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Land Preparation Practices for Maize Production: Short Term Effects on Some Hydro-Physical Properties of Analfisol and Crop Performance

[1]*G.O. Awe and* [2]*T.P. Abegunrin*

[1]Department of Soil Resources and Environmental Management,
Faculty of Agricultural Sciences, Ekiti State University, PMB 5363, Ado Ekiti, Nigeria
[2]Department of Agricultural Engineering, Faculty of Engineering and Technology,
Ladoke Akintola University of Technology, Ogbomoso, Nigeria

Abstract: The suitability of a soil for sustaining plant growth and biological activity is a function of its properties, however soil disturbance is one of the processes modifying soil properties and influencing crop productivity. Therefore the objective of this study was mainly to evaluate the effects of different land preparation methods on some soil hydro-physical properties and maize performance on an alfisol in Ado Ekiti, southwest Nigeria during the 2015 late season. The experimental design was a completed randomized design (CRD) in three replications. The treatments consisted of three land preparation methods, namely ploughing once (PL1), ploughing twice (PL2) and ploughing once followed by harrowing (PL+H). Land preparation did not significantly ($p<0.05$) influence soil bulk density in all the soil layers. Saturated hydraulic conductivity was significantly ($p<0.05$) affected by land preparation in all the soil layers, the highest value was obtained from PL2 treatment in the surface layer. Soil water content was significantly influenced by land preparation in the 0-10 and 10-20 cm layers, with a trend in the order: PL2 >PL + H >PL1. The highest number of leaves, tallest plant and greatest canopy were obtained from PL2 treatment. Land preparation significantly affected the maize grain yield and yield components and in terms of crop performance, the trend was PL + H > PL2 > PL1.Under the soil and weather conditions of the experimental site, the best land preparation method identified for maize production could be double tillage of ploughing followed by harrowing or ploughing twice.

Key words: Land preparation · Soil properties and processes · Temporal changes · Crop productivity

INTRODUCTION

Soil properties are important for creating favorable conditions for crop growth and maintaining soil quality [1]. Mulumba and Lal [2] stated that the suitability of a soil for sustaining plant growth and biological activity is a function of physical and chemical properties. However, soil tillage is one of the factors altering soil properties and influencing crop productivity. According to [3, 4], among the several crop production factors, soil tillage impacts the sustainable use of soil resources through its influence on soil functions, especially soil properties and processes.

Conventional tillage produces a suitable tilth for crop growth by temporarily decreasing bulk density and increasing the volume of macropores [5], with modification in soil matrix [6] that affect associated soil physical and hydraulic properties [7]. On the other hand, conservation tillage methods, such as reduced tillage, chisel tillage, minimum or no-tillage, are now promoted for restoration of degraded soil, check erosion, conserve soil and water and sustain the environment. According to Khurdish *et al.* [8], the use of minimum tillage management practices for crop production has increased as it reduces time, fuel as well as labor requirements and also checks soil erosion on slopes. However, minimum tillage could not compensate the adverse effects of fine texture, very low organic matter and an overall initial weak structure of soil.

Because of the heterogeneity of soil types, climate, cultural practices and crop physiology across regions, there have been different conclusions on the soil microclimatic modifications by tillage on soil physical properties and processes. Khurdish *et al.* [8] found

Corresponding Author: G.O. Awe, Department of Soil Resources and Environmental Management, Faculty of Agricultural Sciences, Ekiti State University, PMB 5363, Ado Ekiti, Nigeria.

that tillage methods significantly influenced the soil physical properties as soil moisture contents increased and bulk density of soil decreased. Aikins and Afuakwa [9] also found that minimum tillage of disc ploughing followed by disc harrowing treatment gave the most favorable soil physical conditions of lowest soil penetration resistance, lowest dry bulk density, highest soil moisture content and highest total porosity compared to no-tillage which produced unfavorable soil conditions. Conversely, [10] found tillage practices of disc ploughing (DP) and harrowing (DPH), ox-ploughing (OX), subsoiling-ripping (SSR), hand hoeing with tied ridges (HTR) and hand hoeing only (H) did not significantly affect bulk density, porosity, or sat values. They concluded that it is apparent that long term tillage experiment (>4 seasons) would be required to detect changes in soil physical properties as a result of the soil management practices. Husnjak *et al.* [11] found differences between tillage systems in soil physical properties of bulk density, total porosity; water holding capacity and air capacity were not significant in winter wheat seasons whereas in soybean seasons, there were significant differences between some tillage systems in bulk density, total porosity, air capacity and soil moisture.

Crop productivity integrates all the complex and dynamic soil properties and processes. Soil properties and processes are often perturbed by the medication caused by tillage [12], by altering soil structure, pore space and moisture removal pattern over the growing season, thus influencing crop growth and yield. Despite the quantum of studies conducted on the effects of soil tillage on crop performance, there has been no well-defined relationship between soil tillage and crop yields due to diverse soil types, regional climate and crop physiology. [13, 14] reported higher crop yield in conventional tillage than traditional no-tillage system. Aikins *et al.* [4] reported that there was no significant difference in maize plant growth, dry matter yield and yield components between the disc harrowing only and the disc ploughing followed by disc harrowing treatments. Similarly, [15] reported that all tillage practices of zero tillage (ZT), minimum tillage (MT), conventional tillage (CT) and deep tillage (DT) showed similar yield after four years of cropping cycles. Conversely, Khurdish *et al.* [8] found that maximum value of maize plant height, number of grains per cob and 1000-grain weight was observed in conventional tillage compared to minimum and deep tillage. According to Aikins *et al.* [4], different tillage methods may affect the growth and yield of maize due to different soil conditions created. Therefore, research is still open on how crops fare under diverse soil management practices.

In Nigeria, maize production has increased in the past decade due to its high demand for food and raw material for industry. Of the total world production (844 MMT) in 2010, Nigeria was the largest producer in Sub-Sahara Africa, accounting for 7.7 million metric tons, representing 0.9% of the world production [16]. Maize is an important staple food for more than 1.2 billion people, about 50% of the population, in Sub-Saharan African [17]. Maize is largely grown in Nigeria by resource-poor smallholder farmers under rain-fed conditions, with limited production with irrigation using laborious and time-consuming crude methods (e.g. traditional mund or heap making) of land preparation. But today, farmers are adapting mechanized land preparation techniques as different tillage practices are being employed to produce the crop in order to meet the demand. While some farmers plant maize after disc ploughing, other farmers disc plough and disc harrow before planting. There are some farmers who disc plough a number times or disc harrow without disc ploughing before planting depending on availability of tillage attachment and capital. Some farmers use "slash and burn" while others use no tillage before planting maize. Despite the success of the various techniques, the farmers perform soil tillage without recourse as to how tillage influence soil properties and crop performance. Therefore, the objective of this study was mainly to evaluate the effect of different land preparation methods on some soil hydro-physical properties and maize performance on an alfisolin Ado Ekiti, southwest Nigeria.

MATERIALS AND METHODS

Description of Experimental Site: The field experiment was conducted during the 2015 late cropping season at the Teaching and Research Farm, Ekiti State University, Ado-Ekiti, Nigeria, located on latitude 7°42' 46"N, longitude 5°14' 42"E and 403 m above sea mean level. The region has total annual rainfall of about 1367.7 mm while the mean annual minimum and maximum temperatures were 12 and 34°C, respectively. The soil of the study site belongs to the broad group Alfisol [18], sandy-loam in the superficial layer and clayey in the subsurface. The results of some physico-chemical properties of 0-15 cm surface layer of the experimental site before the study showed that the pH was 5.64, showing a slightly acidic soil, soil organic carbon was 1.00% while the total nitrogen was 0.86 g kg^{-1}. The bulk density, particle density and total porosity are 1.72 g cm^{-3}, 2.54 g cm^{-3} and 32.3% while the textural analysis showed that the clay, silt and sand contents are 17.76, 8.00 and 74.24%, respectively, giving sandy loam texture. The experimental

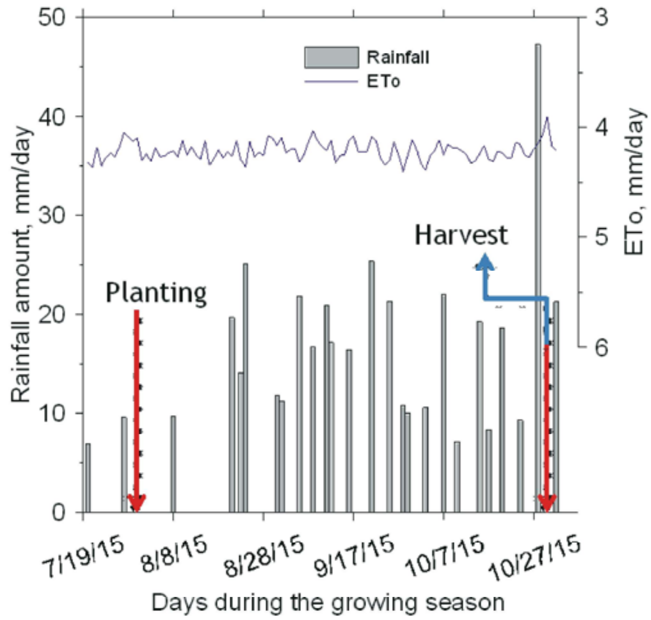

Fig. 1: Temporal distribution of rainfall and evaporative demand of the atmosphere (ETo) during the growing cycle of the maize crop

site has been used for vegetable production under irrigation for over five years before management for maize.

Experimental Design, Treatments, Land Preparation, Planting and Field Management: The experiment was laid out in complete randomized design (CRD) in three replications. The treatment consisted of three land preparation methods, namely ploughing once (PL1), ploughing twice (PL2) and ploughing once followed by harrowing (PL+H). Soil inversion by ploughing was made using a 3-blade disc plough while harrowing was done to pulverize, shred weeds and mix the soil using 24-blade tandem disc harrow. The tillage attachments were fully mounted to a 75hp tractor (Ursus, Holland). Maize seeds, at 2-3 seeds per hole (later thinned to 2 stands) were planted manually at inter-row spacing of 70 cm and 50 cm between plants, giving a plant population of about 57, 000 plants ha^{-1}. Urea (46% N), at recommended rate of 200 kg N/ha in this region [19] was applied 4 weeks after planting while a mixture of atrazine at the rate of 2 kg ha^{-1} and Delsate (360 g L^{-1} glyphosphate) at 3 L ha^{-1} was sprayed for weed control. Each block was 17 x 25 m, with inter-block spacing of 5 m, giving a total experimental area of 1, 285 m^2.

Soil Sampling and Analysis: A week after land preparation, undisturbed soil samples were collected from soil layers 0-10, 10-20 and 20-30 cm in three replicates using core samplers, 57 mm diameter and 40 mm high to determine soil bulk density (BD) according to Blake and Hartge [20] and saturated hydraulic conductivity (Ksat) following the procedure described in [21]. From these same soil layers, disturbed samples were also collected to quantify the field gravimetric water content which was dried to constant weight in the oven at 105°C for 48 hours.

Plant Growth Parameters, Yield and Yield Components: Plant growth parameters of plant height (PH), number of leaves (NOL) and stem girth (SG) were monitored 4, 6 and 9 weeks after planting (WAP). PH was determined from the soil surface to the tip of last leaf using a steel tape (accuracy: ±0.25 mm), number of leaves was obtained by visual counting of green leaves while stem girth of maize stem was determined using digital vernier caliper (accuracy: ±0.01 mm). Leaf area index (LAI) and canopy cover (CC) were determined by taking aerial digital images of the maize field at 1, 3, 5 and 7 WAP. The digital images were processed in Green Crop Tracker software (v. 1.0) to obtain both LAI and CC [22]. At physiological maturity, an area, 4 m^2, was demarcated to obtain total biomass, grain yield and yield components. Grain yield was corrected to 13% moisture content.

Weather Data and Evaporative Demand of the Atmosphere (ETo): Daily minimum and maximum temperature, relative humidity, solar radiation and wind speed were obtained from a weather station about 200 m from the experimental field while rainfall amount was obtained using rain gauge installed at the center of the field. The daily evaporative demand of the atmosphere (ETo) was obtained using Penman-Monthiet equation in $FAO - ET_o$ Calculator software. Fig. 1 shows the temporal distribution of rainfall received and evaporative demand of the atmosphere (ETo) during the growing cycle. A total rainfall of 432.4 mm was received, representing 31% of the total annual rainfall while the cumulative ETo was 442.5 mm. During the period, about 67% of the total number of days had evaporative demand greater than rainfall.

Statistical Analysis: Data were subjected to analysis of variance (ANOVA) and where means was significant, the Fisher's Least Significance Difference (LSD) was used for mean value separation at 5% probability level. Pearson correlation and regression analysis was performed on yield and components. To obtain the extinction coefficient for maize, *X*, regression analysis was performed on CC and LAI data. All statistical analyses were done using SPSS (IBM version 20.0).

RESULTS AND DISCUSSION

Effect of Tillage on Soil Hydro-Physical Properties: The temporal distribution of soil bulk density (BD) of the three soil layers of the maize field under different tillage methods is presented in Fig. 2. Tillage did not significantly ($p<0.05$) influence the BD in all the soil layers during the growing cycle although BD increased over time in both 0-10 and 10-20 cm layers. In the 0-10 cm surface layer, treatments PL1 (soil inversion once) and PL+H (soil inversion once followed by harrowing) had the highest and lowest BD, respectively at 5 and 6 WAP (Fig. 2a). In the subsurface soil layers, there was no discernible trend among the tillage methods and the average BD was as high as 1.82 g cm^{-3} (Fig. 2bc).

The average values of saturated soil hydraulic conductivity (Ksat) of the three soil layers during growing cycle are shown in Fig. 3. Ksat was significantly ($p<0.05$) affected by tillage in all the soil layers. In the 0-10 cm surface layer, Ksat was significantly highest in treatment PL+H compared to other treatments. Over time, there was gradual decrease in the average values of Ksatin all treatments (Fig. 3a). For other soil layers, average values of Ksat were lower than those of the surface layer, with no discernible trend among the tillage treatments (Fig. 3bc).

The temporal variability of gravimetric soil water content (SWC) of the three soil layers of the maize field under different tillage methods are presented in Fig. 4. In the 0-10 cm surface layer, SWC differed significantly ($p<0.05$) due to tillage in the first three weeks after planting. At 1 WAP, PL2 had the highest SWC, at 2 WAP, it was PL + H plot that gave the highest SWC while at 3 WAP, both PL2 and PL + H had the higher SWC compared to PL1 (Fig. 4a). At 5 and 6 WAP, SWC did not differ among the tillage methods. For the 10-20 cm layer, SWC differed significantly ($p<0.05$) at first, fifth and sixth weeks after planting, with PL1 having the highest SWC at 6 WAP (Fig. 4b). In the 20-30 cm sub layer, SWC did not differ due to tillage (Fig. 4c). When the soil moisture content for each tillage method was averaged for the entire growing period and soil depths, no significant difference ($p<0.05$) was found. Nevertheless, soil moisture content by tillage was in the order PL2 > PL + H >PL1. Irrespective of tillage treatment, SWC significantly differed ($p<0.05$) between the soil layers, with the surface layer having the lowest value, about 18% lower than those of the subsurface layers and the highest amplitude was obtained in the 0-10 cm surface layer (Fig. 4).

The results of the regression analysis between the BD and logarithm transformed Ksat and SWC considering a threshold BD of 1.75 g cm^{-3} are shown in Fig. 5. For this threshold BD, the minimum Ksat and SWC for this soil were 6.94 cm h^{-1} and 0.1463 g g^{-1}, respectively. Using these Ksat = 6.94 cm h^{-1}, BD = 1.75 g cm^{-3}, SWC = 0.1463 g g^{-1}, it appears that more than85% of the sampling campaigns had BD values less than reference value; about 70% above the reference value for Ksat and 40% above the reference value for SWC.

As the growing season progressed, there was the tendency of increasing BD especially in both the 0-10 and 10-20 cm layers and this is attributed to the continuous process of rearrangement of soil particles and aggregates as a result of alternate wetting and drying cycles by rainfall. The increase in BD in the surface layer and the elevated BD in the subsurface layers is an indication of compaction process and degradation of soil structure although the values were still below the BD of 1.92 g cm^{-3} considered as critical and an indication of poor structural formation [23].

Soil saturated hydraulic conductivity (Ksat) is a dynamic soil property and its behavior is determined by the degree of compaction [24] and the quantity and continuity of pores, principally macropores [25]. Therefore, any measure that increase the BD as a result of soil compaction, will reduce the total porosity and hence the volume of macropores. In this study, Ksat decreased with time after tillage even down to deeper layers, even though soil bulk density did not differ between the different land preparation methods. This shows that soil management and time after application are very important

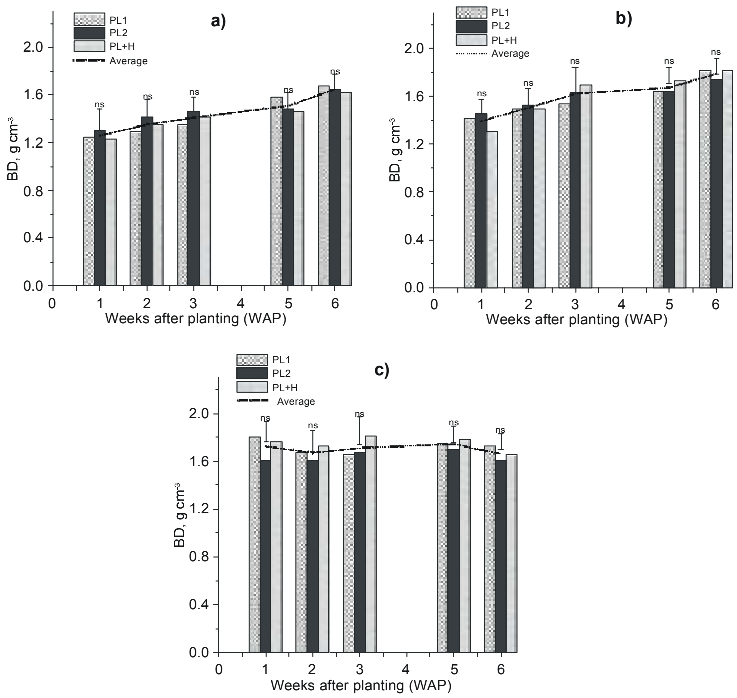

Fig. 2: Temporal distribution of soil bulk density (BD) of the a) 0-10 cm, b) 10-20 cm and c) 20-30 cm layers of the maize field under different tillage methods

The vertical lines on the bars are the standard error. ns: not significant at 5% level of probability by Fisher's least significant difference (LSD) test

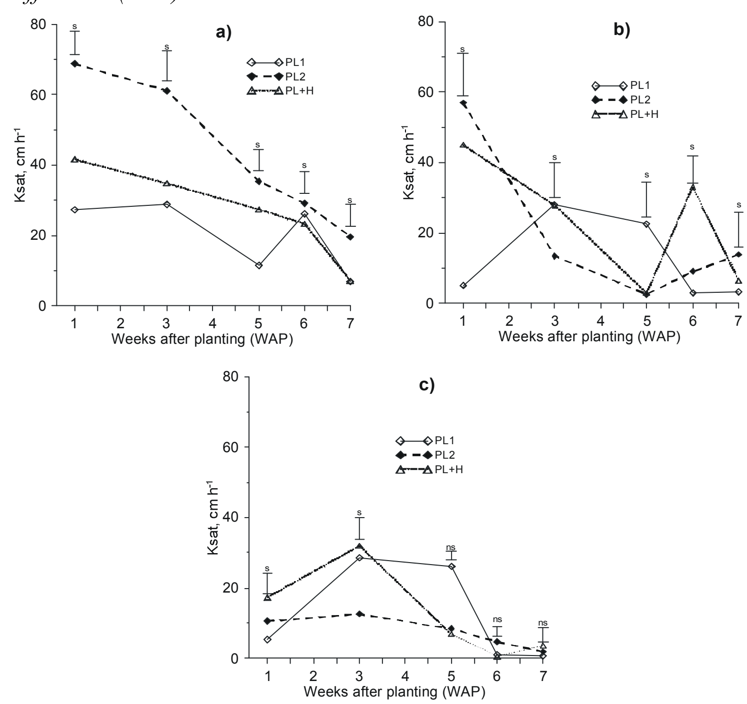

Fig. 3: Temporal distribution of saturated hydraulic conductivity (Ksat) of the a) 0-10 cm, b) 10-20 cm and c) 20-30 cm layers of the maize field under different tillage methods

The vertical bars are the error bars.s: significant; ns: not significant at 5% level of probability by Fisher's least significant difference (LSD) test.

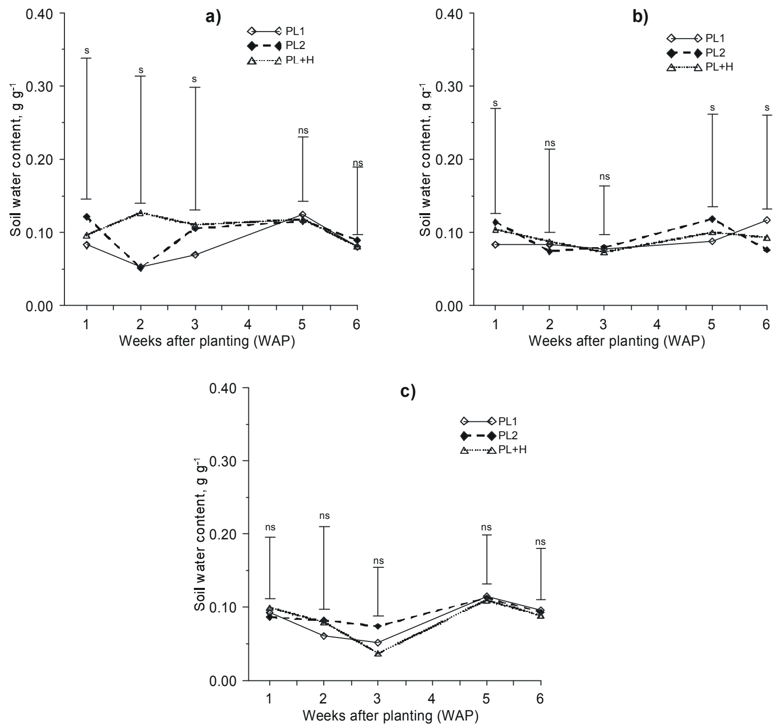

Fig. 4: Temporal distribution of soil moisture content (SWC) of the a) 0-10 cm, b) 10-20 cm and c) 20-30 cm layers of the maize field under different tillage methods

The bars are the error bars.s: significant; ns: not significant at 5% level of probability by Fisher's least significant difference (LSD) test

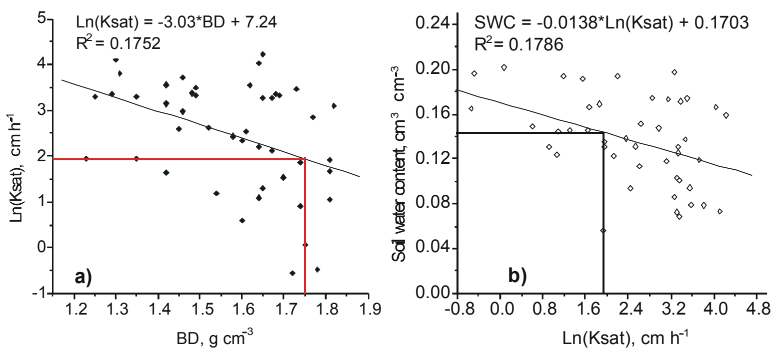

Fig. 5: Critical levels of Ksat and SWC considering the threshold bulk density (BDmax.) of 1.75 g cm^{-3} for the maize field subjected to different tillage methods.

parameters, as significant changes are more detectable and quantifiable using dynamic soil property rather than static soil property [26]. [27] reported that Ksat increased due to mechanical tillage, but with time, soil reconsolidation reduces the Ksat as the soil particles rearrange and become more dense.

Soil moisture is the main source of water for nutrient cycling and availability and plant metabolic processes [28]. According to [29], soil moisture is the single most limiting factor to crop yields and thus tillage techniques that conserve moisture or make moisture available are important for increasing crop yields and limiting the devastating consequences of drought. However, soil moisture is highly variable in time and space, being controlled mostly by the amount, frequency and distribution of rainfall during the growing season. Other factors influencing soil moisture include combined processes of evaporation and transpiration, management practices and soil type [30, 31]. The higher SWC from PL2 may be attributed to rough surface characterized by

Table 2: Effect of soil tillage on plant height (PH), number of leaves (NOL) and leaf area (LA) of the maize crop

	WAP								
	4	6	9	4	6	9	4	6	9
Treatments		NOL			PH, cm			LA, cm²	
PL1	10.0b	12.3b	12.7a	77.8a	135.0ab	298.7a	410.9b	844.1b	856.8b
PL2	12.0a	15.0a	13.3a	77.7a	154.9a	293.4a	506.7a	926.7a	1007.8a
PL+H	10.7b	14.0a	13.0a	71.1b	135.1ab	279.4b	325.9c	772.6c	841.3c
Mean	10.9	13.8	13.0	75.5	141.7	290.5	414.5	847.8	902.0

PL1: ploughing once, PL2: ploughing twice, PL + H: ploughing once followed by harrowing

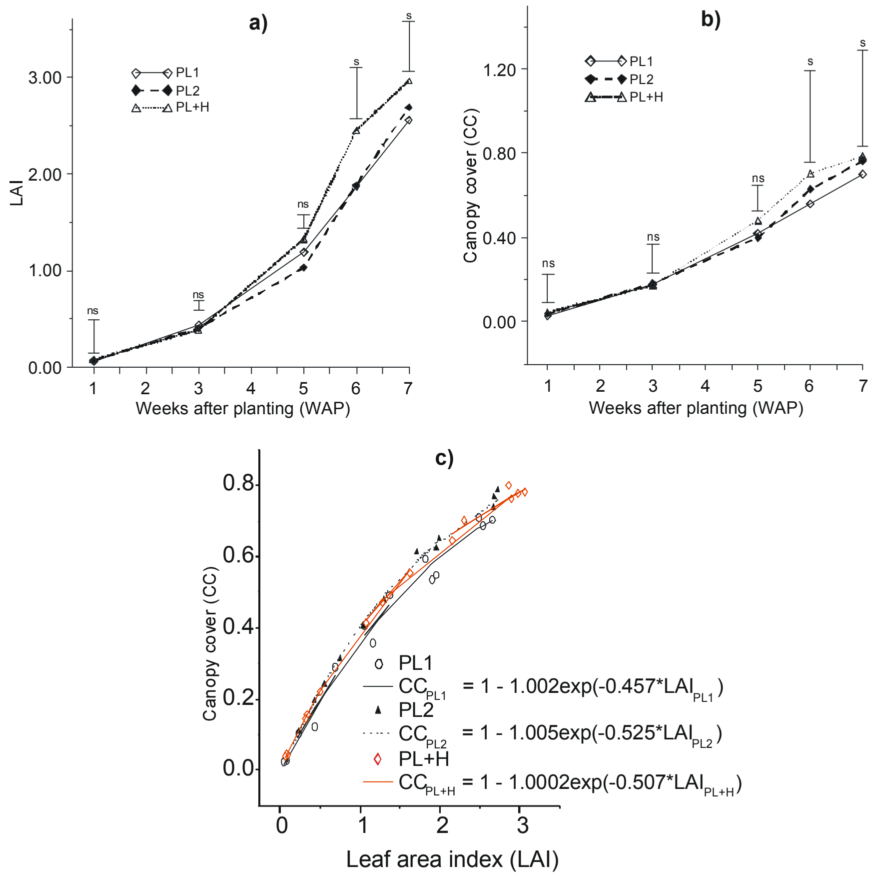

Fig. 6: Effect of tillage method on a) leaf area index (LAI), b) canopy cover (CC) and c) relationship between canopy cover (CC) and leaf area index (LAI) of the maize crop.
The vertical bars are the error bars.s: significant; ns: not significant at 5% level of probability by Fisher's least significant difference (LSD) test

ploughing operations which enables greater infiltration of water primarily by surface retention of water in small depressions. In a review by [32], it was reported that surface roughness produced by tillage increases surface ponding, allowing rainwater to readily infiltrate into the soil, thus preventing runoff and increasing moisture retention in the soil. Thus, management practices aimed at modifying soil surface characteristics could promote soil processes that encourage soil moisture retention within the crop root zone [33, 34]. Furthermore, the surface layer of PL2 treatment had the highest Ksat, indicating enhanced water movement which will promote infiltration of rainfall and water retention.

The high proportion of BD and Ksat values above the threshold shows that the soil did not present any degree of limitation to root growth and crop development in terms of soil compaction. The large proportion of sampling campaigns with SWC above the reference shows there were more drying cycles, especially in the soil surface, at the expense of wetting by rainfall during the growing cycle. Large exposed surface for evaporation during initial growth stage and late season and water uptake for transpiration by the maize plant in meeting the evaporative demand of the atmosphere could cause the low soil water content.

Effect of Tillage on Plant Growth Parameters: The effect of soil tillage on number of leaves (NOL), plant height (PH) and leaf area (LA) of the maize crop under different tillage methods is presented in Table 2. Number of leaf was significantly ($p<0.05$) affected by tillage at 4 and 6 WAP, with PL2 treatment having the highest value. At 9 WAP, there was non-significant effect of tillage on NOL. Plant height was significantly ($p<0.05$) influenced by tillage, the PL2 treatment giving the tallest plant. Similar result was also obtained for leaf area. The leaf area index (LAI), canopy cover (CC) and the relationship between canopy cover (CC) and leaf area index (LAI) of the maize crop due to tillage are shown in Fig. 6. The effect of tillage was significant ($p<0.05$) on both LAI and CC at 6 and 7 WAP, with PL+H having the highest values of LAI and CC (Fig. 6ab).

Plant growth parameters of plant height, number of leaf and stem girth are indicators of crop response to soil management and the overall productivity although vegetative growth does not really correspond to high productivity. The better growth parameters recorded from tillage with secondary operation (PL2 and PL + H) compared with just a single tillage operation (PL1) may be attributed to moderately higher BD, Ksatand SWC. The moderately high BD indicates a more compact structure with better soil-root contact which promotes enhanced water and nutrient extraction by plant roots. Furthermore, high Ksat promotes water movement due to high volume of transmission pores, hence better water availability to plant. Our findings are in line with those of [4] who found that ploughing and harrowing produced the tallest plant and highest number of leaves per maize plant at ten weeks after planting.

Leaf area and leaf area index are of great importance to photosynthesis and yield as the photosynthetic capacity of crops is a function of leaf area. [35] stated that leaf area is important for crop light interception and therefore has a large influence on crop yield. The more the LA, the more the canopy and the lesser the area of land exposed for evaporation, thus more water is conserved. In line with this study, Aikins *et al.* [4] also found the highest LA from disc ploughing followed by harrowing compared to other tillage treatments.

The estimated extinction coefficient, ×, was similar, about 0.5, for the different tillage treatment. This value was comparable with the 0.6 obtained for the same crop by [36]. The little difference in the values observed may be attributed to differences in climatic condition, source of water to replenish the root zone (by rainfall or irrigation), soil and crop management.

Yield and Yield Attributes: Soil tillage significantly ($p<0.05$) influenced biomass, yield and yield attributes of maize crop (Table 3). While PL1 treatment had the highest biomass, PL + H treatment gave the significantly highest 1000-grain weight, grain yield and harvest index, with the grain yield from PL + H treatment was about 3 and 8% greater than those of PL2 and PL1 treatments, respectively.

Comparing PL1 and PL2, biomass yield and 1000-grain weight were about 6 and 2% lower in PL2 compared to PL1 while cob weight, grain yield and harvest index were higher in PL2 by approximately 7, 5 and 10% in that order. In terms of maize performance, the order was PL + H > PL2 > PL1. When the soil is ploughed and harrowed or ploughed twice, clods are broken; the soil is more pulverized while decaying and decomposing plant residues are well incorporated. This makes the soil more porous, enabling better root proliferation and more soil volume is explored for water and nutrients.

The Pearson Correlation results of Table 4 showed that there was non-significant correlation between grain yield and growth parameters. LA was related to both PH and NOL but the relationship with NOL was significant. The regression equation for predicting yield from the growth parameters was found as: $Yield = 2983.34 + 167.87NOL - 1.42LA - 1.19PH, R^2 = 0.6142^{ns}$ which agrees with the results of correlation in terms of individual relationship with yield and level of significance. The variance explaining the prediction of yield from NOL, LA and PH was above average, indicating other factors such as soil properties and climatic conditions are also at play.

The better maize performance in PL + H may be attributed to soil loosening and pulverization by harrowing by providing favorable tilth to crop growth and yield. Optimum crop yields are dependent on optimum root growth by deep and expansive root system and this is possibly only when the soil is in good physical condition [37]. Our result is in line with the findings of [4] who found that the disc ploughing followed by disc harrowing treatment produced the highest dry cob weight and 1000-seed weight. However, the authors did not find significant effect of tillage practices on the variables.

Table 3: Effect of soil tillage on biomass, yield and yield components of the maize crop

Treatments	Biomass kg ha^{-1}	Cob weight, g $plant^{-1}$	1000-grain wt g	Grain yield, kg ha^{-1}	Harvest Index
PL1	9301a	114.4b	262.8b	3589c	0.386b
PL2	8800b	122.4a	258.5b	3788b	0.430ab
PL + H	8750b	120.2a	279.1a	3893a	0.445a
Mean	8950.3	119.0	266.8	3756.7	0.420

PL1: ploughing once, PL2: ploughing twice, PL + H: ploughing once followed by harrowing.

Table 4: Pearson correlation between grain yield and growth parameters

	Yield	NOL	LA	PH
Yield	1			
NOL	0.447	1		
LA	-0.033	0.778*	1	
PH	-0.162	0.474	0.588	1

*.Correlation is significant at the 0.05 level (2-tailed).

NOL: number of leaf; LA: leaf area; PH: plant height.

CONCLUSIONS

The effect of different land preparation methods on some hydro-physical properties on an alfisol and maize performance was investigated. Land preparation significantly influenced soil hydro-physical properties by increasing bulk density and decreasing saturated hydraulic conductivity. Soil water content was less than the threshold for over 50% of the sampling campaigns due to erratic rainfall during the growing period although it was not enough to cause crop physiological stress. Plant growth parameters, yield and yield attributes were significantly affected by land preparation. Under the soil and weather conditions of the experimental site, the best land preparation method identified for maize production in terms of soil physical condition and crop yield was double operations of either ploughing followed by harrowing or ploughing twice.

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