single-row animals-drawn planter. Tillage was done at an average soil gravimetric water content of 0.257 kg/kg (the water content at the time of tillage). They were sown with maize (Zea maiys L.) of TZSR-W crop variety at the rate of 25 $kgha^{-1}$. The crop row spacing, hill spacing and depth of seed placement were 75cm, 25cm and 3cm, respectively.

The treatments were randomly assigned in a 4 x 5 x 2 factorial experiment arranged in a strip-split-plot design with five tillage treatments (*T1, T2, T3, T4* and *T5*) as horizontal treatments, four nitrogen rates (*N0, N1, N2 and N3*) as vertical treatments and two planting methods (*P1* and *P2*) as sub-plot treatments in four replications. Each plot size was 4m x 5m and the experiment was conducted from 1997 to 1999.

3.2 Measurements

Soil temperature readings were taken from Cu-constant thermocouple recorded by a Campbell Scientific CR5 digital recorder equipped with an S250 relay scanner. Installations were at five different locations per plot each year along the sown line. Readings were taken twice per day (at 08.00h and 16.00h) throughout the growing season from 1997 to 1999. Two depths (0-15 cm and 15-30 cm) were used for soil temperature and the thermocouple was inserted into the ground close to the tip of developing plants.

The mean plant height in each plot was measured weekly from 2 to 12 weeks after planting, using the method described by Tisdall and Adam (1986). Rainfall intensity and air temperature measurements were available from the Institute for Agricultural Research, Ahmadu Bello University, Zaria weather station, which is approximately 200m away. Soil penetration resistances were measured with cone penetrometer (ASAE, 1976) at 10 locations on each plot and the mean for each plot was used. Soil moisture content was determined gravimetrically after drying at 105^0C for 24 h. The data were analysed using regression and analysis of variance (ANOVA).

4. Results and discussion

4.1 Climate

The average annual rainfall for the experimental period (May to August in 1997-1999) ranged from 702.0 to 870.0 mm while the long term annual precipitation for the region varies from 944.6 to 1239.2 mm. Mean air temperature during the study period (May-August in 1997 – 1999) remained relatively constant at 29.0^{0}C.

4.2 Tillage and Soil Temperature

Effect of tillage on soil temperature is shown in Table 1. Typical hourly variations in soil temperature during a 5-day period of the study are shown in Figure 1. The temperatures of the soil in the seed zone during planting are generally higher in the days than in the nights. This is probably because rainy seasons at Samaru are characterized by warm days and cool nights. Soil temperature and plant height were significantly affected ($P \leq 0.01$) by tillage treatments (Tables 1 and 2). Soil temperatures were lower in shallow tilled plots of *T1* and *T2*. A difference in early and high number of seedling emergence and crop yield could be expected between shallow and deep tilled soils since soil temperatures were lower in shallow than in deep tilled plots. Tillage treatments exerted a considerable influence on root-zone temperature, plant development and maize yield. High soil temperature enhanced plant growth and crop yield (Figure 2). This result is consistent with the earlier reports of Ehkers (1975), German *et al.* (1984) and Farazdaghi *et al*. (1986) who attributed the enhanced plant growth and crop yield to high soil temperature.

The most rapid seedling emergence and highest crop yield were obtained in soil temperatures that averaged 30^{0}C at seedling level and within the top soil of 0-15 cm zone. It implies that soil temperature can be used as an index of monitoring and predicting plant growth under wide range of temperature conditions and tillage systems. This result is of practical importance to maize farmers in that it will be possible to make decisions regarding the necessity of replanting or the initiation of subsequent cultural practices.

Figure 2: Distribution of mean plant height along gradients of maximum soil temperature (Tmax) and minimum soil temperature (Tmin) using (a) mechanical planter and (b) manual planting

4.3 Soil Compaction

In the months of May-September, mean soil bulk density of 1.90 Mgm^{-3} and soil penetration resistance of 3.7 MPa were recorded at the site. However, by October and November of each year of the study, the soil became drier with high soil penetration resistance (> 3.7 MPa) at any soil depth during the 3-year investigations (1997-1999). Tillage had significant effect ($P \leq 0.01$) on soil penetration resistance (Table 2). The interactions of nitrogen rate, planting method and tillage showed no significance effect ($P \leq 0.05$) on soil penetration resistance. Increase in soil penetration resistance reduced maize grain yield (Figure 3). The *T4* treatment had the lowest mean penetration resistance of 2.7 MPa and highest mean maize grain yield of 4.8t ha^{-1}. This result agrees with the findings of Carry and Evans (1974) and Collebaut *et al.* (1986) which is in agreement with the results reported by Richman *et al.* (1965) and Coote and Rainsey (1983). Though the soil moisture content profile in 1997 and 1998 were similar, the distribution of soil penetration resistance varied widely. Unger (1984) had similar results and reported that in some cases, tillage with identical soil moisture contents, produced significantly different soil penetration resistance.

Figure 3: Response of maize grain yield to soil penetration resistance at Samaru, Zaria (with soil moisture content range of 18 – 23 %)

5. Conclusions and recommendations

Increase in soil penetration resistance reduced maize grain yield. Tillage treatment significantly affected ($P \leq 0.01$) soil temperature, plant height and maize grain yield. The T4 treatment had the lowest mean soil penetration resistance of 2.7 MPa and highest mean maize yield of 4.8t ha^{-1}. Soil temperatures were lower in shallow (15.0 cm) tilled plots of *T1* and *T2* than in deep (30.0 cm) tilled plot *T3*, *T4* and *T5*. The most rapid seedling emergence and highest crop yield were obtained in soil temperatures that averaged 30 ^{0}C at seedling level and within the top soil of 0-15 cm zone.

References

ASAE (1976). American Society of Agricultural Engineers Standards, 1976. Agricultural Engineers Yearbook, ASAER **313**, 1 343pp.

Barlow, E.W; R., L. Boersma and J. L. Young (1977). Photosynthesis, transpitation and leaf elongation in corn seedlings at sub optimal soil temperatures. *Agron, J.* **69**: 95-100.

Bengough, A. G. (1992). Penetrometer resistance equation – its derivation and the effect of soil adhesion. *J. Agric. Eng. Res*., **53**: 163-168.

Brannack, M. V. and A. R. Dexter (1979). Compaction of aggregate beds. In: W. W. Eversion, R. D. bond and A. R. Dexter (Editors). Modification of soil structure, Wiley, New York, 120pp.

Callebaut, F,; D. Gabriels and M. deBoudt (1986). Assessment of soil surface sealing and crusting. Proc. Symp., Ghent, Belgium, 1985. Dept. of Soil Physics, State Univ. of Ghent, 374pp.

Carry, J. W. and D. D. Evans (1974). Soil crust. Agric. Expt. Sta. Univ. Arizona Tech. Bull, 214, Tueson, AZ., 58pp.

Chancellor, W. J.; J. A. Vomocil and K. S. Aref (1969). Energy dissipation in compression of three agricultural soils. *Can. J. Soil Sci*., **63**: 1-14.

Cruse, R. M.; D. R. Linden; J. K. Radke; W. E. Larson and K. Larntz (1980). A model to predict tillage effects on soil temperature. *Soil Sci. Am. J.* **47**: 570-575.

Dexter, A. R. (1988). Advances in characterization of soil structure. *Soil Tillage Res*., **11**: 199-239.

Domzai, H.; J. Hodara; A. Slowinska-Jurkiewicz and R. Turski (1993). The effect of agricultural use on structure and physical properties of three soil types. *Soil Tillage Res*., **27**: 365-382.

Domzai, H. and J. Hadara (1991). Physical properties of three soils compacted by machine wheels during field operations. *Soil Tillage Res*., **19**: 227-236.

Ehlers, W. 1975. Observations on earthworms channels and infiltration of tilled and untitled loess soil. Soil Sci., 119: 242-249.

Farazdaghi, H.; J. W. Ketcheson and J.H.A. Lee (1986). Corn grain yield as influenced by tillage and seasonal weather. Soil Tillage Res., **8**: 369-

German, P. F.; W. M. Edwards and L. B. Owens (1984). Profile of bromide and increased soil moisture after infiltration into soils with macropores. *Soil Sci. Soc. Am. J.* **49**: 237-244.

Gupta, S. C.; J. K. Radke and W. E. Larson (1981). Predicting temperatures of a bare and residue covered soils with and without a corn crop. *Soil Sci. Soc. Am. J.* **45**: 405-412.

24Gupta, S. C.; J. K. Radke; W. E. Larson and M. J. Shafter (1982). Predicting temperatures of bare and residue-covered soils from daily maximum and minimum air temperatures. *Soil Sc. Soc. Am. J.* **46**: 372-376.

Hakansson, I; W. B. Voorhees and H. Riley (1988). Vehicles and wheel factors and crop responses in different traffic regions. *Soil Res*. **11**: 239-282.

Kay, B. (1990). Rate of change of soil structure under different cropping systems. *Adv. Soil Sci.* **12**: 1-41.

Kayombo, R. and R. Lal (1986). Effects of soil compaction by rolling on soil structure and development of maize in no-till and disc ploughing systems on a tropical alfisol. *Soil Tillage Res*., **7**: 117-134.

Ohu, J. O. and O. A. Folorunsho (1989). The effect of machinery traffic on the physical properties of a sandy soil and on the yield of sorghum in north-eastern Nigeria. *Soil Tillage Res*., **13**: 399-405.

Ojeniyi, S. O. (1986). Effects of zero tillage and disc ploughing on soil water, soil temperature and growth and yield of maize. Soil Tillage Res., **3**: 180-200.

Oni, K. C.; J. S. Adeoti and F. G. Braide (1982). Influence of mechanised and clearing on compaction of agricultural soils. Paper presented at the International Conference on Land Clearing and Development, IITA, Ibadan, Nigeria,

Onwualu, A. P. and U. G.N. Anozodo (1989). Soil compaction effects on maize production under various tillage methods in a derived savanna zone of Nigeria. *Soil Tillage Res*., **14**: 99-144.

Radke, J. K.; A. R. Dexter and O. J. Devine (1985). Tillage effects on soil temperature, soil water and wheat growth in South Australia. *Soil Sc. Am. J*. **49**: 1542-1547.

Richman, R. W.; R. Letey and L. H. Stolzy (1965). Soil compaction effects on oxygen, diffusion rates and plant growth. *Calif. Agr*. **19**(2): 3-6.

Ryderg, T. (1986). Effects of ploughless tillage on soil physical and soil chemical properties in Sweden. Swedish Univ. Afric. Sci., Uppsala, Div. Soil Management, report 70, 35pp.

Ryderg, T. and T. Ockerman (1987). The effects of ploughless tillage on root development and evaporations Swedish Univ., Agric. Sci., Uppsala, Div. Soil Management, Report 74, 53pp.

Soane, B. D. and C. van Ouwerkerk (1994). *Soil compaction in crop production. Developments in agricultural engineering, II*. Elsevier, Amsterdam, Netherlands. 662pp.

Soane, B. D.; J. W. Dickson and D. I. Campbell (1982). Compaction by agricultural vehicles; a review, III. Incidence and control of compaction in crop production. *Soil Tillage Res.*, **2**: 3-36.

Soane, B. D.; P. S. Blackwell; J. W. and D. J. Painter (1981). Compaction by agricultural vehicles; a review, II compaction under tyres and other running gear, *Soil Tillage Res*., **1**: 373-400.

Spoor, G. (1982). The causes and nature of soil damage. *J. Agric. Eng.* **37**: 4-7.

Statistical Analysis Systems Institute Inc. 1989. SAS/STAT User's guide, version 6 4th Edn., Vol. 1 SAS Institute Inc. N. C., 943pp.

Tisdall, J. M. and H.H. Adam (1986). The effect of reduced tillage of an irrigated silty soil and of a mulch on seedling emergence, growth for silage. *Soil Tillage Res*., **6**(4): 365-375.

$I = kT$

Unger, P. W. (1984). Tillage effects on surface soil physical conditions and sorghum emergence, *Soil Sc. Am. J*. **48**: 1432-1432.

Valette, J. and I. J. Ibanga (1984). The detailed soil survey of the experimental farm of the Institute for Agricultural Research, Samaru, Zaria, Nigeria. Soil Survey Bulletin. 95pp.

vanWijk, W. R. (1963). Physics of plant environment. North-Hilland and Publ. Co. Amsterdam, Netherlands.

Walker, J. M. (1969). One –degree increments in soil temperatures affect maize seedling behaviour. *Soil Sc. Soc. Am. Proc*. **33**: 729-736.

Wolf, D. and A. Hadas (1984). Soil Compaction effects on cotton emergence. Trans. Am. Soc. Agric. Eng. 27: 635-659.

Yusuf, D. D. (1996). Time and cost conserving farming technique for the resource poor farmers in tropical Africa. *Journal of Engineering for International Development* **2**(3): 31-37.

Yusuf, D. D. and C. N. Asota (1998). Design, development and performance evaluation of a once-over tillage machinery utilizing a single-axle tractor. *Agricultural Mechanization in Asia, Africa and Latin America* (AMA), 29(3). 9-13.

Yusuf, D. D. (2001). Deep ploughing effects on irrigation intake, bulk density, and soil compaction for slowly permeable soil in northern Nigeria. Nigerian Journal of Engineering, **9**(1): 22-26.