Journal of the Ghana Institution of Engineering (2023) 23:3
https//doi.org/10.56049/jghie.v23i3.129

CASE STUDY

Effects of ploughing depth variations on maize (*Zea mays*) growth: a study at Nyankpala in the Northern Region of Ghana

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Received: 25th May, 2023 / **Accepted:** 6th September, 2023
Published online: 30th September, 2023

Abstract

This study evaluated the effect of different ploughing depths on maize (*Zea mays*) growth at Nyankpala in the Northern Region of Ghana. Plant height, leaf count, and stem girth were measured at no-plough (NT), 10-20 cm (PD_{20}), and 20-30 cm (PD_{30}) depths. Soil bulk density and texture were also determined for NT, PD_{20}, and PD_{30}. Plant data were evaluated using one-way analysis of variance in GENSTAT statistical program, and the means were separated with the least significant difference (LSD) at $p<0.05$. The results revealed significant differences between the various depths of ploughing, with the best maize growth characteristics recorded under PD_{30}, followed by PD_{20} and finally, NT. The PD_{30} had nitrogen, phosphorus and potassium (NPK) contents of 0.24 %, 6.08 mg/kg, and 58 mg/kg, respectively, followed by NT with NPK contents of 0.13 %, 5.23 mg/kg, and 46 mg/kg, respectively. The bulk density of the soil decreased with increasing ploughing depth. From the results, the study recommends a plough depth of about 20-30 cm for maize production in the study area and other regions with similar physical soil properties and agronomic practises.

Keywords: Tillage Depth, Maize Growth, Soil Nutrients, Soil Properties

Introduction

Tillage is an important management step in crop production as it has a substantial impact on the soil, crop growth, and yield. It has been an essential part of agricultural technological advancement, particularly in food production (Zewditu *et al.*, 2020). Tillage techniques help to control weeds, create an appropriate seedbed for crop plants, add crop residues to the soil, loosen the soil, boost chemical reactions, and enhance the physicochemical state of the soil, all of which help crop plants grow and develop (Wasaya *et al.*, 2019). Tillage procedures have a significant influence on soil physical qualities. Productive farming needs a variety of tillage practises that improve the soil's physicochemical properties and microbiological activity for agricultural crop growth (Hazarika *et al.*, 2018; Ramadhan, 2021). Tillage systems provide an optimal seedbed for plant growth (Aikins and Afuakwa, 2012; Khan *et al.*, 2020). The process of turning and loosening the soil regulates soil nutrients that are important for optimum crop yield. As a result, the depth of till affects root growth, accumulated nutrients, and yield (Cai *et al.*, 2014). Selecting tillage strategies that improve soil physical qualities is critical not just for increasing yields (Hazarika *et al.*, 2018), but also for reducing agriculture's environmental effect whilst fostering sustainability (Botha, 2013).

Tillage has a range of benefits as well as adverse physical, chemical, and biological impacts on the soil and crops, based on the techniques employed. Negative effects on soil characteristics and crop yield result from excessive or improper tillage techniques. Disturbing the soil may also significantly alter fertility status, with results ranging from favourable to poor crop production (Yaroson *et al.*, 2019). Tillage affects the physical characteristics of the soil, including its organic matter content, aggregation, porosity, bulk density, and moisture content. Proper tillage causes desirable physical changes in the soil environment, which ultimately translates to increased crop yields (Hazarika *et al.*, 2018). Physical factors that directly affect soil productivity and sustainability include aggregate stability, water and soil conservation, and infiltration capacity. On an annual basis, the best tillage technique for a field or farm will vary depending on soil type and weather conditions. Effective tillage procedures give the optimum planting environment for plant emergence, growth and unlimited root extension (Abagandura *et al.*, 2017).

Conventional and conservation tillage systems are the methods that have been established, regardless of the equipment utilized. An effective soil conservation system protects soil from wind and water erosion, maintains a healthy seedbed, eliminates compacted layers, and supports the development of organic substances (Aikins *et al.*, 2012; Hydbom, 2017). With conservation tillage such as no-till, soil physical characteristics are typically better due to improved saturated and unsaturated hydraulic conductivity than conventional tillage systems due to the continuity of pores (Busari *et al.*, 2015). Further advantages include protection of the soil against erosion, preservation of soil and water, cost and time savings, and increases in soil fertility (Sharma and Abrol, 2012). However, other researchers (Schneider *et a*l., 2017; Wang *et al.*, 2022; Schneider *et al.*, 2017; Wang *et al.*, 2022) found conventional tillage practises to improve the accessibility of subsoil nutrients to the plant, which increases its yield. Conventional tillage can disrupt soil layers, allowing roots to penetrate deeper and gain access to additional resources stored in the subsoil. It could facilitate subsoil water uptake and hence stabilise the yield of crops. According to Usharani *et al*. (2019), well-tilled soil promotes rainfall infiltration, reducing runoff and allowing for the storage of moisture for subsequent use by the crop. It also encourages good root formation and development. Deep ploughing is a treatment for undesirable soil compaction that improves crop growth conditions. Mechanical disturbance of the subsoil increases the water-holding ability and lowers its resistance to root penetration (Cai *et al.*, 2014). In the different conventional tillage methods, energy plays a key role. As the depth of tillage increases, so does the amount of energy consumed and the wear and strain on the implement and power source.

In agriculture, the depth of ploughing has been of particular relevance since it may influence soil decomposition rates (Baker, 2016). However, such tillage necessitates a huge amount of energy investment and comes at a significant expense to farmers. Variable-depth deep ploughing applied on a location basis has proven effective in reducing undesirable soil compaction in locations where it occurs while avoiding the use of this costly process (Błażewicz-Woźniak *et al.*, 2015).

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Good crop establishment is essential for high yields. However, many crops require different soil physical characteristics to establish successfully. High bulk density and soil resistance can have an adverse impact on root development and growth, causing root action and features to change to accommodate increasing strength**.** Ploughing practises can have a significant influence on various soil layers, affecting both strength and porosity, which can limit root development (Botha, 2013). The relationship between soil physical properties and plant root systems is essential in this process since both are directly connected to proper tillage practises (Qamar *et al*., 2015). Soil is an important natural source and has an economic and eco-social capability for improving plant growth, quality, and yield (Usharani *et al*., 2019). Choosing the right tillage system for a particular soil type requires careful consideration of the soil type (Wasaya *et al*., 2019). When soil is in good condition, root systems develop well, which is necessary for optimum root growth and maximum crop yields (Aikins *et al*., 2012).

For the past decade, farmers have continued to record a low growth rate and yield of maize (Adzawla *et al*., 2021; Kanton *et al*., 2016). Although they sow improved and certified seeds, this does not produce a significant difference in the growth rate and yield of maize. This is most often linked to the monoculture agricultural practise, where farmers continuously till the soil to the same depth each season, depleting its nutrients beyond that depth. According to Cai *et al*. (2014), due to several years of overexploitation of the topsoil and inappropriate mechanical manipulation, the useful topsoil depth could gradually decline and the plough pan thickens which can potentially affect root penetration. Also, many farmers carry out tillage operations without considering the impact on soil physical characteristics and crop growth (Ozpinar and Isik, 2004; Yaroson *et al*., 2019). The impact of ploughing depth on crop productivity as well as soil physical properties is important. In the Tolon District and many other parts of Ghana, not much research has been done on the effects of ploughing depth on crop growth and soil properties. Varying the depth of the plough can uncover leached minerals and restructure the soil to make it more conducive for the growth of crops. While different studies propose different optimal ploughing depths for different soils and crops (Abagandura *et al*., 2017; Aikins *et al*., 2012; Zhang *et al*., 2018; Zikeli *et al*., 2013), there is still no consensus on the best ploughing depth for maximizing crop yields and preserving soil health. This may be due to the complex interactions between soil type, crop type, and other factors such as climate and agronomic management practises (Bonfante *et al*., 2019; Wasaya *et al*., 2019). The main objective of this study was to investigate the effects of ploughing depth variation on maize growth.

Materials and Methods

Description of the experimental site

The study was conducted at Nyankpala in the Northern Region of Ghana. The study area is situated within the Tolon District, which is bordered to the north, east, west, and south by Kumbungu, Sagnarigu, North Gonja and Central Gonja Districts respectively. It is situated between latitudes 9° 15′ and 10° 02′ north, and longitudes 0° 53′ and 1° 25′ west.

Crop farming is the major agricultural activity in the district, with about 90 % of the population involved in crop production such as maize, rice, yams, groundnut and livestock. The climate is characterized by a unimodal rainy season spanning from April - October with minimum rainfall at the end of April to its maximum in July and August. The production of primary crops such as maize is capped at one cropping season due to the rainfall pattern. The dry season in the district lasts from November to April. The average annual precipitation varies from 950 mm to 1200 mm. Except for the lowlands with alluvial deposits, the soil is primarily of the sandy-loam type. Because of the composition of the soil, the area is extremely susceptible to erosion (Ahmed and Anang, 2019; Ghana Statistical Service, 2014). Figure 1 is a map of Tolon district showing Nyankpala.

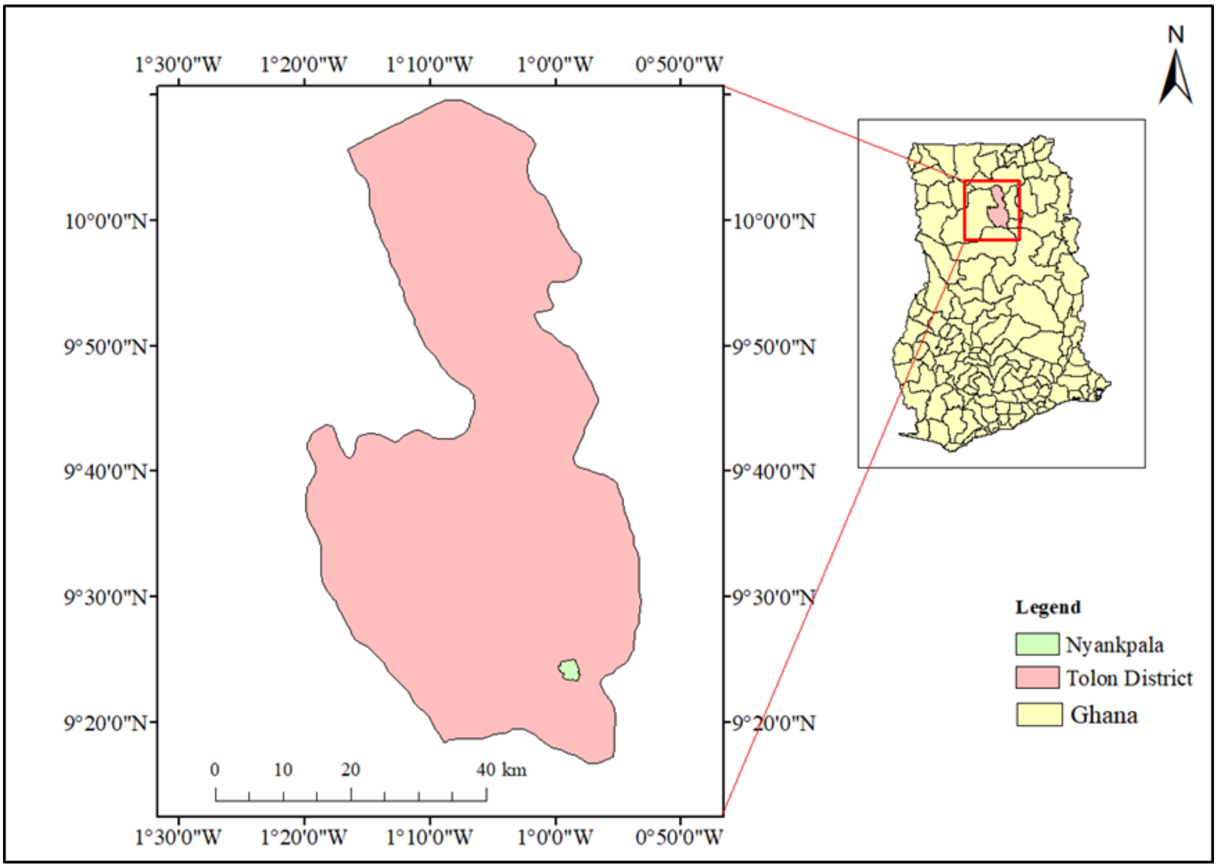

Figure 1 Map of Tolon district showing Nyankpala

https://doi.org/10.56049/jghie.v23i3.129

Experimental design

A completely randomized design (CRD) with three replicates on 5 m x 4 m plot each was adopted for this experiment. The field experimental design consisted of three ploughing depths. The treatments were the ploughing depth at 0 cm (no-plough), 10-20 cm and 20-30 cm levels designated as NT, PD_{20} and PD_{30}, respectively. This gave a total of nine experimental plots spaced at 2 m between rows and 1 m between columns. The spacing was necessary to clearly distinguish plots and to serve as walkways.

Land preparation and planting

The ploughing depth variations were achieved using the disc plough. Ploughing was done using a 3-bottom disc plough with a disc diameter of about 66 cm hitched to an 85-hp Massey Ferguson MF 385 tractor. The desired depth was achieved by careful control of the hydraulic system by the operator and the addition of weights to the plough beam to attain penetrations beyond 20cm. The soil was wet enough after a rainfall for easy penetration of the plough for all the treatments. The initial soil moisture content of the field was determined using the oven drying method (Susha Lekshmi *et al.,* 2014) to be 17.32 % at the time of ploughing. *Wang-Dataa* maize variety, one of the recommended maize varieties for northern Ghana with a maturity period of 3 months (Adu *et al.,* 2014; APNI and CSIR-SARI, 2022) was chosen for the study. A planting depth of 5 cm was adopted throughout the experiment. The interrow and intra-row planting distances were 80 cm and 25 cm, respectively, with three seeds per hole, which were later thinned to two, after 10 days of germination. There were eight rows in a plot. The plants started emerging on the fourth day and by the 12^{th} day, almost all had germinated.

Data collection

Determination of soil physical properties

Soil dry bulk density was determined for NT, PD_{20} and PD_{30} treatments. At each treatment, three soil samples were collected and analysed. To determine dry bulk density, a core sampler with dimensions of 5 cm length and 5 cm diameter was used. The samples collected were dried for 24 hours at a temperature of 105 ^oC (de Oliveira *et al.,* 2015; DeAngelis, 2007; Pappoe *et al.*, 2009). The bulk density was determined using Equation (1).

$$Bulk\ density, \rho_d = \frac{Mass\ of\ dried\ soil\ particles}{Total\ volume\ of\ sample} = \frac{W}{V_t} \quad (1)$$

The soil texture was analysed using the hydrometer method (Huluka and Miller, 2014) and the textural class obtained from soil texture triangle. Sodium hexametaphosphate, $Na(PO_3)_6$ and deionized water were used as reagents.

Determination of soil chemical properties

The analysis of soil chemical properties was carried out at the soil laboratory of the Savannah Agricultural Research Institute (SARI) in Nyankpala. Three sets of soil samples were taken from each treatment (NT, PD_{20}, and PD_{30}), dried, sieved in a 2 mm diameter sieve and analysed for their chemical properties. This was done to determine the proportions of soil nutrients in each depth of plough. The chemical properties investigated included total nitrogen (N), available phosphorus (P), available potassium (K), and soil pH.

In the laboratory, the procedure for determining soil N involved the digestion of a sieved (< 2mm) air-dried soil sample in concentrated H_2SO_4, the Kjeldahl distillation of the NH_3 formed and quantifying the N by titration (FAO, 2021a). The available soil P test was conducted using Bray P1 method (Boem *et al*., 2011; Ebeling *et al*., 2006; Lumbanraja *et al.,* 2017; Mallarino, 1995) with the extractant being NH_4F solution and dilute HCl.

In determining the available soil K, the exchangeable cation K^+ method (McLean and Watson, 1985; Moody and Bell, 2006) was used. The reagents used were ammonium acetate and distilled water. The pH of the soil was determined using the electrometric method (Adamchuk and Mulliken, 2005; FAO, 2021b).

Crop parameters measured

The germinated *Wang-Dataa* maize plants were randomly tagged per plot to monitor and determine the plant height, stem girth, and number of leaves per plant in two-week intervals for eight weeks, beginning two weeks after planting. The germination rate was 80 – 85 % due to the activities of field rodents. Thirty (30) plants were tagged in each of the nine plots, given a total of 270 plants. A metre rule was used to determine plant height. The girth of the stem was measured using a thread and a ruler. At two-week intervals, the leaves of the tagged plants per plot were counted. The average of the parameters recorded for each treatment was determined.

Data analysis

Analysis of variance (ANOVA) of the data gathered for this study was done using the GENSTAT statistical program (Payne, 2009), and the means separated using the least significant difference at a 5 % probability level. The results were presented in tables and graphs.

Results and Discussions

Soil chemical and physical properties

Soil pH and NPK content

Nitrogen, phosphorus and potassium (NPK) levels as shown in Table 1 were found to be highest in the 20 – 30 cm (PD_{30}) ploughed depth, followed by the 10 – 20 cm (PD_{20}) and the NT having the least nutrient content. This could be attributed to leaching of nutrients from the top surface to that depth over time. It might have well been due to the vulnerability of the topmost layer to agents of erosion, which have depleted the nutrient content. Compared to NT, total N accumulation under the other treatments increased by 30.8 – 84.6 %, whereas avail-

Table 1 Chemical and textural analysis of soil at various ploughed depths

Depth of soil	pH	N (%)	P (mg/kg)	K (mg/kg)	Texture			
					% Sand	% Silt	% Clay	Class
NT	5.79	0.13	5.23	46	71.6	26	2.4	Sandy loam
PD_{20}	5.43	0.17	5.48	48	68.2	25	6.8	Sandy loam
PD_{30}	5.28	0.24	6.08	58	67.6	22	10.4	Sandy loam

NT = no-plough , PD_{20} =10-20 cm, PD_{30} = 20-30 cm

https://doi.org/10.56049/jghie.v23i3.129

able P increased by 4.8 -16.3 % and available soil K increased by 4.3 – 26.1 % (Table 1). A similar trend was observed by Cai et al. (2014), where N, P and K increased with depths ranging from 0 – 80 cm. If nutrients are growth-limiting, tillage enhances the availability of subsurface nutrients to plants, which boosts crop production (Schneider *et al*., 2017). This is, however contrary to the observation by Zikeli *et al*. (2013) that nutrient content such as available P, K and soil organic carbon decrease with soil depth in the sample depth from 0 cm to 20 cm.

The soil pH decreased with increasing depth, though all were within the range of 5.28 and 5.79. The soil pH of PD_{20} and PD_{30} was strongly acidic whereas the NT was slightly acidic. A soil pH of 5.1-5.5 is strongly acidic and 5.6 - 6.0 is moderately or slightly acidic (Kicińska et al., 2022; Odutola Oshunsanya, 2019). The mineral composition of the parent soil material and the weathering processes that parent material has gone through have an impact on the pH of the soil. In wet environments, soil acidity occurs because of the products of weathering that are leached by water moving laterally or downward through the soil. Tillage had an effect on the soil total N, available P, K and pH.

Soil texture

The particle size analysis results showed that the textural class of the field is sandy loam with little variation in particle composition. The proportions of sand in the soil samples were high, with 71.6 %, 68.2 % and 67.2 % recorded at NT, PD_{20} and PD_{30}, respectively whereas silt content was 26 %, 25 %, and 22 % for NT, PD_{20} and PD_{30} respectively. Clay content was 2.4 %, 7.4 % and 10.4 % for NT, PD_{20} and PD_{30}, respectively. The results indicated a generally high sand content and a very low clay content (Table 1). These soils drain easily and as a result, are vulnerable to the leaching of nutrients from the soil surface to the PD_{30}.

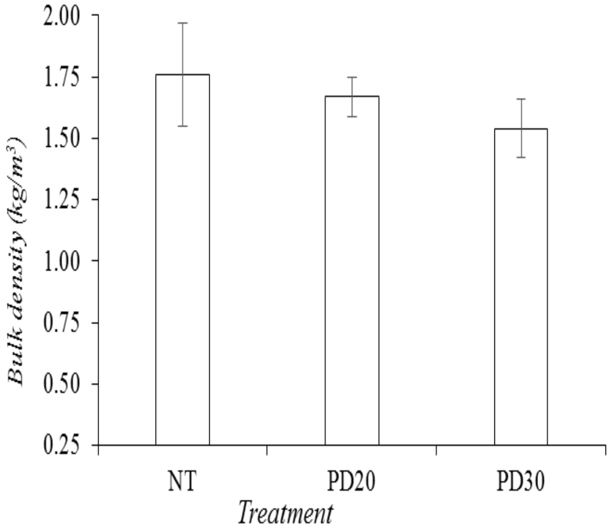

Figure 2 Bulk densities of the soil at various ploughing depths

Bulk density

The soil bulk density values for the two ploughing depths (PD_{20} and PD_{30}) were lower than the NT within the various ploughing depths (Figure 2). The ploughed treatments loosened the soil, resulting in a lower soil bulk density than the NT. Ploughing therefore affected the soil bulk density with respect to the depth of tillage and had an impact on the growth of the crop as a result of easy root penetration and high nutrient absorption rate. According to Stirzaker *et al*., (1996), plants respond to variations in bulk density by growing the fastest at an intermediate density or lower. Bulk density often characterises the state of soil compactness in response to land use and soil management activities (Indoria et al., 2020). A high soil bulk density negatively affects soil physical properties, and therefore can limit microbial activity and biochemical processes, which are crucial for nutrient availability (Hazarika *et al*., 2018; Ramadhan, 2021; Yaroson *et al*., 2019). An increasing bulk density implies a decrease of macropores and an increase in meso- and micropores and the resultant changes impact hydraulic conductivity (Indoria et al., 2020). It also has an effect on soil aeration, which influences water and nutrient uptake. The results are similar to findings by Alamouti and Navabzadeh (2007) that mean soil bulk density decreases with increasing depth. Deep tillage is necessary to decrease the initial bulk density and penetrometer resistance of the soil profile (Baumhardt and Jones, 2005) resulting from continuous and several years of practising soil management at only a particular depth.

Growth characteristics

The height of maize plants

The ANOVA of the maize plants' height is shown in Table 2. The plant height was significantly different ($P<0.05$) among the different ploughing depths except on the 8th week after planting. The plants' height for the PD_{30} depth was significantly higher than the other two treatments. Although there was no significant difference in height between NT and PD_{20} at two weeks after planting (2WAP) and 4WAP, there was a significant difference at 6WAP and 8WAP.

Maize plants in the NT and PD_{20} were similar in height but substantially ($P<0.05$) lower than the plants in the PD_{30}. The PD_{30} treatment produced the tallest plants, which were also significantly ($P< 0.05$) taller than plants in PD_{20} plots. The NT and PD_{20} treatments had poor growth characteristics, which could be attributed to high bulk density and low NPK. High bulk density indicates limited soil porosity and high compaction, which lead to restricted plant development and general maintenance.

According to Sharma and Abrol (2012), the loss of root penetration depth induced by high bulk density soils can reduce plant height significantly when compared to plants growing in

Table 2 Effects of different ploughing depths on the height of maize

Depth of plough	Plant height			
	2WAP	**4WAP**	**6WAP**	**8WAP**
NT	14.98a	30.37a	76.1 a	150.4a
PD_{20}	20.41a	41.38a	113.9b	231.9 b
PD_{30}	35.66b	66.36b	182.8c	250.4 b
p-value	<0.03	< 0.02	<0.01	<0.07
LSD	10.05	15.88	32.83	NS

NT = No-plough, PD_{20} = 10-20 cm, PD_{30} = 20-30 cm, WAP = weeks after planting, NS = Not significant

Table 3 Effects of different ploughing depths on the number of leaves of maize

Depth of plough	Number of Leaves			
	2WAP	4WAP	6WAP	8WAP
NT	7.23a	7.23a	10.10a	10.47a
PD_{20}	8.15a	8.15a	11.00a	12.68b
PD_{30}	10.63b	10.63b	12.47b	14.57c
p-value	<0.01	<0.01	< 0.15	<0.01
LSD	1.157	1.157	NS	1.026

NT = No-plough, PD_{20} = 10-20 cm, PD_{30} = 20-30 cm, WAP = weeks after planting, NS = Not significant

Table 4 Effects of different ploughing depths on the stem girth of maize

Depth of plough	Stem girth (cm)			
	2WAP	4WAP	6WAP	8WAP
NT	4.035a	3.950a	4.800a	6.252a
PD_{20}	4.540a	4.635ab	5.992a	6.562a
PD_{30}	6.367b	6.545b	8.615b	8.543b
P-value	<0.29	<0.35	<0.04	<0.07
L.S.D.	NS	NS	1.927	NS

NT = no-plough, PD_{20} = 10-20 cm, PD_{30} = 21-30 cm, WAP = weeks after planting, NS = Not significant

low bulk density soils. In research to compare the plant density and crop production of various tillage regimes, Kisić *et al.* (2010) observed that no-tillage treatment had significantly lower maize plant height and thickness, ear size, and kernel count per ear than the other treatments which this study confirms.

Number of maize leaves

Table 3 presents the number of leaves at 2WAP, 4WAP, 6WAP and 8WAP. The number of maize leaves was not significantly ($p < 0.05$) different among the treatments except at 6WAP, with PD_{30} being higher than the other treatments, followed by PD_{20} and then NT. Maximum leaves in the PD_{30} plot could be attributed to the mutual relationship that exists between the bulk density (Figure 2) and roots penetration and the available nutrients (Table 1) at that depth which fix nitrogen into the roots of the maize, thus increasing the growth of leaves. A study by Abagandura *et al*. (2017) showed that the number of maize leaves in a conventional tillage practise was significantly higher and lower in zero tillage practise. Similarly, Aikins *et al*. (2012) observed that, no tillage plots recorded the least number of maize leaves, significantly less than other tillage practises.

Stem girth

Table 4 illustrates the impacts on the stem girth throughout the first eight weeks of the experiment from the various ploughing depths. There was no significant change in the plant stem girth between NT and PD_{20}, but statistical analysis of the data indicated there was a difference in PD_{30}.

There was no significant difference between NT and PD_{20} at all the weeks after planting. However, there were significant differences between the PD_{30} and other two (NT and PD_{20}) treatments. This might be due to the low bulk density in the NT which allows for a high rate of water absorption, nutrient uptake and easy root penetration. The increase in the stem diameter could also be a result of the high NPK content recorded at that depth of the soil. In a study by Aikins *et al*. (2012), no-tillage plots had the smallest stem girth, smallest plant, and fewest leaves per plant among other features. Maize growth characteristics such as plant height and stem girth are influenced by soil fertility management practises (Kanton *et al*., 2016).

Conclusions

Differences in soil bulk density were caused by variations in tillage depth. No-ploughed depth had the highest bulk density and therefore recorded the least maize growth characteristics, followed by the 10 - 20 cm ploughing depth. The ploughing depth of 20 - 30 cm had lower soil bulk density and highest NPK content. In general, the number of leaves, height of plants, and stem girth were similar at no-plough and 10 - 20 cm ploughing depths The ploughed depth of 20 - 30 cm improved the maize growth characteristics measured in this experiment.

Thus, it can be stated that ploughing at a depth of 20 - 30 cm is required for maize to have better growth characteristics which could lead to higher yields. This is vital information for farmers on the optimal tillage practise required for maize cultivation. Further research should focus on long term studies on the effects of ploughing depth variations on maize growth and yield, as well as economically evaluating the costs of varying the plough depth.

Conflict of Interest Declaration

The authors declare no conflict of interest.

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