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Research Article

The Impact of Tillage and Weed Control Methods on Physical Properties of Sandy Clay Loam Forest Ochrosol in Cassava Cultivation

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The field study was carried out on a sandy clay loam forest ochrosol at Hodzo, near Ho in Ghana, from July 2017 to May 2018. The objective was to determine how tillage and weed control techniques affect the physical properties of the soil. The split-plot design was used in the study, with tillage serving as the main factor and weed control serving as the subplot factor. The tillage treatments were no tillage (NT), minimum tillage (MT), and ploughing followed by harrowing and ridging (PHR) and deep tillage followed by Ploughing, harrowing, and ridging (DPHR). On the other hand, the weed control treatments comprised hoe weeding, machete weeding, and no weeding. It was realised during the study that, in the upper layer (0–15 cm), the PHR treatment produced lower soil penetration resistance (38.57 kPa), high dry bulk density (1.019 Mgm^{-3}), and slightly lower soil moisture content (5.0%) in comparison with the other tillage treatments at three months after planting (3 MAP). The results on initial and basic infiltration rates portrayed a trend where the more intensive the tillage regime (hence, soil disturbance), the lower the initial and basic infiltration rates, and vice versa. Moreover, tillage had a higher impact on the physical characteristics of the soil than weed control methods. Nonetheless, tillage with machete weeding resulted in lower soil dry bulk density and higher moisture content, while tillage with hoe weeding reduced penetration resistance and increased infiltration rates. Given similar weather and soil conditions, the study recommends that farms and farmers in the Ho Municipality and the Volta Region adopt conservative tillage methods such as heaping with machete or hoe weeding and use the savings to expand their farm sizes. Therefore, the adoption of conservation tillage practices is more crucial than ever in order to ensure sustainable food production with minimal impact on the soil and environment.

1. Introduction

Soil tillage is an essential management technique that influences the physical properties of the soil and crop production [1]. Tillage makes up to 20% of the crop production parameters [2]. Enhancements of soil moisture storage and infiltration of water, weed control, root penetration, and provision of nutrients from rapid breakdown of organic matter are considered the greatest benefits of tillage to crop productivity [3–5]. Tillage may be described as conventional, reduced (minimum) or conservational if it maintains crop residue covering >30% of the soil surface after planting [6]. Howeler et al. [7] stated that, since root crops experience significant root development and, hence, grow best in loose or light-textured soils that do not solidify upon drying, they usually require more intensive tillage practices different from those of other crop types. Other reasons for this practice, according to the study, include the deeper planting depth of root crops and the intensive soil-disturbing operations carried out to harvest them, compared to other crop types such as cereals or legumes. The challenges with intensive tillage practices in root crop cultivation are the comparatively slower pace at which they establish complete canopy cover coupled with the considerable soil disturbance associated with their harvesting. The extent to which tillage systems can alter the physical characteristics of soil depends on a number of variables, including past cropping systems, soil type, prevailing climatic circumstances, and preceding tillage regime [8, 9]. Long-term conventional tillage can alter the soil's organic matter content, aggregate stability, pore volume, and overall soil structure [10, 11]. It also alters the characteristics of the soil by affecting the rate of soil infiltration and the flow of soil water. In no tillage, there is low labour and fuel cost, less soil compaction [12, 13], and 30–40 percent substantial time savings [14]. Other studies have also identified several benefits of conservation tillage for farming systems, such as reductions in crop establishment time due to moisture conservation and energy use, with their associated economic advantages [15, 16]; reduction in interrill erosion [17] and enhanced moisture storage and stabilisation of soil temperature fluctuations [18]; high infiltration rates and improvement of aggregate stability [19]; and reduction in weed population [20]. High levels of organic matter in soils tend to have lower bulk density. High bulk density indicates low soil porosity and most likely compaction, which presents poor conditions for cassava tuber expansion, occasioned by poor movement of air and water. Studies by Blevins and Frye [21] found no substantial effect of no-till on bulk density compared to plough-tillage systems. In contrast, Roth et al. [22] stated that, relative to the conventional tillage system, no-tillage and minimum tillage systems presented significantly lower bulk density at 20–30 cm depths. Jongruaysup et al. [23] had similar findings, attributing the trend in no-till plots to residue retention of the plant biomass. Balan et al. [24] examined the effects of three different soil tillage practices on soil porosity, including no tillage, reduced tillage, and conventional tillage. They discovered that no-tillage produces higher total porosity than conventional tillage, particularly at 0–10 cm depth.

Badalı´kova [25] found that the lower the tillage intensity, the higher the soil bulk density and the lower the total porosity; this accounted for the higher water content observed under no-till and minimum tillage planting systems in the soils sampled during the study. Over one growing season of Cowpea (*Vigna unguiculata L.*), Aikins and Afuakwa [19] noted that tillage practices significantly affect soil penetration resistance. The study also found higher soil penetration resistance in no-till plots while the lowest was recorded in the disc ploughing followed by disc harrowing plots. Tillage effects on penetration resistance for clayey soil were found to be significant at a soil depth of 0–40 cm. When compared to tilled plots, no-till treatments had higher penetration resistance values, which also rose with depth [26, 27]. The infiltration rate's responses to tillage methods vary. For example, Lindstrom and Onstad [28] found infiltration to be slower in soils under conservation tillage practices because these soils were denser or less susceptible to crust disturbance. Other studies have demonstrated that no-till, compared to ploughed soil, had higher infiltration rates (as in [29] and as similarly reported by [30]) or lower infiltration rates (as observed by [31]). Nonetheless, weed control is a very important aspect of any crop production enterprise. Although a method such as hand weeding with a hoe or machete is labour-intensive and consumes 50–70 per cent of total labour time [32], it is the most common among smallholder farmers in Ghana. Soil quality and crop growth are affected by the direct and indirect impacts of weed management, which can range from positive to negative [33]. Studies have proven the use of herbicides for weed control on farms to be relatively cheaper, provided such chemicals are applied at the right time and in technically recommended dosages [34]. These requirements, in addition to the high cost of such chemicals, are quite difficult for the average smallholder farmer to meet [35]; a situation which makes them rely on manual weeding. A three-year study by Islami et al. [36] in Indonesia found that mechanical weed control in cassava gave a higher yield and improved soil organic matter content and aggregate stability and was, hence, less erodible, compared to the chemical method.

Appah [37] determined the effect of tillage methods and weeding (hoeing) frequency on soil properties and yield of maize. The effect of tillage and weed control methods using different mechanical weed control treatments have rarely been investigated. Thus, it is important to study tillage and weed control methods (hoeing, machete weeding, and no weeding) and their interactions on soil physical properties under cassava production in Ghana. Consequently, this field study was undertaken in a sandy clay loam forest ochrosol from July 2017 to May 2018 at Hodzo near Ho in Ghana, to assess the impact of tillage and weed control methods on soil physical properties under cassava cultivation. It was hypothesised that different tillage and mechanical weed control methods will induce significant changes in soil physical properties, making it conducive for cassava cultivation.

2. Materials and Methods

2.1. Study Site. The test was conducted at CALTECH Farms in Hodzo, close to Ho. The area has latitudes between 6°207 and 6° 55, longitudes between 0°127 and 0°53, and a height between 60 and 152 meters above sea level and is drained by Volta Lake [38]. Figure 1 shows a map of the Ho Municipality and the location of the experimental site. The SW monsoons from the South Atlantic and the dry Harmattan winds from the Sahara had a significant impact on the tropical climate in the study area. The yearly mean temperature ranged from 16.5°C to 37.8°C, while the mean monthly temperature varied between 22°C and 32°C. The area is characterised by two distinct rainfall seasons in the year; the first runs from March to June (major season) and the second is from July to November (minor season). The maximum average yearly rainfall was 2,103 mm, and the minimum was 1,168 mm. The month of June experiences the highest average rainfall of 192 mm, while November experiences the lowest average rainfall of 20.1 mm. The area's

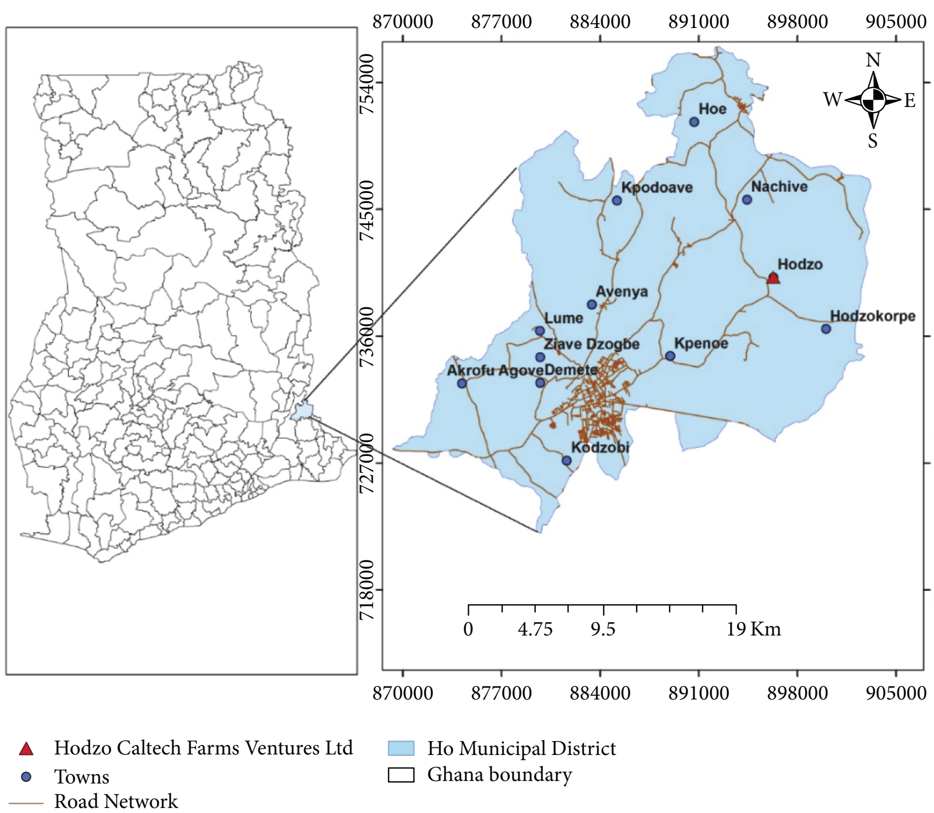

Figure 1: Map of Volta regional location showing study site (source: Ghana Statistical Service, GIS (2010 Population and Housing Census District Analytical Report, Ho Municipality, 2014)).

relative humidity hovers around 80% on average. Moist semideciduous forest made up the majority of the vegetation on the municipality's hills, while savannah woodland dominated the remaining area. The area is characterised by two types of soils: the savannah soils; and the forest ochrosols, lethosols, and intergrades, which are located in the mountainous and wetter northern regions. Selected physico-chemical soil parameters for the experimental site are shown in Table 1.

2.2. Experimental Design and Treatments. Three replications of the split-plot design in a randomized complete block design were used. The main factor on the main plots was tillage, with weed control on the subplots as the sub factor. The experimental area was divided into 12 main plots and 36 subplots. The main plots had dimensions of 15 m by 8 m with 2 m buffers, while the subplots measured 8 m by 5 m separated by 1.2 m buffers. The tillage treatments consisted of NT, MT in the form of heaping, PHR, and DPHR. Hoeing using the hand hoe, weeding by machete, and no weeding were the weed control treatments. Weeding was carried out at 2 MAP, 4 MAP, 6 MAP, and 8 MAP and after harvesting.

2.3. Data Collection. Data on the following soil physical properties were collected during the field experiment: dry bulk density, moisture content, penetration resistance, and infiltration rate. Except for data on infiltration capacity, all other soil data were taken before land preparation, three months after planting and after harvesting.

Table 1: Selected soil physico-chemical properties at the experimental site.

	Soil depth		
Soil property	0–15 cm	15–30 cm	30–60 cm
Sand (%)	67.13	76.00	75.72
Silt (%)	10.37	1.50	1.77
Clay (%)	22.50	22.25	22.25
Organic carbon (%)	0.93	0.19	1.29
EC (μs/cm^3)	279	397.00	87.40
pH H_2O	6.59	6.31	6.22
Total N (%)	0.13	0.07	0.05
Ca (cmol kg^{-1})	8.73	5.12	3.63
Mg (cmol kg^{-1})	1.77	0.99	0.65
K (cmol kg^{-1})	0.52	0.14	0.15
Available P (mg kg^{-1})	14.44	6.43	7.02
Na (cmol kg^{-1})	0.20	0.18	0.20

2.3.1. Dry Bulk Density and Moisture Content. At depths of 0–15 cm, 15–30 cm, and 30–60 cm, three sets of undisturbed soil samples were taken from each plot. The soil in the cylinder was trimmed to volume, weighed, and then dried for 24 hours at 105°C in an oven for the determination of dry bulk density and moisture content [39]. Dry bulk density was calculated and represented in Mgm^{-3} as follows:

Bulk density,

$$\rho b = \frac{W_2 - W_1}{V}, \quad (1)$$

where W_2 = weight of sample container + oven-dried soil, W_1 = weight of empty sample container, and V = volume of core cylinder.

Soil moisture content was determined by the gravimetric method and expressed as percentage moisture.

$$M_w(\%) = \frac{M_t - M_s}{M_s} \times 100, \quad (2)$$

where M_w = soil moisture content , M_s = mass of dry soil, and M_t = mass of moist soil.

2.3.2. Penetration Resistance. Ten penetrometer readings were taken on each plot using a pocket penetrometer, and the penetration resistance was expressed in $kgcm^{-2}$ and converted to kPa. The average of these readings was taken as the penetration resistance value for the plot.

2.3.3. Infiltration Rate. The double ring infiltrometer, which has outer and inner rings with diameters of 60 cm and 30 cm, was used to measure infiltration capacity [40]. Using a driving plate and a mallet, the inner ring was first pushed into the soil at a 5 cm depth, followed by the outer ring, after taking care to remove any surface impediments. The depth of both rings was checked with a spirit level, and the concentricity was checked with a steel tape.

A little straight rod was placed 10 cm above the ground in the middle of the inner ring. The outer ring was filled with water first, and the stop clock was set off just as the water level in the inner ring rose to the top of the rod. When the requisite amount of time had passed, the amount of water added to fill the top of the rod per unit of time was noted. The process was repeated several times at minute intervals of 1, 2, 5, 10, 15, 20, 25, and 30 where constant or near-constant readings were recorded as the basic infiltration rate.

The amount of infiltrated water per unit time defined as depth of water (d) was calculated as

$$d\,(\text{mm}) = \frac{4V}{\pi D^2} \times 10, \quad (3)$$

where V = volume of water added per unit time and D = diameter of inner ring.

The infiltration rate was calculated as follows [41]:

$$\text{Infiltration rate (mm/min)} = \frac{\text{Depth infiltrated (mm)}}{\text{Time interval (minutes)}}. \quad (4)$$

2.4. Field Crop Management. Stems of the *Bosome Nsia* or *Dzinu Ade* cassava variety were obtained from a farmer in the Ho Municipality and screened to remove diseased ones. Healthy stem cuttings, about 20–25 cm long, were planted with a machete in an inclined position at an angle of about 45°, with about a third of the cutting remaining above the ground [42]. A plant spacing of 1 m × 1 m was used, giving a total of 10,000 plants ha^{-1} (120 stakes per main plot). The experiment was rain-fed without chemical or mechanical pest and disease control, and no fertilizer was applied. After cutting off the tops, the tubers were harvested by hand lifting.

2.5. Data Analyses. The research data was analysed using inferential and descriptive statistics. The data collected was analysed with R-Statistical software version 3.6.0 [43]. In the context of descriptive statistics, tables and graphs were generated to describe soil physical properties such as dry bulk density, moisture content, penetration resistance, and infiltration rate in terms of tillage and weed control. With the inferential statistics, ANOVA and general linear models were used to determine the treatment and interaction effects of tillage and weed control methods on soil physical properties. Due to variations in moisture content and penetration resistance observed at different depths, as well as the very close average bulk densities, a factorial design analysis was performed to test for significant interaction effects of tillage and weed control measures at the respective depths at a significant level of 0.05.

3. Results

3.1. Tillage and Weed Control Methods' Effects on Physical Properties of Soil

3.1.1. Tillage Methods' Effect on Soil Dry Bulk Density. Tillage effect on dry bulk density at 0–15 cm, 15–30 cm, and 30–60 cm depths before land preparation, three months after planting (3 MAP), and after harvest is presented in Table 2. Over the period of the experiment, tillage methods influence soil dry bulk density significantly ($p < 0.05$) in the 0–15 cm and 30–60 cm layers at 3 MAP and after harvest. The trend is rather erratic. According to Logsdon and Karlen [44], the bulk density of the soil may fluctuate over time, but not always in a predictable way. Temporarily during a season, bulk density can rise or decline as a result of a number of variables, including the quantity and intensity of rainfall, the drying and wetting of the soil, the position of the land, and the type of crop, among others [45]. The highest soil dry bulk density at depths of 0–15 cm at 3 MAP and at harvest is recorded in DPHR plots and the lowest in the NT plots. At 3 MAP, the PHR plots recorded the highest value (1.128 Mgm^{-3}) and the DPHR plots the lowest value (1.109 Mgm^{-3}) in the bottom layer (30–60 cm). The highest dry bulk density in the upper layer after harvest is recorded in the DPHR and the lowest in NT plots. A similar pattern is observed at the 15–30 cm depths, although not statistically significant. The sharp decrease in soil dry bulk density across all tillage treatments at 3 MAP is very favourable for cassava establishment and, particularly, for the formation of tuberous roots (tuberization), the extent of which strongly predicts the eventual cassava root yield.

3.1.2. Weed Control Method's Effects on Soil Dry Bulk Density. In Table 3, we present the effect of weed control methods on dry bulk density under the *Dzinu Ade* cassava variety. There is no statistically significant effect of weed control treatments on dry bulk density across 0–15 cm, 15–30 cm, and 30–60 cm depths before tillage and after

Table 2: Tillage method's effect on soil dry bulk density.

Soil dry bulk density (mgm^{-3})									
	Depth (cm)								
	0–15	15–30	30–60	0–15	15–30	30–60	0–15	15–30	30–60
Tillage method	Before tillage			At 3 MAP			After harvest		
NT	1.201	1.364	1.302	1.013*	1.047	1.151*	1.182*	1.212	1.364*
MT	1.187	1.381	1.431	1.092*	1.109	1.182*	1.302*	1.364	1.423*
PHR	1.204	1.339	1.507	1.019*	1.078	1.128*	1.374*	1.397	1.393*
DPHR	1.193	1.400	1.502	1.114*	1.142	1.109*	1.628*	1.308	1.462*

Interpretation:* = significant difference at $p < 0.05$.

Table 3: Weed control method's effect on soil dry bulk density.

Soil dry bulk density (mgm^{-3})									
	Depth (cm)								
	0–15	15–30	30–60	0–15	15–30	30–60	0–15	15–30	30–60
Weed control method	Before tillage			At 3 MAP			After harvest		
Hoe	1.173	1.215	1.354	1.059*	1.094	1.142*	1.346	1.308	1.391
Machete	1.189	1.241	1.232	1.051*	1.109	1.126*	1.198	1.270	1.315
No weeding	1.146	1.285	1.318	1.124*	1.172	1.203*	1.323	1.289	1.323

Interpretation:* = significant difference at $p < 0.05$.

Table 4: Tillage method's effect on soil moisture content.

Soil moisture content (%)									
	Depth (cm)								
	0–15	15–30	30–60	0–15	15–30	30–60	0–15	15–30	30–60
Tillage method	Before tillage			At 3 MAP			After harvest		
NT	15.17	13.69	13.51	6.690	7.302	4.393	12.306*	14.050*	9.469*
MT	13.23	10.97	11.04	5.493	7.610	4.288	8.299*	8.883*	7.847*
PHR	16.25	12.79	13.29	4.989	6.831	5.703	5.281*	10.191*	8.585*
DPHR	16.16	14.84	11.90	3.780	6.400	6.925	3.645*	9.000*	6.908*

Interpretation: * = significant difference at $p < 0.05$.

harvest. The effects of all weed control measures on dry bulk density at 3 MAP in the 0–15 cm and 30–60 cm layers are, however, statistically significant. The lowest in both layers is recorded under machete weeding and the highest under no weeding. The 15–30 cm layers follow a similar trend but not at significant levels. Generally, soil dry bulk density is highest in no-weeding treatments in comparison to the hoe and the machete.

3.1.3. Tillage Method's Effect on Soil Moisture Content. The effect of land tillage methods on soil moisture content before tillage, at 3 MAP, and after harvest at 0–15 cm, 15–30 cm, and 30–60 cm depths is summarised in Table 4.

Although NT and MT exhibit increased moisture levels compared to plots under plough-till, there is no significant difference in the soil moisture content before tillage and at 3 MAP. After harvest, a significant difference in soil moisture content is observed in the upper and middle layers, with NT recording the highest, followed by MT, and the lowest in the DPHR plots. The middle layer recorded the highest moisture content across all the tillage treatments. Notably, whereas the moisture content in the upper layer (0–15 cm) of the conservation tillage plots is higher than the lower layer (30–60 cm), the opposite is seen in the conventional tillage plots.

3.1.4. Weed Control Method's Effect on Soil Moisture Content. Table 5 summarises measured soil moisture content under the various weed control regimes. Largely, the soil moisture content is highest across all depths before weed control treatment but not at statistically significant levels ($p > 0.05$). A significant decline and marginal recovery ($p < 0.05$) are noticed at 3 MAP and after harvest, respectively.

At 3 MAP and after harvest, the highest moisture content at all depths is seen under machete, followed by hoe, with the lowest in no-weeding treatment. The highest soil moisture is observed in the middle (15–30 cm) and the lowest in the upper (0–15 cm) layer.

3.1.5. Tillage Method's Effect on Penetration Resistance. Results on tillage effect on soil penetration resistance before tillage, 3 MAP, and after harvest at 0–15 cm, 15–30 cm, and 30–60 cm depths are presented in Table 6. The results show no significant difference before tillage, although penetration

Table 5: Weed control Method's effect on soil moisture content.

Soil moisture content (%)									
	Depth (cm)								
	0–15	15–30	30–60	0–15	15–30	30–60	0–15	15–30	30–60
Weed control method	Before tillage			At 3 MAP			After harvest		
Hoe	12.31	11.87	11.16	5.238*	7.036*	5.327*	7.383*	10.531*	8.202*
Machete	14.18	14.42	13.86	5.050*	7.040*	5.513*	8.772*	10.635*	8.568*
No weeding	13.23	14.74	13.52	4.324*	5.789*	5.297*	7.584*	9.652*	7.463*

Interpretation:* = significant difference at $p < 0.05$.

Table 6: Tillage method's effect on penetration resistance.

Soil penetration resistance (kPa)									
	Depth (cm)								
Tillage method	0–15	15–30	30–60	0–15	15–30	30–60	0–15	15–30	30–60
	Before tillage			At 3 MAP			After harvest		
NT	77.80	102.64	155.93	51.81*	72.24	130.76*	62.11*	52.30	98.07*
MT	92.18	116.70	159.52	53.28*	87.61	126.83*	34.32	77.47	123.40
PHR	84.99	131.41	148.08	38.57*	48.05	123.56*	101.34*	134.84	184.69*
DPHR	83.36	101.99	136.64	37.59*	49.03	91.53*	118.33*	97.25	150.37*

Interpretation:* = significant difference at $p < 0.05$.

Table 7: Weed control Method's effect on soil penetration resistance.

Soil penetration resistance (kPa)									
	Depth (cm)								
	0–15	15–30	30–60	0–15	15–30	30–60	0–15	15–30	30–60
Weed control	Before tillage			At 3 MAP			After harvest		
Hoe	75.62	101.21	144.53	45.31	64.23	118.17	78.27	86.85	130.61
Machete	82.75	108.35	132.23	48.67	73.80	111.39	90.10	100.11	143.63
No weeding	79.63	111.46	141.07	59.09	80.33	127.73	77.16	90.03	144.79

Interpretation:* = significant difference at $p < 0.05$.

resistance increases with depth. Soil penetration resistance is influenced by tillage and soil depth [46]. At 3 MAP and after harvest, all tillage treatments significantly influence penetration resistance at the top and bottom layers. Minimum and no-tillage plots show higher readings across the depths at 3 MAP, in contrast to PHR, with readings as low as 38.57 kPa; and DPHR had 37.59 kPa.

However, the opposite trend is observed after harvest, where the upper and lower layers in conventional tillage methods indicate markedly higher readings than in the conservation tillage plots.

3.1.6. Weed Control Method's Effect on Soil Penetration Resistance. In Table 7, we show the weed control method's effect on penetration resistance before tillage, at 3 MAP, and after harvest. None of the weed control treatments had a statistically significant effect on soil penetration resistance during the study. The pattern here is that penetration resistance increases with depth across treatments. The least resistance (45.31 kPa) at 3 MAP is recorded at the upper layer under hoe weeding, while the greatest (144.79 kPa) at the lower depth after harvest is read under no weeding.

In comparison with readings before tillage, soil penetration resistance decreases at 3 MAP but increases marginally after harvest in all three soil layers.

3.1.7. Effect of Tillage Methods on Infiltration Rate. Figure 2 displays the tillage method's effect on infiltration rate. Analysis of variance confirms that tillage significantly influences infiltration rate, with plots under conservation tillage regimes showing almost twice as high initial and basic infiltration rates as plots under conventional tillage treatments. Infiltration rates are higher under conservation tillage regimes, a situation attributable to contributing to flow-active macropores made by soil macro-organisms and/or roots of vegetation [47].

The highest initial infiltration rate (110.14 $mm{\cdot}hr^{-1}$) is recorded in no till, followed by MT (70.07 $mm{\cdot}hr^{-1}$). PHR and DPHR plots indicate lower (46.26 $mm{\cdot}hr^{-1}$ and 35.27 $mm{\cdot}hr^{-1}$, respectively) infiltration rates. After 15 minutes, a significant split (difference) in infiltration rates between plots under conservation tillage and those under conventional tillage systems is observed. This trend continues up to the end of the experiment (279 minutes or 4.65 hours).

3.1.8. Effects of Weed Control Methods on Infiltration Rate. Results on the effect of weed control methods on infiltration rate are shown in Figure 3. The various weed control treatments have no significant effect on the infiltration rate. Hoe, machete, and

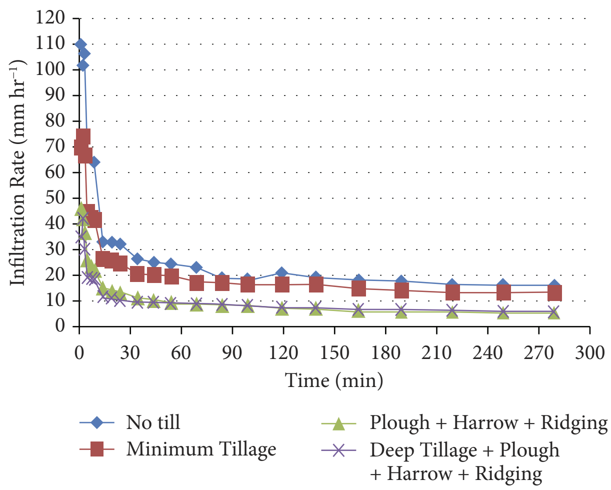

FIGURE 2: Effect of tillage methods on infiltration rate.

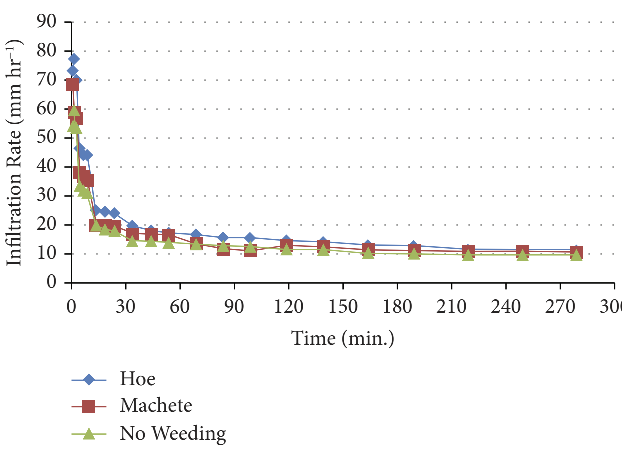

FIGURE 3: Effect of weed control methods on infiltration rate.

no weeding recorded 73.27 mm hr^{-1}, 68.89 mm hr^{-1}, and 54.14 mm hr^{-1} initial infiltration rates, respectively.

The results show similar basic infiltration rates under all weed control treatments although readings in hoe and machete weeding are marginally higher than in no weeding.

3.2. Tillage and Weed Control Methods' Interaction Effect on Soil Physical Properties

3.2.1. Tillage and Weed Control Methods' Interaction Effect on Dry Bulk Density. Results on the interaction effect of tillage and weed control methods on soil dry bulk density are summarised in Figure 4. Specifically, dry bulk density increases with depth across all treatment combinations. Analysis of variance (ANOVA) results show significant interaction effects on soil bulk density across treatments but not with depth. The soil bulk density across the various tillage and weed control techniques at different depths show very close mean values of around 1.20 Mg/m^3 across various possible interactions considered. The highest average bulk density (1.371 Mg/m^3) was observed in the upper layer (0–15 cm) of the DPHR and hoe combination. Moreover, MT with no weeding resulted in high bulk densities of

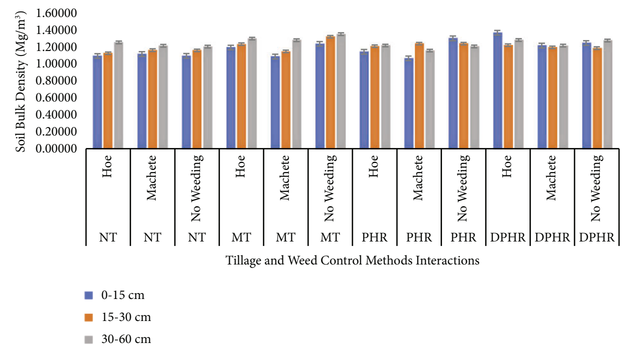

FIGURE 4: Tillage and weed control methods' interaction effect on soil dry bulk density.

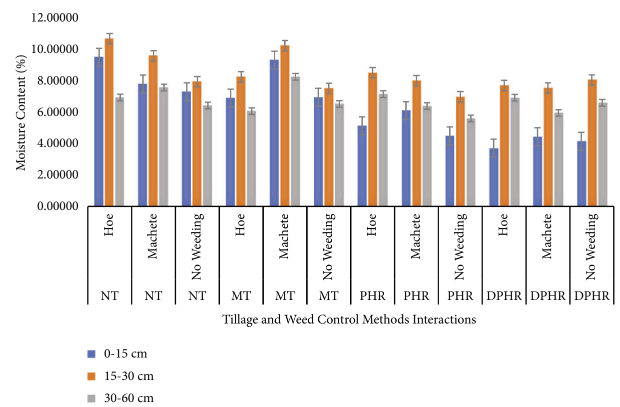

FIGURE 5: Tillage and weed control methods' interaction effect on moisture content.

1.325 Mg/m^3 and 1.356 Mg/m^3 at depths of 15–30 cm and 30–60 cm, respectively.

3.2.2. Tillage and Weed Control Methods' Interaction Effect on Moisture Content. Figure 5 shows the interaction effect of tillage and weed control methods on soil moisture content. The levels of weed control/tillage interaction effect on moisture content follow the trend, hoe on NT > machete on MT > hoe on PHR > no weeding on DPHR, all in the middle layer. The middle layer (15–30 cm) mostly has the highest soil moisture. In plots under conservation tillage with all weed control permutations, there is more moisture in the upper layer than the lower, while the converse holds for plots under conventional tillage. The highest average moisture content (10.676%) is observed at the middle layer in NT with the hoe, while the upper layer of DPHR with a hoe is the lowest (3.713%). ANOVA results show no significant interaction effects between tillage and weed control on moisture content.

3.2.3. Tillage and Weed Control Methods' Interaction Effect on Penetration Resistance. The interaction effect of tillage and weed control method combinations on soil penetration resistance is presented in Figure 6. The results show no significant difference ($p > 0.05$) in the interaction effect on

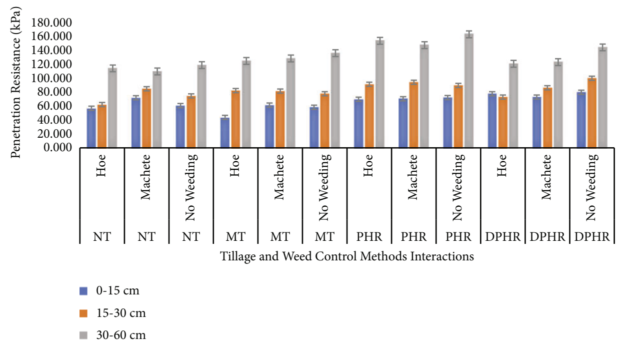

Figure 6: Tillage and weed control methods' interaction effect on penetration resistance.

Table 8: Tillage and weed control methods' interaction effect on bulk density, moisture content, and penetration resistance.

	Bulk density			Moisture content			Penetration resistance		
Tillage and weed control	0–15 cm	15–30 cm	30–60 cm	0–15 cm	15–30 cm	30–60 cm	0–15 cm	15–30 cm	30–60 cm
Tillage	0.002*	0.100	0.038*	<0.01*	0.040*	0.561	0.008*	0.285	0.002*
Weed control	0.022*	0.413	0.334	0.071	0.050	0.257	0.371	0.452	0.186
Tillage* weed control	0.080	0.345	0.950	0.139	0.194	0.200	0.700	0.774	0.981

*Significance factors at $p < 0.05$.

soil penetration resistance (Table 8). It is also observed that treatment combinations on conservation tillage plots recorded low resistance in the upper layer compared to those on conventional tillage plots. The bottom layer under PHR with no weeding is the most impenetrable (at 163.44 kPa), while the upper layer in MT with hoe offers the least penetration resistance to potential tuber development at 43.80 kPa. The results further show penetration resistance increasing with depth irrespective of the tillage and weed control permutations employed.

3.2.4. Tillage and Weed Control Methods' Interaction Effect on Infiltration Rate. Table 9 shows the interaction effect of tillage and weed control method combinations on infiltration rate. Overall, there was no significant interactive effect ($p > 0.05$) of the treatment combinations on infiltration rate. The results also reveal that tillage and hoe weeding combination treatments produce the highest basic infiltration rates, while the lowest is recorded in tillage and no weeding plots.

Table 9: Tillage and weed control methods' interaction effect on infiltration rate.

	Infiltration rate
Tillage × weed control	Basic infiltration rate (mm hr^{-1})
NT × hoe	13.64
NT × machete	13.470
NT × No weeding	12.816
MT × hoe	12.470
MT × machete	12.302
MT × no weeding	11.649
PHR × hoe	8.524
PHR × machete	8.356
PPHR × no weeding	7.703
DPHR × hoe	8.767
DPHR × machete	8.599
DPHR × no weeding	7.945

Interpretation: * = significant interaction at $p < 0.05$.

4. Discussion

Results from the study reveal that tillage and weed control treatments significantly influence all four soil physical properties examined: dry bulk density, moisture content, penetration resistance (mostly in the 0–15 cm and 30–60 cm depths), and infiltration rate. The level of changes in soil physical properties by tillage methods is substantial compared to the contribution of weed control treatments. Comparatively, tillage with machete weeding shows a positive interaction effect on bulk density and moisture retention, possibly due to less disruption of mulch cover and interconnected pores opening at the soil surface, and less exposure of the soil surface to evaporation. The lower dry bulk density observed under NT plots can be attributed to the presence of a vegetal cover with limited or no modification of soil stable aggregate and pore continuity improved by soil fauna over the lengthy fallow period at the site, as well as the high moisture retention from the two months (September and October) before sampling that saw relatively heavy rainfall [48].

This reflects similar findings reported in other studies by Jongruaysup et al. [23]; Sharma et al. [49] and Ordonez-Morales et al. [50] but contrasts with those reported by [51, 52], Osanyipeju and Dada [53] and Martins et al. [56] where bulk density is greater with conventional tillage than no tillage and minimum tillage. Jabro et al. [57] reported that lower bulk density in conventional tillage plots was associated with intense soil disturbance and disruption of aggregate stability, increasing the availability of pore spaces in conventional tillage and deep tillage systems compared to conservation tillage systems. The timing of the sampling can also have an impact on how much different tillage systems' bulk densities differ from one another [58].

Amegashie [59] maintains that intensive tillage treatments initially give lower dry bulk density but, due to the impact of raindrops over time, soil particles settle, subsequently leading to increased bulk density. This explains the sharp rise in bulk density after harvest on plots under conventional tillage systems where a rise in dry bulk density with tillage intensity is observed at the upper soil layer. Also, a study by Gbadesin et al. [60] on sandy loamy sand in the south-eastern forest zone of Nigeria discovered a statistically significant inverse relationship between bulk density and soil moisture content to the extent that rapid cassava tuberization led to a corresponding decrease in bulk density and moisture content in such soils.

While plough-till methods pulverise the soil surface, increase soil voids and encourage water admittance (as recognised by [37], moisture retention can be offset by the apparently little or no mulch cover and deep soil voids, which are flow-active, leading to moisture loss at upper layers through evaporation [61] and at greater depths by percolation. The higher moisture contents in no tillage and minimum tillage treatments with the lower layer in deep tillage is likely because of this phenomenon, a finding corroborated by Sharma et al. [49] and Lui et al. [62], although it is in contrast with those reported by Kurshid et al. (2006), Khan et al. [51] and Aikins and Afuakwa [19]. In comparison to conventional tillage systems, Filho et al. [63] noticed an increase in soil moisture content under NT and MT systems. There are two methods that can account for the protection of soil water provided by residue return in a conservation system. First, residue return raises albedo to lessen soil heat flux and aerodynamic resistance to lessen water losses and vapor flux [18]. According to Fabrizzi et al. [64], an improvement in soil protection from raindrop impact and an increase in soil moisture storage under conservation tillage systems are caused by decreased evaporation and increased soil infiltration. Reduced soil water infiltration is responsible for the lower moisture content seen in the tilled plots. The soil surface may have been exposed to moisture loss by evaporation due to the disturbance and disruption of soil macropores, soil aggregate and structure, and subsequent blockage of micropores by the impact of raindrops [65, 66]. The enhancement of water transmission characteristics caused by subsoiling activities in the deeper soil layers [67], which permits plants with deeper roots to access water and nutrients [66], could be the cause of the lowered bulk density and increased moisture content in the bottom layer (30–60 cm) of the DPHR plot. According to Jabro et al. [57], when analysing tillage effects on penetration resistance, penetration resistance must be considered together with moisture content as subsoiling leads to a decrease in penetration resistance (Tables 4 and 6). This is because water absorption weakens the soil structure, and a lower matric potential results in less cohesion between soil particles [68]. The increase in penetration resistance after harvest shows that penetration resistance is typically at its lowest right after tillage and gradually rises throughout the growing season as a result of climatic factors, rearrangement of the soil grains, and the mechanical load placed on the soil surface [69]. A comparison of the means of soil penetration resistance at various soil depths showed that the resistance to soil penetration increased as the soil depth ranged from 0–15 cm to 30–60 cm (Table 6). This is likely due to the internal soil friction and the overburden pressure brought on by farm machinery traffic [18, 70, 71].

While tillage and weed control treatment permutations have not shown significant interaction effects on penetration resistance, results indicate that tillage with hoe treatment combinations presents lower resistance in the upper (0–15 cm) and middle (15–30 cm) layers in comparison with other permutations. Appah [37] has reported similar findings under maize cultivation and attributed the trend to marked surface disturbance by hoeing. Results obtained by Olaoye [72] while working in Ferric Luvisols in Nigeria confirm the lower penetration resistance under the plough-till system confirmed in this study. Lower penetration resistance within the cassava root zone creates favourable conditions for tuber formation and subsequent thickening [73]. The higher penetration resistance in the no-till system may be due to nondisturbance of the soil surface, a situation which is in conformity with the findings of de Almeida et al. [27] and Aikins and Afuakwa [19].

Data from infiltration tests conducted from February to May of 2018 indicates a significant effect of tillage treatments. Higher initial and basic infiltration rates in no tillage and minimum tillage compared to ploughing followed by harrowing and ridging, and that preceded by deep tillage in this study suggests a trend where, the more intense the tillage system, the lower the initial and basic infiltration rates, and vice versa. This could be ascribed to the occurrence of undisturbed interconnecting pores that have been preserved by surface mulching and improved by soil macro-organisms, which quickly transmit water.

Additionally, under NT, root density may be higher close to the soil surface, especially when managed with a cover crop, which has the effect of loosening the soil and enhancing water percolation [74]. In sandy clay loam soil, Fatumah et al. [65] found an increased infiltration capacity of 20.3 mm/h for no tillage, which was 3.2% higher than conventional tillage (15.5 mm/h) and 4.2% more than deep tillage (14.3 mm/h) correlating with the findings of this study.

Findings by Horne et al. [73]; however, disagree with this outcome. But, as observed by Kutı´lek [74]; apart from pore size distribution, infiltration rate is also influenced by the existing continuity of pores or pathways usually found in plots under conservation tillage. Since the infiltration experiments were conducted between 7 MAP and 10 MAP, and given the relatively high clay content of the soil, settlement of particles [59], lower porosity and closed-pore openings may account for the low initial and basic infiltration rates in the plough-till plots. The infiltration rate under no-tillage and conventional tillage systems estimated by Amami et al. [31] also disagrees with our study. They found that, in the order of mouldboard plowing, tine cultivation, and no tillage, the investigated sandy clay loam soil's infiltration capacity was reduced. These contradictory results may, in some cases, be explained by the time variant in infiltration rate, which is typically high immediately after tillage operations but quickly declines a few weeks later, making it higher under no tillage and minimum tillage than in conventional tillage systems and occasionally even under the first wetting drying cycle [73].

Relatively high infiltration rates are required to minimise or prevent soil erosion and drain the root zone to increase aeration, facilitate growth and tuberization, and forestall long periods of ponding, which can cause cassava tubers to rot.

Aspects of the study that may constitute drawbacks are the fact that the experiment was carried out for one cropping season, and it has not yet been replicated in intergrade soils found in the wetter northern parts of the municipality.

5. Conclusion

Findings from the study affirm that tillage and weed control treatments significantly influenced all four soil physical properties, namely, dry bulk density, moisture content, penetration resistance (mostly in the upper and bottom layers), and infiltration rate. Also, the influence of tillage on soil physical properties was greater than that of weed control treatments. Regardless, tillage with machete weeding resulted in lower soil dry bulk density and higher moisture content, while tillage with hoe weeding reduced penetration resistance and increased infiltration rates. Relatively high infiltration rates observed in conservation tillage systems are required to minimise or prevent soil erosion and drain the root zone, to increase aeration, to facilitate growth and tuberization, and to forestall long periods of ponding which can cause cassava tubers to rot.

Under similar weather and soil conditions, the study recommends that farms and farmers in the Ho Municipality and the Volta Region adopt conservative tillage methods like heaping with machete or hoe weeding and use the savings to expand their farm sizes. The results may be useful in guiding decision-making for the popularisation of conservation tillage in the ochrosols of the study region.

Data Availability

The research data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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