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IMPACT OF CONTINUOUS CULTIVATION ON PHYSICAL PROPERTIES OF SOILS AT THE INSTITUTE FOR AGRICULTURAL RESEARCH FARM, SAMARU, KADUNA STATE, NIGERIA

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ABSTRACT

Changes in soil physical properties associated with continuous cultivation including natural grassland were compared in research Farm of Institute for Agricultural Research, Samaru. The study was conducted on pre-existing soil units identified from soil survey report of 1984. Soil profile pits were dug on each of the soil units, and soil samples were collected from the profiles and the site beyond the profiles for impact assessment. The result of analysis revealed a non-significant difference in coarsening of soil texture among all the soil units. Soil conditions were better in soil unit P2 than other soil units. The significant difference in soil moisture at permanent wilting point in soil unit A1 could be attributed to antecedent soil moisture content. The evidence from this study indicates that soil unit P2 offers only slightly greater improvement in soil physical properties compared to other soil units.

Keywords: Continuous cultivation; physical properties; soil and fertility

INTRODUCTION

Continuous cultivation has replaced shifting cultivation and bush fallow that were traditionally used to regenerate soil fertility in the savannah and has significantly decreased the nutrient level of the soil and its total fertility for a particular crop under cultivation, which, finally leads to a decrease in yield of the crops. Continuous cultivation practices alter soil physical properties, such as aeration and the degree of mixing of soil crop residues within the soil matrix. This affects particle size distribution, bulk density, and water holding capacity, field capacity, total porosity, and many others. Cropping system has immense effect on soil physical properties. Jaiyeoba (2003) reported that continuous cropping and intensive land use affects particle size distribution and that these changes resulted in increasing coarseness of texture over time. Demessie *et al*. (2012) reported that continuous cultivation results in the deterioration of soil physical properties such as increased bulk density and lower rate of infiltration. Continuous cultivation causes deterioration in the soil structure, leading to low porosity and poor pore continuity. The research farm of the Institute of Agricultural Research had been under continuous cultivation hence there is need to assess the impact of this cultivation on soil physical properties.

MATERIALS AND METHODS

The Study Area

The western and eastern boundaries of the study area are marked by approximately 7°34" E and 7°47" E longitude and the northern and southern boundaries by 11° 16" N and 11°50"N (Fig 1) The area covers about 227.8 hectares. The area has a mean annual rainfall of about 1011±161mm concentrated mainly in five months (May/June to September/October), and mean daily temperatures (minimum and maximum) range between 15°C and 38°C. There is a great range in the age, composition and structure of the underlying geology which include a Precambrian basement complex and an alluvial deposit from Bomo River (a tributary of River Shika) to the north-east. Based on FAO World Reference Base for Soil Resources (IUSS Working Group, 2014) soil classification system, the major soil groups in the area are Fluvisols, Ferralsols, Regosols and Luvisols

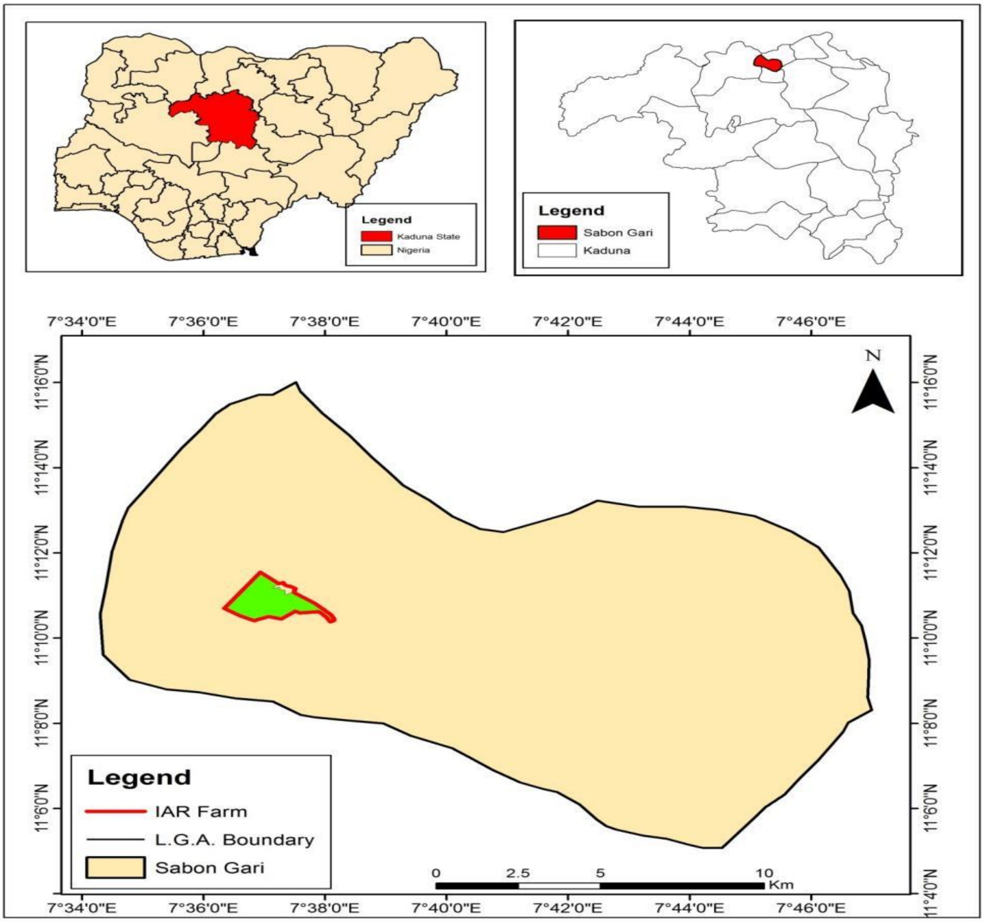

Figure 1. Map showing the location of the study area

Fieldwork

A total of 13 profiles were dug in 8 soil units identified from previous soil survey (Valette and Ibanga, 1984) and a Natural grassland in the farm were used for assessing the influence of land uses on soil physical properties. The natural grassland had no history of land use changes as it is well protected by the Research Institute. Soil units P1 to P7 and PP have been continuously under cultivation for the rainfed farming with varying cropping sequence. Soil units A1 to A2 have been continuously under irrigation and rainfed cultivation of different vegetables, rice and sugar cane.

Representative profiles (1 × 1 m) were located for each soil units and the Natural grassland. Within each soil unit and the Natural grassland, soil samples were collected using auger from five different points (at the four corners and at the centre of the plots). The soil samples were air-dried and crushed to pass through 2 mm sieve for the soil physical analysis. In addition, an undisturbed soil core samples were collected from each soil unit to determine the bulk density.

Laboratory Analysis

Particle size distribution was determined using hydrometer method (Gee and Or, 2002). Bulk density (ρb) was determined by core-sampling method (Blake and Hartge, (1986). Particle density (ρp) was measured with the liquid pycnometer method using de-aired water (Blake and Hartge, 1986). Available water capacity was determined by calculating the difference in moisture content at field capacity (33kPa) and permanent wilting point (1500kPa) pressure (Klute, 1986) using the pressure plate method. Total porosity (TP) was computed from the measurements of soil dry bulk density (ρb) and soil particle density (ρp) (Danielson and Sutherland, 1986) as:

$$TP(\%) = 100(1 - {}^{\rho b}/_{\rho p})$$

Hydraulic conductivity of soils was determined via the constant head permeameter method (Youngs, 1991).

Data Analysis

Soil units and soil depths were considered as main factors, the natural glass land served as the control. The various data on soil physical parameters were subjected to analysis of variance (ANOVA) using the general linear model (GLM) procedure of statistical analysis system (SAS) software, version 9.1 (SAS, 2001) to assess if the variations in the soil attributes among soil units and soils depths were significant or not. The mean comparison was done using fisher's least significant difference (LSD) test at $P < 0.05$ significant level.

RESULTS

Soil Physical Characteristic of the Site

The distribution of soil physical properties within the soil units is shown in Table 1. Sand fractions are usually the most dominant particle size fractions. The dominating coarser fractions (sand) could be of siliceous granite and gneiss parent material which are inert and resistant to further weathering (Yaqub *et al*., 2017). Omenihu and Opara-Nadi (2015) attributed high sand contents to pulverisation of soil due to repetitive tillage operation, preferential removal of clay by erosion and eluviation resulting in high residual accumulations of sand. All profiles in Table 1, show a lower clay fraction in the surface horizon and increases with increase in soil depth. The low clay content of the surface soil could be a characteristic of soils formed on Basement Complex (Maniyunda, 2012). The lowest values of clay fractions in topsoil might be attributed to relatively higher rate of eluviation of clay (Adugna and Abegaz, 2015), and cultivation due to clay mobilization by tillage in the plough layer (Asadu and Dixon, 2002).

Results in Table 1 shows a general decrease in silt content down the profile in most of the soil units except in soil units A1 and A2 where the distribution is irregular. High content of silt in the surface soils has been reported by many authors (Ya'u, 2015 and Ya'u and Maniyunda, 2018) who ascribed it to the influence of the Harmattan dust especially in the Northern Guinea Savannah of Nigeria. Deng *et al*. (2017) attributed high silt content on the surface soil to loessal deposit. The random distribution of silt in soil units A1 and A2 could be attributed to fact that these units received constant alluvial materials from Bomo dam. Senjobi and Ogunkunle (2011) attributed the irregularity in silt content of the profiles to the fact that silts are coarser than clay, which tend to restrict its movement with percolating water. The values of bulk density (Table 1) were below the critical value of 1.7 to 1.8 Mg m^{-3} for sandy soils and 1.4 to 1.65 Mg m^{-3} for clayey soil stated by FAO (2006), except for soils in units P2 and P3 which has bulk density value greater than the critical value at the lower horizon. The result of bulk density in this study implies that, the soils will support good plant growth and root penetration.

Low soil bulk density in these surface soils could be attributed to the loosening effect of tillage as a result of continuous cultivation and higher organic matter content. Aliyu (2022) reported a higher organic matter content in the soil surface of IAR farm. Ayolaha and Opene (2012) maintained that increase in bulk density with pedal depth could be resultant effect of decreased in organic matter, less aggregation and compaction caused by weight of the overlying soil layer. Ahukamere and Akpan (2012) concluded that clay migration into the subsoil was responsible for high bulk density in the subsoil.

The result of Particle density shows that the values (Table 1) were generally below 2.69 Mg m^{-3} indicating that quartz, feldspar, mica and other colloidal silicate clays with particle densities between 2.50 to 2.90 Mg m^{-3} are the most predominant minerals in these soils. Low particle density in the surface soil was attributed to low clay high sand contents and high organic matter accumulation. Idoga at al. (2007) maintained that organic matter weighs less than equal volume of mineral in the soil; thus, its presence in large quantities will markedly reduce the particle density. Malgwi *et al*. (2000) explained that lower particle density in B horizon may be attributed to lesser weathering of primary silicate minerals such as Kaolinite which dominated these horizons. Total porosity (Table 1) of the soil was greater than 25% (compacted range) and less than 66% (well aggregated) which favours good aeration, root penetration and free water movement except in soil unit P2 with value outside the range. High total porosity in the surface soil could be attributed to soil organic matter and loosening effect of cultivation. Low porosity in the other soil units is due to soil compaction, while high total porosity in the B horizons of those soils was as a result of higher clay content and good structural management (Awujoola, 1979).

Soil hydraulic conductivity was rated moderately low to moderate based on Ghildyal and Tripahtil (1971) ratings. Decrease in hydraulic conductivity with increase in soil depth was similar to the trend reported by Abubakar (2015) in DNPK field in Samaru. This trend was as a result of higher organic matter in the surface and increase in bulk density and clay content with depth. Abdulkadir and Habu (2013) reported that organic matter increases the availability of pore spaces. Abubakar (2015) observed that increase in clay content in subsoil will swell and clog conducting pore thereby, decrease hydraulic conductivity.

The result of the hydrological properties of the soil is presented in Table 1 which shows that the moisture content of the soil at field capacity (FC) increased with increase in soil depth in soil units P1, P2, P3, P7 and PP. With regard to soil moisture content at permanent wilting point (PWP) increased down the depth in soil units P1, P3, P4, P7 and PP; these could be attributed to increase in clay, downward movement of water through gravity and less evaporation in the sub surface soil. Dagnachew et al. (2019) stated that clay particles are finer in texture thus has better water retaining ability. Similarly, higher moisture content in the surface soils of soil units P5, P6 and NG, both at FC and PWP might be due to higher organic matter in the surface horizon. Oguike and Onwuka (2018) reported that high moisture content in soils were due to high organic matter which provided large surface area required for the absorption and retention of water molecules. The unsystematic pattern in the distribution of soil moisture at FC and PWP in soil units A1 and A2 could be attributed to textural differentiations within the profiles. According to Onweremadu et al. (2012) textural differentiations influenced movement of water in the soil on Soils of Different Lithosequences in South-eastern Nigeria.

The available water content (AWC) in all the soil units were lower than 9.5 to 12.5%, which is a range considered adequate for plant growth (FAO, 1979). The decrease in AWC with increase in soil depth except in soil units P7, PP and A1 could be due to high clay content, because clay creates a complex matrix of smaller pore which holds water at a high pressure making it less available (Sheppard and Hoyle, 2020).

Table 1: Soil physical and hydrological properties at Institute for Agricultural Research farm, Samaru

Soil Units	Hor	SD cm	Gravels	Clay g kg^{-1}	Silt	Sand	Textural class	BD mg m^{-3}	PD	TP %	Ks cm s^{-1}	FC %	PWP	AWC mm cm^{-}
P1				Latitude 11 º 10'36"N				Longitude 007 º 37'59"E						
	Ap	0-25	3.67	120.00	620.00	260.00	Silt loam	1.37	2.54	46.16	1.40	11.01	8.22	2.79
	Bt	25-74	10.67	340.00	200.00	460.00	Sandy clay loam	1.41	2.39	40.99	1.10	24.55	20.27	4.29
	Bt2	74-124	-	280.00	260.00	460.00	Sandy clay loam	1.40	2.62	46.67	1.12	22.08	19.57	2.50
	Bt3	124-165	6.00	280.00	280.00	440.00	Clay loam	1.22	2.30	47.05	1.57	23.13	19.42	3.71
P2				Latitude 11º10'47"N				Longitude 007º 37'12"E						
	Ap	0-32	2.67	120.00	420.00	460.00	Clay loam	1.33	2.36	43.79	2.25	19.55	13.74	6.81
	Bt	32-63	10.33	420.00	300.00	280.00	Clay	1.52	2.53	39.89	1.83	19.29	15.55	3.74
	Btcg1	63-90	11.00	320.00	340.00	340.00	Clay loam	1.21	2.33	48.19	5.76	20.06	18.02	2.04
	Btcg2	90-150	10.70	400.00	320.00	280.00	Clay	1.26	2.32	45.54	2.59	21.07	18.71	2.36
P3				Latitude 11 º 10'48" N				Longitude 007 º 30'11" E						
	Ap	0-14	3.67	120.00	400.00	480.00	Loam	1.26	2.25	44.01	2.73	19.15	10.68	8.48
	BE	14-27	4.00	220.00	240.00	540.00	Sandy clay loam	1.37	2.45	44.20	1.57	17.69	15.93	1.76
	Bt	27-53	13.00	360.00	260.00	380.00	Clay loam	1.53	2.65	42.23	2.24	20.00	17.88	2.12
	Btc	53-99	6.33	360.00	260.00	380.00	Clay loam	1.77	2.37	25.51	1.65	21.49	16.01	2.47
P4				Latitude 11o10'55"N				Longitude 007o 37'11"E						
	Ap	0-30	1.00	120.00	420.00	460.00	Clay loam	1.31	2.59	49.64	1.91	13.93	9.62	4.31
	Bt1	30-44	6.33	240.00	380.00	380.00	Sandy clay loam	1.57	2.55	38.46	1.21	8.94	5.73	3.22
	Bt2	44-80	-	420.00	300.00	280.00	Clay	1.62	2.51	38.02	0.64	21.48	18.63	2.85
	BCt	80-140	9.67	440.00	280.00	280.00	Clay	1.71	2.45	30.11	0.47	19.76	17.13	2.63
P5				Latitude 11º11'1"N				Longitude 007º 37'4" E						
	Ap	0-23	3.00	260.00	300.00	440.00	Clay loam	1.44	2.85	49.53	0.44	25.83	17.22	8.61
	Btc	23-60	16.33	400.00	240.00	360.00	Gravelly clay loam	1.50	2.87	47.65	1.21	19.35	14.92	4.43
	Bt	60-150	12.33	320.00	300.00	380.00	Clay loam	1.50	2.45	38.95	1.27	18.08	14.97	3.10
P6				Latitude 11º11'10"N				Longitude 007 º 37'20"E						
	Ap	0-30	14.67	120.00	500.00	380.00	Clay loam	1.49	2.38	37.43	1.21	19.50	14.34	5.16
	Bt1	30-59	25.67	160.00	400.00	440.00	Gravelly clay loam	1.60	2.47	35.39	1.82	19.37	15.53	3.84
	Bt2	59-97	22.67	320.00	300.00	380.00	Gravelly clay loam	1.61	2.45	34.38	1.82	18.41	14.87	3.53

Table 1cont.: Soil physical and hydrological properties at Institute for Agricultural Research Farm, Samaru

Soil	Hor	SD	Gravels	clay	Silt	Sand	Textural class	BD	PD	TP	Ks	FC	PWP	AWC
Units		cm		g kg^{-1}				mg m^{-3}		%	cm s^{-1}	%		mm cm^{-1}
P7				Latitude 11°11'27"N				Longitude 007 ° 36'54"E						
	Ap	0-13	8.67	60.00	420.00	520.00	Sandy loam	1.32	2.40	45.13	1.91	12.78	11.90	0.88
	Bt	13-26	10.67	220.00	280.00	500.00	Sandy clay loam	1.60	2.79	42.74	2.48	17.69	15.93	1.76
PP				Latitude 11°10'51"N				Longitude 007 ° 36'34"E						
	Ap	0-21	4.00	120.00	320.00	560.00	Sandy loam	1.61	2.48	34.78	0.87	10.17	8.31	1.86
	Bt	21-37	6.67	300.00	320.00	380.00	Clay loam	1.41	2.58	45.19	2.10	13.83	11.15	2.69
A1				Latitude 11 ° 10'58"N				Longitude 007 ° 37'33"E						
	Ap	0-20	9.00	100.00	440.00	460.00	Loam	1.41	2.04	31.01	1.75	20.31	19.01	1.30
	Btc	20-38	-	300.00	540.00	160.00	Silt clay loam	1.44	2.36	38.90	1.50	19.61	16.97	2.64
	Bt	38-88	14.67	140.00	420.00	440.00	Loam	1.31	2.48	36.96	2.01	28.49	26.50	2.00
	Btg	88-150	12.67	420.00	420.00	160.00	Silty clay	1.58	2.25	29.66	0.72	19.78	15.95	3.83
A2				Latitude 11 ° 11'19" N				Longitude 007 ° 37'12"E						
	Ap	0-24	3.67	140.00	380.00	480.00	Loam	1.44	2.13	32.19	0.42	19.69	16.11	3.58
	Bt1g	24-57	16.33	280.00	420.00	300.00	Gravelly clay loam	1.53	2.41	36.34	1.27	20.01	17.56	2.45
	Bg1	57-83	10.33	140.00	380.00	480.00	Loam	1.18	2.47	52.22	1.68	13.37	11.56	1.81
	Bt2g	83-111	23.00	260.00	420.00	320.00	Gravelly loam	1.13	2.59	56.45	2.10	21.72	19.35	2.36
	Bg2	111-150	6.33	160.00	300.00	540.00	Sandy loam	1.59	2.65	40.06	1.27	13.95	12.68	1.27
NG				Latitude 11 ° 10'31"N				Longitude 007 ° 36' 50"E						
	A	0-15	19.00	280.00	320.00	400.00	Clay loam	1.67	2.53	34.05	0.10	22.34	15.99	6.36
	Bt	15-60	25.67	220.00	400.00	380.00	Gravelly clay loam	1.42	2.51	43.38	1.85	19.59	15.91	3.69
	BCv	60-130	18.00	320.00	300.00	380.00	Gravelly clay loam	1.59	2.41	34.32	0.36	16.81	14.01	2.80

Hor=Horizons, SD=soil depth, BD=Bulk density, PD=Particle density, TP=Total porosity, Ks=Hydraulic conductivity, FC=moisture at field capacity, PWP=moisture at permanent wilting point, AWC= moisture at available water content

Impact of Continuous Cultivation on Soil Physical Properties

The non-significant variation in clay, silt and sand contents within the soil units (Table 2) indicates that soil the management practices did not have effect on particle size distribution. This result agrees with the findings of Omenihu and Opara-Nadi (2015) who reported that management practices do not affect soil texture. The highly significant difference in clay content with depth (Table 2) is an indication of the movement of clay size particles, higher rate of chemical weathering associated with high temperatures in the solum of the cultivated soil (Millette *et al.,* 1980), downward eluviation of clay (Aina, 1979) and in-situ synthesis of secondary clay or the residual accumulation of clayparticles from the selective dissolution of more soluble minerals of coarser grain size in the B horizon (Mengistu *et al.,* 2017). The significant difference in silt and sand contents with depth (Table 2) could be attributed to the eluviation of these particles during tillage operation.

The significant different in BD and high total porosity in soil unit P2 could be because the unit is a mango orchard, hence has high organic matter due to litter deposition. Several authors (Malgwi *et al*., 2000; Idoga *et al*., 2007; Ayolaha and Opene, 2012) reported that organic matter content is a major factor affecting the bulk density of soils. The similarity in particle density values (Table 2) in all the soil units and depths was due to similarity in the mineral composition of the soil (Awujoola, 1979).

High hydraulic conductivity (Ks) in soil unit P2 could be due to high root density and cracks which enhanced pore size distribution (Mann *et al.*, 2010). Similarly, high Ks in soil units P3, P7, PP and A1 could be due to alterations of soil structure and properties during tillage operations (Mohanty and Zhu, 2007). Low Ks in pedon NG might be attributed to the fact that the land was under natural grass hence not tilled, therefore, making it susceptible to surface crusting during rainfall, reducing their macroporosity and hydraulic conductivity (Carmeis Filho *et al*., 2016).

Higher moisture content at FC in soil unit P2 (Table 2) was attributed to the fact that the unit was under plantation hence, high in organic matter. Arévalo-Gardini et al. (2015) attributed increase moisture content at field capacity to higher content of organic matter. Similarly, Mwonga (1986), reported that organic matter increases water retention at low suctions but had little effect on the rate of release at high suctions. Higher moisture content at PWP in soil unit A1 maybe because the unit is lying on a lower slope thus high in clay content. Additionally, Oyedele et al. (2009) reported that the high amount of moisture retained at high soil potentials (PWP) was due to high clay content of the soil. Similarly, surface soil significantly retained less amount of water compared to the subsoil horizons ($P < 0.01$) and was due to significant amount of clay in the sub-soils compared to surface horizons. This was confirmed by the highly significant ($P < 0.001$) difference between the surface and subsoil (Table 2). High amount of water retained in soil unit P2 could also be attributed to high organic carbon.

Table 2: Impact of continuous cultivation on soil physical properties at the Institute for Agricultural Research Farm, Samaru

Soil units	Clay	Silt g kg^{-1}	Sand	BD	PD mg m^{-3}	TP %	Ks cm s^{-1}	FC	PWP %	AWC
P1	270	370	360	1.35 a-c	2.45 a-c	44.89 ab	1.46 bc	13.77 ab	11.62 b	2.16 ab
P2	220	325	455	1.20c	3.52 a-c	52.87 a	2.88 a	18.75 a	14.74 ab	4.02 ab
P3	180	333	490	1.48 a-c	2.51 a-c	40.72 ab	2.17 ab	15.37 ab	10.82 bc	4.55 a
P4	175	420	405	1.54 ab	2.42 bc	36.1 b	1.21 bc	10.60 b	7.55 c	3.06 ab
P5	240	350	455	1.30 a-c	2.76 a	37.12 b	1.04 bc	15.77 ab	11.88 b	3.89 ab
P6	185	412	455	1.21 bc	2.43 bc	45.83 ab	1.46 bc	16.15 ab	12.53 ab	3.39 ab
P7	135	370	475	1.59 a	2.63 ab	37.72 ab	2.04 ab	14.41 ab	13.09 ab	1.31 b
PP	125	330	364	1.41 a-c	2.61 ab	45.83 ab	1.80 a-c	13.14 ab	11.27 bc	1.87 ab
A1	220	395	385	1.48 a-c	2.40 bc	37.63 b	1.93 a-c	17.93 a	16.23 a	1.70 b
A2	155	370	425	1.41 a-c	2.30 c	38.75 b	1.18 bc	15.44 ab	13.48 ab	1.96 ab
NG	230	375	372.5	1.46 a-c	2.54 a-c	42.53 ab	0.86 c	15.82 ab	12.94 ab	3.03 ab
SE±	41.330	42.674	57.342	0.103	0.084	4.381	0.353	1.712	1.274	0.840
LOS	NS	NS	NS	*	*	*	**	*	**	*
Depth										
surface	124.55 b	393.64 a	477.73 a	1.41	2.48	44.58	1.51	14.61	11.31 b	3.26
subsurface	268.64 a	333.64 b	369.91 b	1.39	2.53	42.26	1.78	15.78	13.45 a	2.36
SE	17.620	18.194	24.451	0.043	0.042	1.874	0.153	0.732	0.541	0.360
LOS	***	*	**	NS	NS	NS	NS	NS	**	NS

LOS (P): NS > 0.05, * ≤ 0.05, ** ≤ 0.01, *** ≤ 0.001 at 5%

SE= standard error, LOS= level of significance, NS= non-significant

BD=Bulk density, PD=Particle density, TP=Total porosity, Ks=Hydraulic conductivity, FC= Moisture content at field capacity, PWP=Moisture at permanent wilting point, AWC=available water content

CONCLUSION

The result of the study indicates that the bulk density of the soils in all the soil units were optimum for crop production and particle densities were generally less than 2.69 Mgm^{-3}. Total porosity of the soil was greater than 25% for compacted range and less than 66% for well aggregation range. The preceding analysis suggested that continuous cultivation did not exert any influence on soil particle size fraction; however, there was significant difference with depth. The result of the study indicates that soil unit P2 was relatively better in all the physical parameters of the soil due to the influence of mango orchard that improves the organic matter content of the soil. The evidence from this study indicates that soil unit P2 offers only slightly greater improvement in soil physical properties compared to other soil units.

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