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Effects of Mulching on Soil Hydro-Physical Properties in Kibaale Sub-catchment, South Central Uganda

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Abstract Mulching is one of the major soil and water conservation measures applied for conserving soil moisture and modifying soil physical and chemical environment. The study aimed at assessing the effect of mulching on soil hydro-physical properties in Kibaale sub-catchment in South Central Uganda. Samples were obtained between 0-20 cm depths and under 0, 5, 10 and 15 cm mulch thickness levels. The experiment involved 3 farmers and 4 treatments of corn residue mulch thicknesses each replicated thrice on each of the farmer sites. The main parameters of study were; bulk density, saturated hydraulic conductivity ($K_{sat)}$ and water retention. The parameters were determined using core method, constant head method and pressure plates' method respectively. Laboratory data was statistically analyzed using Analysis of Variance (ANOVA) from Genstat software Edition 4 and the means differentiated using 5 % least significant difference (LSD). The application of mulch significantly improved all the soil hydro-physical properties that were studied (bulk density, K_{sat}, field capacity, wilting point, porosity, soil organic matter (SOM), mean weight diameter (MWD) after two seasons. The level of improvement was highest with 10 cm mulch thickness while K_{sat}, porosity and SOM varied significantly ($P < 0.05$) with mulch thickness. The study recommends the use of 10 cm mulch thickness. This study provides information to stakeholders such as agricultural experts, watershed managers, farmers and policy makers which will help in formulating guidelines on how to incorporate mulching as an effective method for soil and water conservation in the Sub-catchment.

***Keywords**: Uganda, Kibaale sub-catchment, mulching, soil hydro-physical properties, soil organic matter, corn residue*

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1. Introduction

The estimate of global land degradation according to [16] is that a quarter of the land has been degraded. Majority of the people depend on degraded and marginal lands for their livelihood with 42 % of the poor compared with 32 % of the moderately poor and 15 % of the non-poor [21]. Many developing countries are under pressure because of high population growth rate on the already degraded land, increasing poverty levels and thus threatening per capita food production [10]. Soil erosion, soil nutrient depletion and soil moisture stress are non-anthropogenic forms of land degradation [10] that have been linked to constraining the agricultural sector [1]. These three forms of degradation have been identified in Lake Victoria Basin (LVB) of which Kibaale sub-catchment is part [18,40]. The infertile soils in this area make efforts to increase food production to support the increasing population futile. Therefore, smallholder farmers in East Africa have resorted to the use of soil and water conservation measures to overcome the effects of soil degradation on food production at farm level [10].

Mulching is one of the measures of soil and water conservation that is widely adopted for banana land use in Uganda [3,18,31,39]. The results from these studies show significance of the parameters (water retention and bulk density) to crop growth conditions. In East Africa especially Uganda, Tanzania and Kenya, intercropping for green manure is rare because of fear of competition for soil moisture [13]. The disappearance of the mulch on the soils has been worsened by human export of crop residues, high termite activity and the long dry seasons. Uganda's banana per capita annual consumption is averaged to 1 kg per person per day, ranked highest in the world [36]. Despite the high dependency on bananas and having its traditional roots in central part of Uganda [2], the yield of bananas is on a decline [34]. Soil erosion, nutrient depletion and poor land management are identified as the major reasons for the decline [40].

Considering the high rate of soil degradation vis-à-vis the high dependence on banana as a traditional food crop in this area, food security in Kibaale sub-catchment becomes a challenge given the growing population. The high population growth rate and an equivalent food demand have resulted into encroachment on the fragile lands. Human activities like cultivation on steep slopes, bottom swamps and overgrazing have taken lead in trying to meet population food demands. However, these activities do not incorporate improvement in land management which has largely exposed the soils to agents of degradation thus impacting negatively on soil hydro-physical properties. The degraded soils have therefore contributed to banana yields decline in the catchment. Bananas grow better under relatively high humidity and well drained loam soils with humus content [43] and such conditions (well drained loam soils with humus content) can be provided through mulching. In Kibaale sub-catchment, lack of irrigation in crop farming had resulted in soil moisture stress contributing to low crop yields. Although mulch materials are available to re-instate low productivity of the soils, little work had been done on correct application of mulch materials in the Kibaale sub-catchment [25]. Therefore, additional documentation on the recommended mulch thickness in relation to soil hydro-physical properties improvement in Kibaale sub-catchment was required.

2. Materials and Methods

2.1. Study Area Characteristics

Kibaale sub-catchment is geographically located in Rakai District in south central Uganda, and located between 0^0 35'-1^0 00' S and 31^0 15'- 31^0 48' E. Rakai District is the closest district to the Lake Victoria Basin. The total land area of Kibaale sub- catchment is 147.3 km^2 and it is part of a large catchment of Bukora which covers an area of 839.7 km^2. It is drained by river Kibaale which drains from Lake Kijanebarola extending to the west towards Lake Victoria. The rainfall is bi-modal occurring generally between March-May and October-December. According to [37], fifteen soil units were identified in Rakai District based on FAO classification. However, the dominant soil units in Kibaale Sub-catchment are Regosols (41.4 %), Luvisols (22 %) and planosols (16.62 %). Majority of the people in Rakai practise mixed cropping alongside other land uses like grazing especially in the Lake Victoria plain. Crops grown range from perennials to annuals and pastures. Bananas, coffee, beans, cassava, sweet potatoes and Irish potatoes are cultivated here. Agriculture here is at subsistence level and it employs over 90 % of the people [15]. The map of the study area is presented in Figure 1 below:

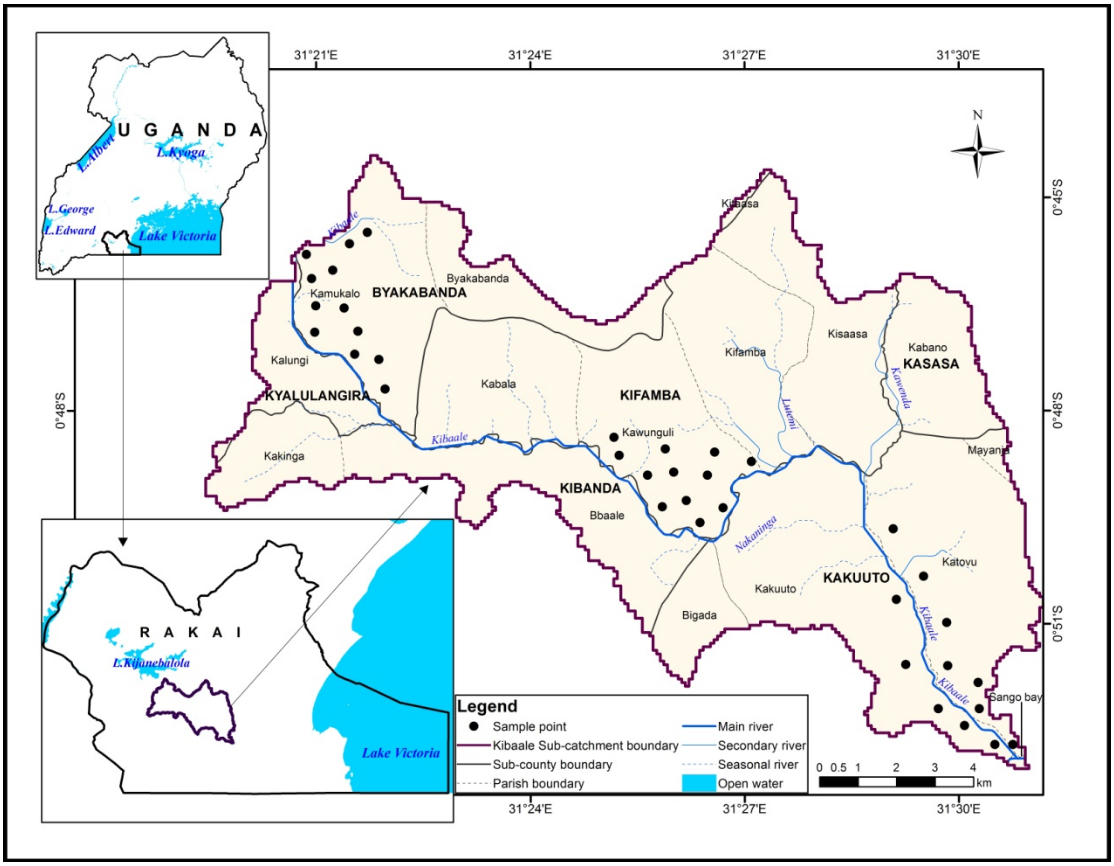

Figure 1. Map of the study area

Source: Generated from Topographic Maps.

2.2. Experimental design

The experiment was set up on thirty six (36) plots of 2 x 9 m on selected banana gardens of the same maturity (planted in the year 2000). The experiment involved 3 farmers, 4 treatments of corn residue mulch thicknesses (0, 5, 10 and 15 cm); the 0 cm mulch being the control as seen in Figure 2. Each treatment was replicated thrice on each of the farmer site. The mulch application rates were based on a number of studies. [7] showed that maximum benefits were attained at 10 cm mulch thickness which is in agreement with other studies by [11] and [17]. The slope gradient was determined using a clinometer and all the plots were at 8% gradient. The experiment was monitored for two cropping seasons (October- December, 2013 and March–May, 2014). The plots were maintained for the entire trial duration and mulch was not applied again in the second season as recommended by [38]. A manual rain gauge was installed at each of the farmers' site to keep record of the daily rainfall received. The selected sites were characterised before experimental set up. Soil porosity and organic matter were analysed following procedures described by [27] while soil structure (MWD) was determined using a dry sieving technique as described by [6]. The different parameters were monitored at the beginning of the season (before mulch application) and at the end of the season for both seasons (October- December, 2013 and March–May, 2014). The monitoring process involved; site characterization and then soil samples collection at the start of the season and at the end of each of the planting seasons in the set plots.

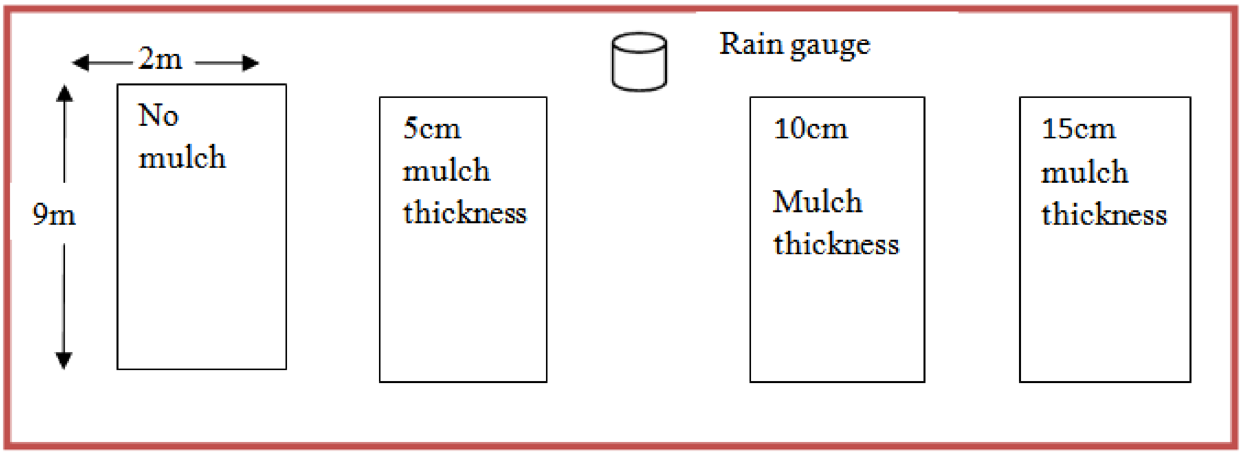

Figure 2. Experimental lay out

2.3. Site Characterization

Composite soil samples were collected on undisturbed soils after the experimentation layout. Plant litter on the surface was removed before sampling was done. The samples were collected from four locations on each of the three farmer selected gardens. The selected gardens were under banana land use because the amount of organic matter is strongly related to land use, climate and Terrain [8]. In addition, all the gardens selected had been under banana land use for thirteen years. The entire three farmers had the same slope angle of 8 %. Slope is a key parameter because bulk density, water retention and hydraulic conductivity can be affected by slope gradient [42].

2.4. Soil Water Retention

A total of 96 soil samples were randomly collected from each plot at 0-20 cm depth using soil core sampler. The soil samples were taken to Makerere University Soil Science laboratory and analyzed for soil water retention at field capacity (-33 kPa) and wilting point (-1500 kPa) using Pressure Plates as described by [28].

2.5. Soil Bulk Density

A total of 48 undisturbed soil samples were collected using soil core samplers and taken to the laboratory for analysis of bulk density using the core method as described by [4].

2.6. Soil Hydraulic Conductivity

48 soil samples were collected from the treatments using core samplers and saturated hydraulic conductivity was determined using the constant head method as described by [20].

2.7. Rainfall Amount Measurements

Rainfall in the study area was collected for each storm event using non-recording rain gauge at each farmer site. The daily rainfall amounts were added to obtain monthly totals and seasonal totals.

2.8. Other Soil Analyses

Other measured soil parameters includes soil organic matter (SOM) and mean weight Diameter (MWD) of aggregates as an indication of structure. Soil organic matter was determined using Walkley-Black method [24] and MWD was measured using the dry sieving technique described by [6]. The soil samples were passed through a 10 mm sieve before analysis [14] and later passed through a nest of concentric rings with different but declining sieve sizes: 6.36, 4.75, 2, 1.18, 0.53 and 0.25 mm. A sieve shaker was set at amplitude 5 for 30 minutes.

2.9. Data Analysis

To determine the effect of mulches on soil hydro-physical properties, obtained values were entered in Microsoft Excel and later imported to Genstat Discovery Edition 4 for statistical analysis. Water retention, hydraulic conductivity and bulk density means for the two seasons from the four treatments were analyzed using ANOVA. Differences between individual means were tested using the LSD at 5 % for significance.

3. Results

3.1. Effects of Mulch on Selected Soil Hydro-Physical Parameters

Table 1 shows the values of the selected soil hydro-physical parameters for all the different levels of mulch.

Bulk density ranged between 1.335 and 1.343 gcm^{-3}. Bulk density was relatively highest with 15 cm mulch thickness and lowest at 10 cm mulch thickness. Field capacity (FC) also ranged between 32.680 at 0 cm and 33.810 % at 10 cm mulch thickness. FC was highest (33.810 %) at 10 cm mulch thickness and retained least amount of water (32.680 %) at control (0 cm) mulch level. On the other hand, mean weight diameter ranged between 5.97 at control to 6.176 mm at 10 cm thickness, with the latter being indicative of good soil structure and the former being indicative of poor soil structure. The highest amount of water retained at wilting point (20.090 %) was at 15 cm thickness compared to the lowest (18.910 %) at 5 cm mulch thickness level. Saturated hydraulic conductivity (K_{sat}) ranged from 0.681 to 0.619 cm/h. However, only K_{sat}, SOM, and soil porosity significantly varied with mulch thickness ($P \leq 0.05$). K_{sat} was higher for 10 cm mulch thickness compared to the other mulch thicknesses (P = 0.014). There were two groups of SOM pairwise significantly different (0 cm and 5 cm) and (10 cm and 15 cm), the latter having greater concentration of SOM than the first group. 0 cm had the lowest value of soil porosity compared to the 5 and 15 cm. Soil porosity for 10 cm mulch thickness was not significantly different from the other mulch thicknesses.

Table 1. Effects of Mulch on Selected Soil Properties under Banana (thickness levels)

	Bulk density, g/cm^3	Saturated hydraulic conductivity, cm/h	Field capacity, %	Wilting Point, %	Organic matter, %	Porosity	MWD, mm
Control	1.335	0.681^a	32.680	19.000	2.340^a	14.060^a	5.977
5cm	1.334	0.640^a	33.060	18.910	2.600^a	16.860^b	6.025
10cm	1.332	0.750^b	33.810	19.760	3.755^b	16.080^b	6.176
15cm	1.343	0.619^a	32.810	20.090	3.074^b	16.390^b	6.062
LSD, 0.05	NS	0.107	NS	NS	0.626	2.259	NS
Prob	0.619	0.014*	0.434	0.165	0.001*	0.001*	0.147

*: Statistically significant at 0.05; same letters (a and a or b and b) are not statistically different and different letters (a and b or b and ab) are statistically different.

Table 2 shows the seasonal effect of mulching on the selected hydro-physical properties. All the parameters were significantly affected by season (P = 0.001). All the hydro-physical soil properties were significantly improved after the second season. Soil bulk density in the first season improved from 1.364 to 1.307 g/cm^3 in the second season. Ksat also changed in the first season from 0.549 to 0.786 cm/h in the second season. The change in field capacity was also significant with season; from 31.090 % in the first season to 70.170 % in the second season. Additionally, water retained at field capacity also positively changed from 16.895 to 21.980 %. SOM and soil porosity were not exceptional from the positive significant changes due to seasons from mulch application. The two parameters changed from 1.972 to 3.913 % and 13.055 to 18.640 respectively. Mean weight diameter also showed a positive change from 5.958 to 6.163 mm, but the change was not statistically different when compared to the LSD of 0.490 (Table 2).

Table 2. Effects of Mulch on Selected Soil properties Under Banana (First season compared to second season)

	Bulk densityg/cm^3	Saturated hydraulic conductivity, cm/h	Field capacity, %	Wilting Point, %	Organic matter, %	Porosity	MWD, mm
First season (October-Dec, 2013)	1.364^a	0.549^a	31.090^a	16.895^a	1.972^a	13.055^a	5.958^a
Second season (March-May, 2014	1.307^b	0.786^b	70.170^b	21.980^b	3.913^b	18.640^b	6.163^a
LSD, 0.05	0.017	0.087	1.475	1.223	0.490	1.517	0.490
Prob.	0.001	0.001	0.001	0.001	0.001	0.001	0.001

*: statistically significant at 0.05, same letters (a and a) are not statistically different while different letters (a and b) are statistically different.

4. Discussions

4.1. Soil Bulk Density

The ideal soil bulk density ranges are 1.0 to 1.6 mg/m^3 and 1.2 to 1.8 mg/m^3 for clay and sand respectively with potential root restriction occurring at ≥ 1.4 mg/m^3 for clay and ≥ 1.6 mg/m^3 for sand [5]. Therefore, from the bulk density values obtained (ranged between 1.300 and 1.343 g/cm^3) (Table 1 and Table 2), the soils of Kibaale sub-catchment are considered to be of good quality and health [5] since soil bulk density is used as a measure of soil quality and health. The improvement in soil organic matter, soil structure and soil porosity (Table 1 and Table 2) could have led to the subsequent improvement in soil bulk density over time. These results are in line with those of [5] and [26] who found that soil bulk density depended on soil compaction, soil organic matter and soil porosity and equally improved over time due to mulch application. The correlation analysis in this study showed a strong negative correlation (r = -0.966) between the soil bulk density and soil organic matter (Table 3 and Figure 3). This means that as organic matter increases, bulk density decreases and vice versa. A number of authors have made similar observation of a strong correlation between soil bulk density and soil organic matter [5,32,33].

Furthermore, the moisture content from the added mulch and rainfall events, which was more in the second season (Figure 15), also contributed to improvement in the soil bulk density. Similar results were obtained by [23], where soil moisture content decreased bulk density from 402.1 to 360 kg/m^3. The lower soil bulk density value at 10 cm mulch thickness can further be explained by the large amount of mulch that was applied compared to the control (0 cm and 5 cm). However, this would translate that the 15 cm mulch thickness would ideally result into the lowest value of soil bulk density. This difference is hardly explained even in similar findings [7,11,17]. These studies also attained maximum yield at 10 cm mulch thickness.

4.2. Saturated Hydraulic Conductivity (K.$_{sat}$)

The significant difference of saturated hydraulic conductivity obtained due to mulch thickness (*P* = 0.014) (Table 1) and change in season (*P* = 0.001) (Table 2) could be attributed to improvement in soil porosity (*P* = 0.001) as a result of mulching (Table 1 and Table 2). Mulching increased the soil porosity which in turn led to significant improvement in the saturated hydraulic conductivity. The larger the soil pores, the more water is easily transmitted through the soils. These findings are in agreement with those of [44]. [12] also reiterated that saturated hydraulic conductivity is largely associated with the soil porosity and pore size distribution. The correlation analysis showed a strong positive association (r = 0.9178) between the soil porosity and saturated hydraulic conductivity (Table 3 and Figure 6). [45] made similar observation and attributed water movement through the soil to the soil's structure.

4.3. Water at Field Capacity and Wilting Point

The increase in the amount of water retained at field capacity and wilting point over the season can be attributed to the greater amount of rains that was received in the second season (March-May, 2014) compared to the first season (October-December, 2013) (Figure 15). In addition, the increased amount of water in the soil can be related to the surface organic mulch which reduced water and soil losses through surface run off. [35] also found that surface organic mulch is capable of storing more precipitation water in the soil by reducing storm runoff, increasing soil infiltration and decreasing evaporation. Studies have also shown that higher amount of water is held at field capacity at lower bulk densities. [12] found a strong negative correlation (r = -0.863) between amount of soil water held at field capacity and the soil bulk density. This implies that the higher the bulk density, the less the amount of water held in the soil at field capacity and vice versa. This is because bulk density is used as a measure of soil compaction and health [9]. Therefore, at lower soil bulk densities, the soils are less compacted thus being able to retain water.

4.4. Soil Porosity

Soil bulk density is inversely proportional to the soil porosity. This study confirms the relationship between soil bulk density and porosity in which a strong negative correlation (r = -0.9149) between the two properties was obtained (Table 3 and Figure 4). This is similar to findings by [5] who also found a strong negative correlation (r = -1) between soil bulk density and porosity. The significant improvement in soil organic matter (Table 1) subsequently reduced soil compaction and bulk density of the soil. Good soil compaction leads to aggregate stability thus increasing pore size and volume.

4.5. Soil Organic Matter

The study shows significant improvement in soil organic matter due to mulch application and seasons (*P* = 0.001) (Table 1 and Table 2). Soil organic matter improved due to organic corn materials/residues that were added to the soils which later decomposed over time. Mean weight diameter and soil organic matter (SOM) are closely related. Soil organic matter improves soil aggregate stability [30]. Therefore, the significant improvement in mean weight diameter of the soil was due to soil organic matter improvement. The correlation analysis in this study showed strong positive relationship (r = 0.8994) between the soil organic matter and mean weight diameter (Table 3 and Figure 5). [41] indicated that reduction in soil organic matter translates into adverse effects of water logging and soil structure destruction.

Table 3. Relationship between Hydro-Physical properties

Soil parameters	Correlation(r) coefficient	Relationship strength
Bulk density and organic matter content	-0.9660	Strong negative correlation
Bulk density and Porosity	-1	Strong negative correlation
Organic matter and Mean weight Diameter	0.8994	Strong positive correlation
Saturated hydraulic conductivity and Porosity	0.9788	Strong positive correlation

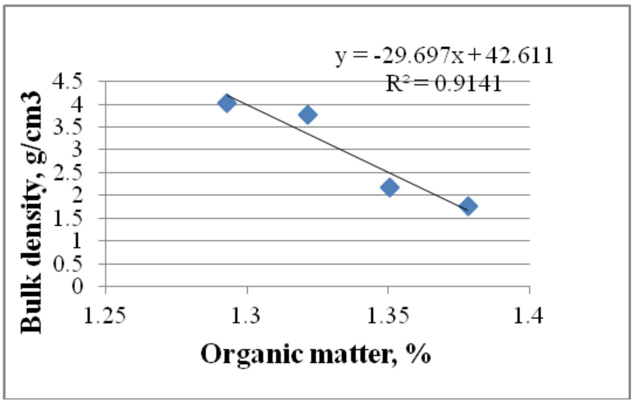

Figure 3. Relationship between SOM and Bulk density

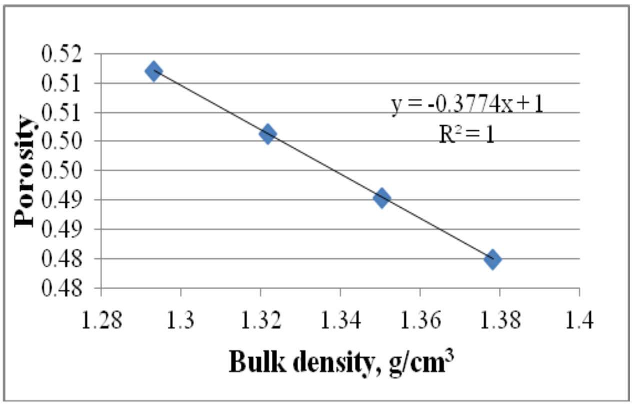

Figure 4. Relationship between Bulk density and porosity

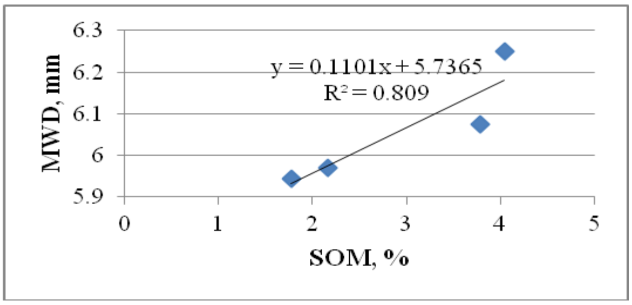

Figure 5. Relationship between SOM and MWD

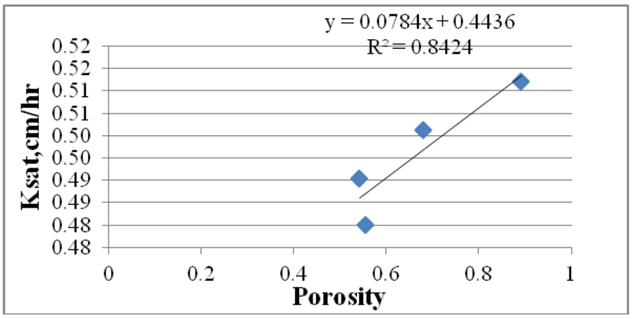

Figure 6. Relationship between Porosity and Ksat

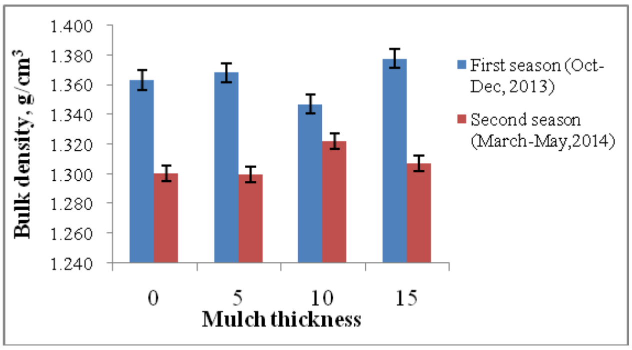

Figure 7. Interaction between bulk density and mulch thickness

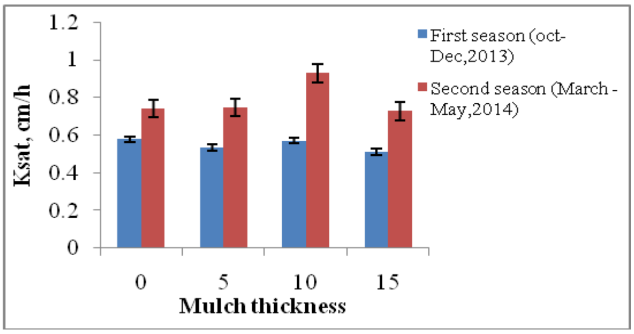

Figure 8. Interaction between Ksat and mulch thickness

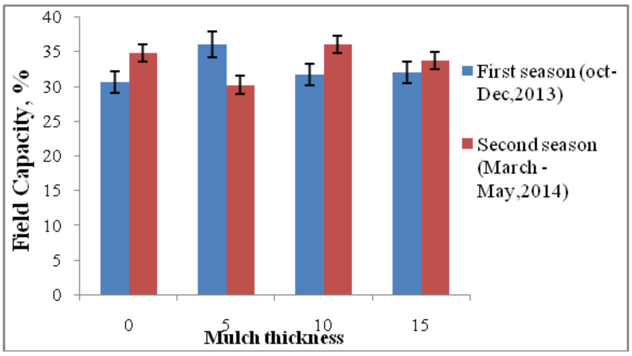

Figure 9. Interaction between field capacity and mulch thickness

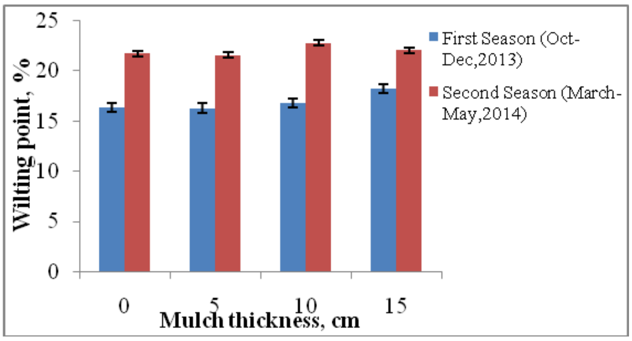

Figure 10. Interaction between wilting point and mulch thickness

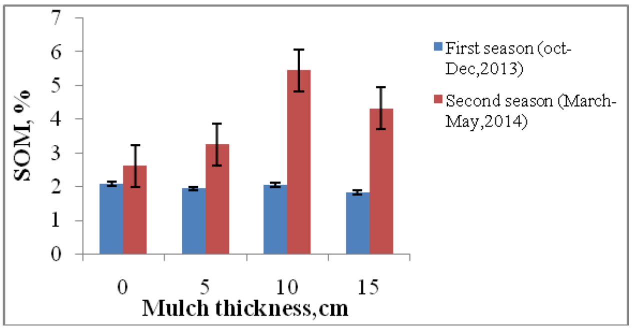

Figure 11. Interaction between SOM and mulch thickness

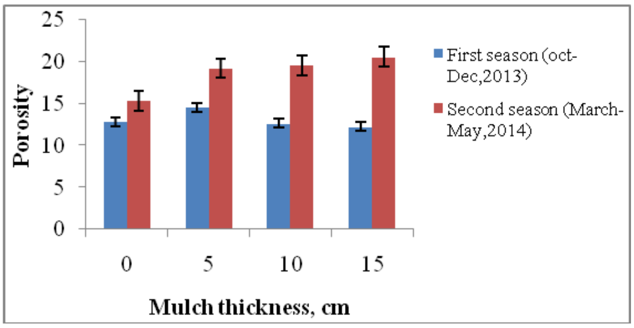

Figure 12. Interaction between porosity and mulch thickness

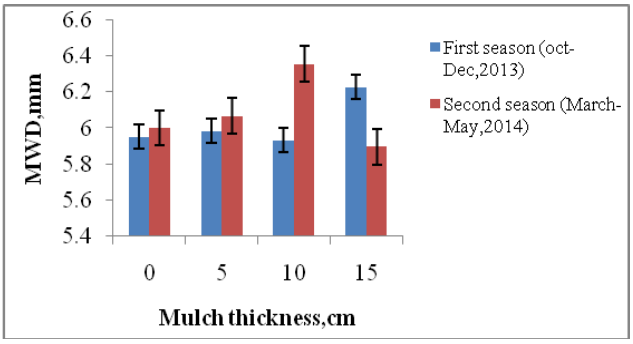

Figure 13. interaction between MWD and mulch thickness

4.6. Interaction between Seasons and Mulch Thickness Levels

The graphs show that significance difference ($P < 0.05$) was obtained at different mulch thickness levels of the different hydro-physical parameters. Using the error bars, soil bulk density (Figure 7), K_{sat} (Figure 8), wilting point (Figure 10) and soil porosity (Figure 12) were all significantly different at the four mulch thickness levels and for both seasons while field capacity (Figure 9) was significant at the control (0 cm), 5 cm and 10 cm thicknesses. Soil organic matter (Figure 11) concentration was also significantly different at 5, 10 and 15 cm mulch thickness levels. Additionally, mean weight diameter (Figure 13) was only significant at 10 and 15 cm thicknesses.

4.7. Relative Change with Reference to the Control

In this case, change with reference to the control (0 cm) for soil bulk density, saturated hydraulic conductivity, field capacity, wilting point, soil organic matter; soil porosity and mean weight diameter were obtained.

$$\text{Relative chang to the control} = \frac{\text{Value (at mulched)} - \text{Value (at control)}}{\text{Value (at control)}} * 100\%$$

Figure 14 shows that relative change became significant at 10 cm mulch thickness for all the parameters except at porosity. Relative change recorded at 10 cm thickness was 1.67 %, 25.59 %, 3.44 %, 4.87 %, 109.28 % and 5.97 % for soil bulk density, saturated hydraulic conductivity, field capacity, wilting point, soil organic matter and mean weight diameter respectively while at porosity, highest relative change (34.52 %) was at 15 cm. However, beyond the 10 cm mulch thickness, the relative change decreases at 15 cm thickness for soil bulk density, saturated hydraulic conductivity, wilting point, soil organic matter and mean weight diameter. The parameters changed as follow; soil bulk density (from 1.67 to 0.57 %), saturated hydraulic conductivity (25.59 to -1.89 %) wilting point (4.87 to 1.48), soil organic matter (109.28 to 65.68 %) and mean weight diameter (5.97 to -1.72 %). Figure 1 shows that although highest relative change for all the parameters was obtained at 10 cm mulch thickness level except for porosity, there was a decline for some parameters (soil bulk density, saturated hydraulic conductivity, wilting point, soil organic matter and mean weight diameter) beyond the 10 cm level. This implies that an increase in mulch beyond the 15 cm level decreased the relative change of the parameters. These findings are similar to those of [17], who attained optimal value at 10 cm mulch thickness while [19] found that any more mulch additions could not benefit the soils in any form but leads to degradation and identified 6 cm thickness as the bench mark.

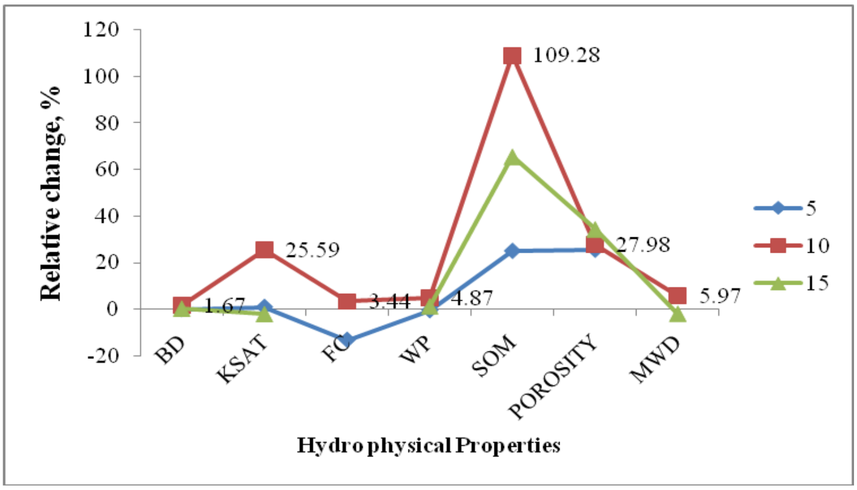

Figure 14. Effects of mulch on soil hydro physical parameters

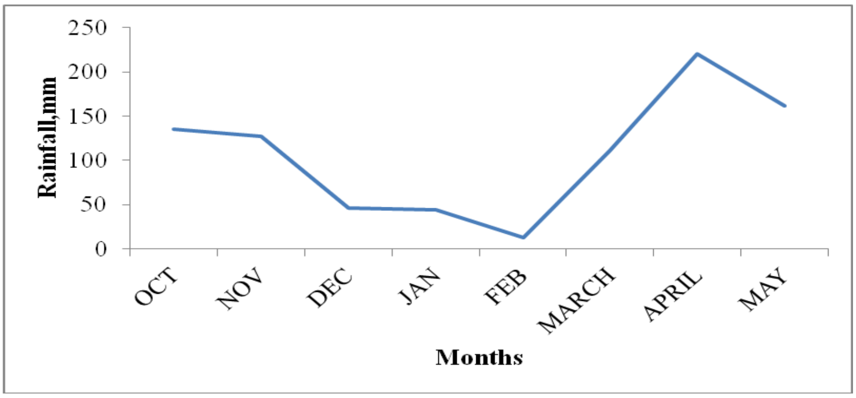

Figure 15. Monthly rainfall totals recorded at the rain gauge sites within the three experimental sites (Oct, 2013 to May, 2014)

4.8. Rainfall Distribution and Amount at the Experimental Site

The amount of rainfall received greatly contributes to the amount of water retained in the soil as well as the amount of soil and nutrients retained. Monthly rainfall totals ranged between 12.8 and 220.2 mm with the highest recorded in April, 2014 (220.2 mm) in season two which also had the greatest number of rain days of 50 as compared to season one whose highest rainfall recorded in October, 2013 was 135.9 mm and during this season, 35 rain days were observed. Total rainfall received for the entire eight months: 860.2 mm (Figure 15). The rainfall events affected soil properties; rate at which organic materials decomposed; rate at which saturation occurred; field capacity; wilting point and the amount of water that was retained as earlier discussed

5. Conclusions

The study demonstrated that the application of mulch significantly improved all the soil hydro-physical properties that were studied (bulk density, Ksat, field capacity, wilting point, porosity, SOM, MWD) after two seasons. The level of improvement is highest with 10 cm mulch thickness. The study therefore, recommends the use of 10 cm mulch thickness.

Statement of Competing Interests

The contents of this paper are a product of research done jointly and severally by the above authors. This paper has not been published elsewhere, and the authors take responsibility jointly and severally over the information provided therein.

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