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Soil Surface Treatments and Moisture Characteristics of a Luvisol under Cowpea (*Vigna unguiculata*) in the Transition Zone of Ghana

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Authors' contributions

This work was carried out in collaboration between all authors. Author KK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors KA and BOY managed the analyses of the study. Author EKA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Productivity of cowpea is strongly regulated by the availability of water and thus water the shortage can result in great yield losses. Field experiments were carried out at the University of Education, Winneba, Mampong campus to study the effects of grass mulch on moisture characteristics of a luvisol in the transition zone of Ghana. A Randomized Complete Block Design (RCBD) was used with four mulch treatments and four replications. Grass mulch was applied on the soil surface at different rates, using cowpea as a test crop. The grass mulch rates were: 1 t / ha, 3 t / ha and 5 t/ ha the control (no mulch). Parameters assessed included soil gravimetric and volumetric moisture contents, cumulative infiltration, infiltration rate, sorptivity and grain yield. Mulching improved soil moisture status particularly, soil gravimetric moisture content, soil volumetric moisture content, cumulative infiltration amount, infiltration rate, sorptivity and soil residual moisture. All the soil parameters measured in both seasons were higher on 5t/ha mulch than the other treatments. There was a positive correlation between the cowpea seed yield and soil gravimetric moisture content.

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1. INTRODUCTION

The use of grass mulch has extensively proven to preserve soil moisture, reduced soil temperature and increased nutrient uptake and crop productivity [1]. The research on grass mulching of cowpea in Mampong-Ashanti where the study was carried out has not attracted much attention. Although the location of the experiment is in the transitional climatic zone, rainfall amounts are often erratic and low during the season which is the main growing season for cowpea. Therefore, mulching could be beneficial for some period during the growing season. Soil physical condition may improve with grass mulching for dry periods in this region. The combined effect of organic matter depletion due to overgrazing, continuous cultivation and adverse climatic conditions such as erratic rainfall pattern, high temperatures have resulted in severe adverse soil conditions. The effect being crusted soils [2]. The constant decline in cowpea production as a result of shortened rainfall periods and poor soil condition has prompted farmers to employ conservative agricultural practices in order to improve the soil by conserving soil moisture to enhance plant growth and increase crop yield. One cheap and useful practice which is becoming popular to many farmers is grass mulching. There is evidence that, during most parts of the year, cowpea lands in the dry zones remain idle because of insufficient water for production and poor soil physical condition. Therefore this study sought to evaluate the effect of different rates of mulch on moisture characteristics of a luvisol under cowpea cultivation in the transition zone of Ghana.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted first from September to December 2010 and experiment two, from August to October 2011 at the College of Agriculture Education, University of Education, Winneba, Mampong-Ashanti (7°08'N, 1°24'W). Mampong-Ashanti is located at an altitude of 457.5 m above sea level. The area has bimodal rainfall pattern with the major rainy season occurring from March to July and minor rainy season from September to November with an annual rainfall of between 1094 mm and 1200 mm. The average monthly minimum and maximum temperatures are 29.4°C and 36.6°C [3]. The soil at the site is of the Bediesi series of the savanna Ochrosol. It is further classified by the FAO/UNESCO legend as Chromic luvisol [4]. The soil is sandy loam well- drained with a thin layer of organic matter [5] with the characteristics of deep yellowish red, friable and free from stones. The pH ranges from 6.5-7.0 [5]. The soil is permeable and has moderate water holding capacity [6,4].

2.2 Treatments and Experimental Design

The experimental field covered an area 165 m^2, which was divided into 16 plots, each plot measuring 6 m^2 with a path of 1m between adjacent plots. There were 4 treatments of different rates of grass mulch which was applied evenly on the various plots 21 days after planting cowpea. The treatments were no mulch (control), 3 t / ha 1 t / ha, 5 t / ha The treatments were replicated four times in a Randomized Complete Block Design (RCBD).

Seeds of cowpea 'Nhyira' variety were sown to a depth of about 2-3 cm at a spacing of 60cm between-rows by 20cm within-rows. Germination was observed four days after sowing. Replanting of ungerminated seeds (filling in) was done 7 days after planting (DAP).

2.3 Assessment of Parameters

2.3.1 Gravimetric and Volumetric soil moisture

Soil sampling for moisture determinations was done two days after a heavy rainfall when the soil was close to field capacity.

Three soil samples from each of the sixteen plots were randomly taken daily at about the same time (08-09 hours GMT) at a constant depth of 0-15cm which is within the zone of active root activity for most food crops that are grown on the Luvisol. Each sample was oven-dried at 105°C and weighed before and after drying. The gravimetric water content (ϴg) was then calculated for each sample from the formula [7]:

$$\Theta g = \frac{Mw}{Ms}$$

Where: Θ_g = gravimetric water content of soil (g/g)
M_w = mass of water in soil sample (g)
M_s = mass of oven-dried sample (g)

The volumetric moisture content (Θ_v) was determined from the gravimetric moisture content (Θ_g), the density of water (D_w) and bulk density (BD) using the formula [8]:

$$\Theta_v = \Theta_g \times \frac{BD}{D_w}$$

2.3.2 Residual moisture storage

The residual moisture storage was obtained from the measurement of the gravimetric moisture and volumetric moisture contents of the soil at the end of the growing season, using the methods by [7] and [8]. The residual moisture storage (R) for the depth 0.15 m was then determined from the relationship [8]:

$$R = \Theta_v \times \Delta Z$$

Where ΔZ**,** depth of sampling, set to 0.15m.

2.4 Cumulative Infiltration and Infiltration Rate

Cumulative Infiltration was determined by the single-ring infiltrometer method [8]. An infiltrometer, measuring 0.3 m diameter and 0.3 m in height was used. The cylinder was driven into the soil to a depth of about 0.2 m. A constant head of water of about 3 cm was maintained in the infiltrometer by careful and gradual addition of water from a measuring cylinder. The rate at which water entered into the soil in the infiltrometer was obtained from the water that was added from the measuring cylinder to maintain a constant head of 3 cm. This was read directly from the scale on the measuring cylinder as a function of time recorded by means of a stopwatch.

2.4.1 Sorptivity

considering that water poured on the soil and infiltrated to a depth of x m in t s, it can be shown that:

$$I = (\varnothing_f - \varnothing_i)\,x$$

where $\varnothing_f$ = final water content after infiltration
$\varnothing_i$ = initial water content before infiltration

Using the Boltzmann similarity variable λ **=** $\mathbf{x\ t^{-1/2}}$**,**

The equation can be re-written by substituting for x as:

$$I = (\varnothing_f - \varnothing_i)\,\lambda\ t^{½}$$

- By defining sorptivity, S, as: $\mathbf{S = (\varnothing_f - \varnothing_i)\,\lambda_{(o)}}$

Where λ = Boltzmann similarity variable, then sorptivity becomes:

$$I = S_{(O)}\, t^{1/2}$$

The sorptivity was determined after cumulative infiltration I, [9]:

Where I = cumulative infiltration

$S_{(O)}$ = sorptivity

$t^{1/2}$ = time

2.4.2 Cowpea seed yield

The two middle rows sampled for studies were harvested, threshed after harvesting in 2010 and 2011. One thousand (1000) seeds were randomly selected and weighed with an electronic balance to obtain the 1000 seed mass. The total mean seed yield per plant was determined for each mulched plot by dividing the total seed yield from the plot by a number of plants for which the pods were harvested. From this the yield in kg m^{-2} and ton ha^{-1} were determined.

3. RESULTS AND DISCUSSION

3.1 Effect of Different Rates of Mulch on Soil Moisture Studies

Moisture plays a vital role in crop growth and development. With the addition of mulch, the moisture rose from 10.50 % in the control plot to 28.24 % on 5 t/ha mulch plot in 2010 and from 14.72 % to 26.15 % on 5 t/ha mulch plot in 2011 on the gravimetric basis. On a volumetric basis, there was an increase from 12.36 % on control plot to 31.44 % on 5 t/ha mulch plot in 2010 and from 17.29 % on control plot to 29.46 % on 5 t/ha mulch plot in 2011. These increases could be attributed to the fact that mulch applied to the soil surface reduced evaporation from the plot surfaces, increased pore spaces for higher porosity (Table 1) values which means enough water was stored for the crop to meet its water requirement through mulching. [10] further confirmed that there could be 34 to 50% reduction in soil water evaporation losses and a considerable decrease in soil temperature after mulching so as to meet the crop's water requirement. Mulching at the experimental site helped to increase soil infiltration (Figs. 1, 2, 3) and this might have contributed to the water availability for cowpea. A similar observation has been made by [11,12] that there is a reduction in run off, evaporation and increased infiltration for effective soil water storage to meet crop's water requirement after mulching. Santos AL [13] further reported that mulching reduced run off on luvisols by 10 % of the total rainfall of 600 mm.

Soil residual moisture is the moisture storage at the end of the growing season. The data for soil residual moisture of the various plots obtained indicated that the 5 t/ha mulch plot contained the highest level of residual moisture (5.70 mm/plot) followed by the 3 t/ha mulch plot (4.75 mm / plot), 1 t/ha mulch plot (4.50 mm / plot) and the lowest being the control (3.32 mm / plot) plot in 2010 season. A similar trend was observed in 2011 when the 5 t/ha mulch plot recorded the highest residual moisture (5.01 mm per plot) the followed by 3 t/ha mulch (3.16 mm per plot) plot, 1 t/ha mulch plot (2.21 mm), and the control (1.53 mm per plot) as the lowest residual moisture (Table 2).

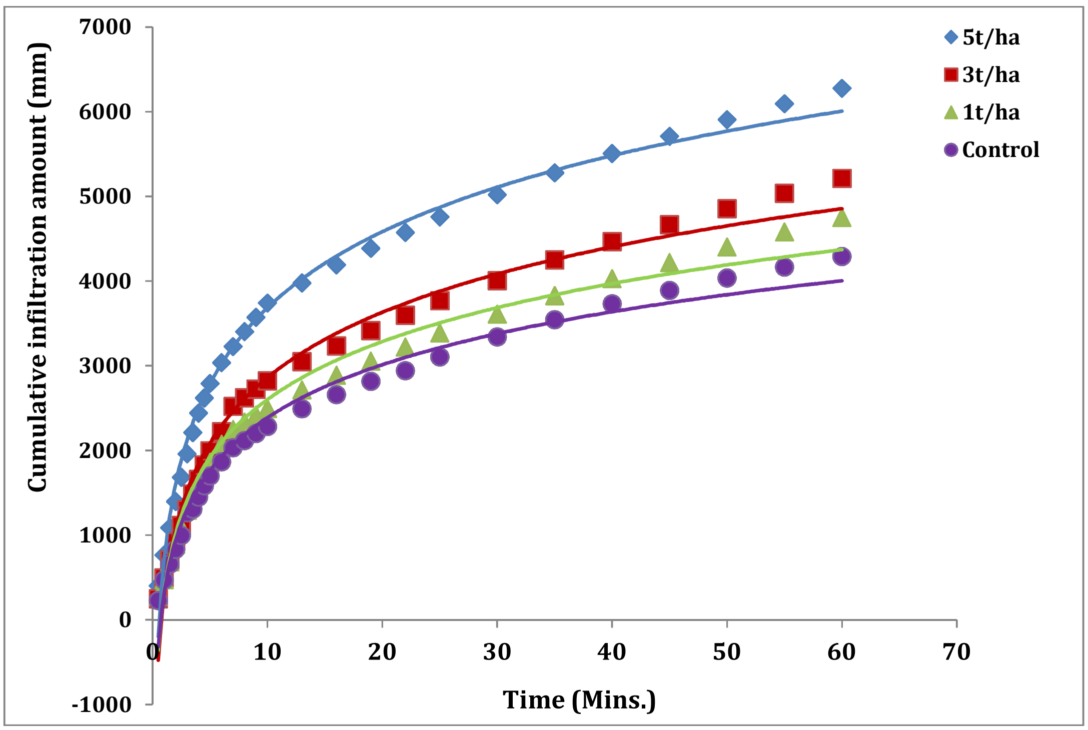

Fig. 1. Cumulative infiltration curves for various plots (2011)

Table 1. Effect of different rates of mulch on soil moisture status

Mulch rate (t/ha)	Gravimetric water content (%)		Volumetric water content (%)	
	2010	2011	2010	2011
Control	10.50	14.72	12.36	17.29
1	17.21	19.80	19.74	22.94
3	20.63	22.07	23.28	25.23
5	28.24	26.15	31.44	29.46
LSD ($p < 0.05$)	1.16	1.58	1.28	1.81
CV (%)	3.40	4.00	3.20	4.10

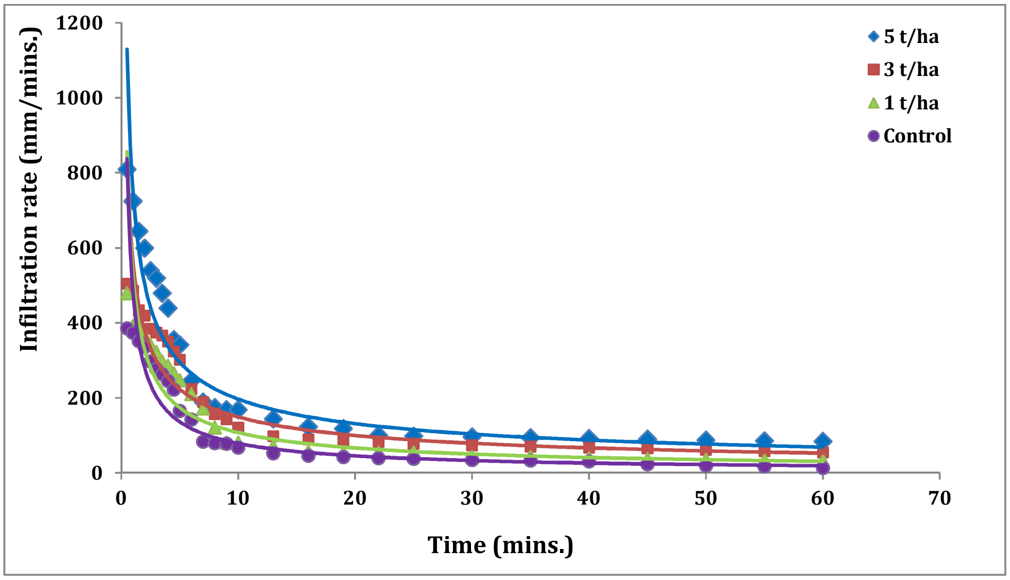

Fig. 2. Infiltration rate in the various plots (2011)

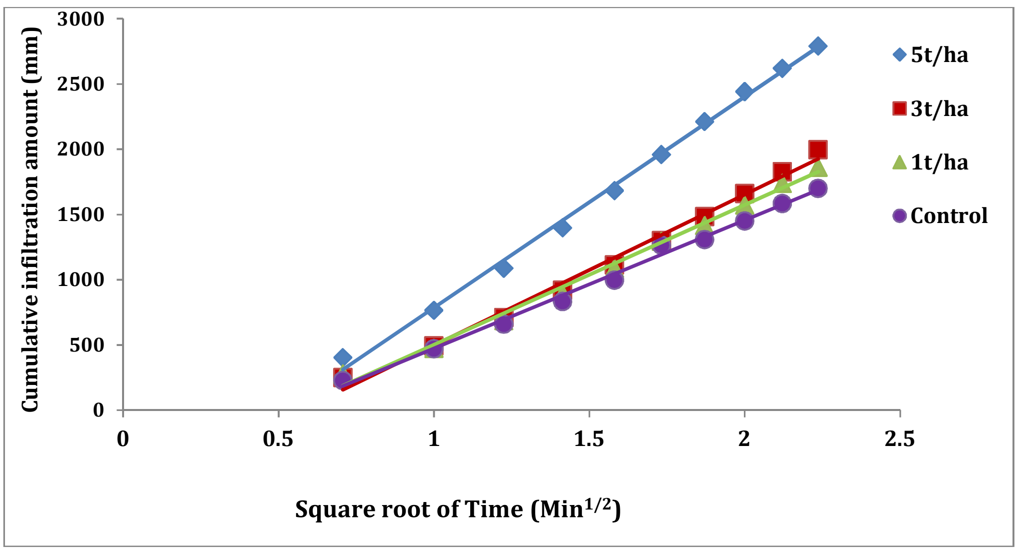

Fig. 3. Sorptivity for various plots (2011)

Table 2. Effect of different rates of mulch on soil residual moisture

Mulch rate (t/ha)	Residual soil moisture (mm)	
	2010	2011
Control	3.32	1.53
1	4.50	2.21
3	4.75	3.16
5	5.70	5.01
LSD ($p < 0.05$)	0.37	0.24
CV (%)	6.50	10.1

[10] share a similar view. The findings indicated a positive correlation between soil moisture content and rate of mulching as the amount of soil moisture (Table 2) increased as mulch application rate increased in both 2010 and 2011. Olabode OS [14] Mashingaidze 15] confirmed that less moisture depletion occurred after mulching which prevented a contact between soil and dry air and reduced water loss through evaporation [10] found that 34 to 50% reduction in evaporation and a considerable decrease of soil temperature may occur as a result of mulching.

The organic matter derived from mulch applied might have protected the soil surface from the effect of erosion losses and provided increased moisture storage for crops to maximise production. According to [12,16], soils rich in organic matter originating from organic materials are less prone to soil moisture losses and erosion processes than soils with the low organic matter.

Table 3. Correlation coefficient of cowpea seed yield with soil gravimetric moisture and grass mulch in 2010 and 2011

Correlation (linear) of Seed yield with	Correlation coefficient (r)	
	2010	2011
Soil organic matter	--------	0.606*
Soil gravimetric moisture	0.320	0.230
Mulch rate	0.346	0.234

* *Significant ($p<0.05$)*

It is worth mentioning that if the emphasis is to readily make available high amount of residual moisture to meet the moisture requirement of any crop that follows cowpea in a rotation, then, the 5t/ha mulch plot should be the best desirable technology, 3 t/ha mulch plot, 1 t/ha mulch plot, followed in that decreasing order with the control (no mulch) plot being the least desirable technology for both 2010 and 2011. This is due to the fact that 5 t/ha mulch was able to conserve higher amounts of residual moisture (Table 2) after rainfall with a reduced evaporation rate, increased infiltration (Figs. 1 and 2), increased sorptivity (Fig. 3) by covering the soil surface and these invited macroorganisms like termites and earthworms which might have increased pore spaces for water, gas exchange and an effective infiltration.

3.2 Infiltration on the Various Mulch Plots

The cumulative infiltration amount and infiltration rate as a function of time of the various mulch plots are presented in Figs. 1 and 2, respectively. It was observed in Figure 1 that, the cumulative infiltration was highest in the 5 t/ha mulch plots. This was followed by the 3 t/ha mulch plot, the 1t/ha mulch plots and the control plots in that decreasing order. For example, after 40 minutes of cumulative infiltration, approximately 5508.8 mm of water entered the 5 t/ha mulch plot; 4468.5 mm entered the 3t/ha mulch plot; 4031.5 mm entered the1t/ha plot and only 3734.3 mm entered the control (no mulch) plot. The 5 t/ha mulch plot had the highest infiltration rate (92.3 mm/min), followed by the 3 t/ha (68.5 mm/min) plot, 1t/ ha (40.2 mm/min) plot and the control (31.5 mm/min) plot in that decreasing order (Fig. 2).

Cumulative infiltration and infiltration rates followed the order 5t/ha mulch > 3t/ha mulch > 1t/ha mulch > control. These results could be explained by the fact that the 5 t/ha mulch plot was the least compacted with the greatest volume of soil pores and highest porosity, thereby allowing the largest volume of water to move down through it per unit time. The reverse conditions were true for the control (no mulch) plot while the 3t/ha mulch plot and the 1t/ha mulch plot were intermediate. These findings conform to an earlier work by [17] that a soil management practice like mulching which affects infiltration have great implications for soil and water conservation in meeting crop's water needs. The mulched plots were observed to have left high amounts of organic matter to the soil than the control plots and this might have contributed the greater amount of soil water content (Table 1) on 5 t/ha mulch plot than the other plots. This has made 5 t/ha the best desirable technology and controls the least desirable technology. Olabode OS [14] and Mapanguwa W [12] are in agreement that mulching improves soil water storage through reduced run off, reduced soil evaporation and increased infiltration. Mando AL [18] further reported that mulch application is more sustainable and more affordable option for farmers to improve soil water infiltration. The terminal infiltration rates were expected to be the same for all the plots but the time taken to reach this rate was expected to affect drainability of the various mulch plots. The 5 t/ha mulch plot with the highest infiltration rate is expected to be the best technology to make water readily available to meet cowpea's water requirement, while the control (no mulch) plot is expected to be the least desirable technology.

3.3 Effect of Different Rates of Mulch on Sorptivity

Sorptivity is a measure of the soils ability to absorb water without reference to gravitational effects. Sorptivity values were obtained from the slope of curves obtained by plotting cumulative infiltration (I) against the square root of time (t), for a 5-minute duration only. Sorptivity for the 5 t/ha mulch plot was highest with 1249.11 mm/min. This was followed by the 3 t/ha mulch plot with 893.78 mm/min and 1 t/ha mulch plot

(833.99 mm/min) in that decreasing order with the control plot (765.3 mm/min) giving the lowest sorptivity value (Fig. 3).

The 5 t/ha mulch plot was the most well-drained; it was likely to have more macrospores. Therefore, the 5 t/ha treatment was likely to have the greatest ability to absorb and conduct initial water during the infiltration process. The reverse is true for the control (no mulch) plots which recorded the lowest sorptivity value. The 3 t/ha and 1 t/ha mulch plots were intermediate in their behaviour.

High sorptivity value on the 5 t/ha mulch and low sorptivity value on control plot could be explained with the fact that the 5 t/ha mulch plot performed better than the other mulch plots especially the control plot with reference to reduction of the impact of raindrops and splash, thereby preventing soil compaction, reducing surface sealing and increasing porosity (Table 2), reducing surface run off and increasing infiltration (Fig.1), reducing soil erosion and readily making available soil water for the plant. This result is supported by [14].

If sorptivity is used as an index for evaluating the agricultural potential of the various mulch plots, the 5 t/ha mulch plot is likely to be most preferable technology, followed by the 3 t/ha mulch plot, the 1 t/ha mulch plot, and the control (no mulch) plot in that decreasing order. This is because, among other things, the lower the sorptivity, the more the likelihood of run off problems on the land. Thus the control (no mulch) plot is likely to have the most severe problem of surface run off. Such problem, on the other hand, would be expected to be minimum on the 5 t/ha mulch plot. This makes 5 t/ha mulch plot a little higher than the 4 t/ha mulch rate given by [19] as the best technology to manage readily available soil moisture in order to meet crop water requirement to maximise production.

Stability of the soil which is also a characteristic of soil structure was found to be highest on 5t/ha mulch plot and lowest on the control plot. This affected the moisture regime of the treatments (Table 2). This might be due to the fact that the soil structure of the mulched plots affected water flow transmission and retention on the various treatment plots as a result of the effect of high organic matter on soil aggregation. This increase provided more available water to cowpea because a well-structured soil is likely to have a high sorptivity value (Fig. 3).

Table 4. Effect of mulch on cowpea seed yield

Mulch rate (t/ha)	Cowpea seed yield (t/ha)	
	2010	2011
Control	1.98	3.04
1	2.08	3.31
3	2.09	3.44
5	2.16	3.76
LSD (p < 0.05)	0.11	0.60
CV (%)	2.20	2.40

3.4 Relating Cowpea Seed Yield with Other Parameters

Correlation analysis between the cowpea seed yield and some other parameters in 2010 season indicated that cowpea seed yield positively correlated with soil gravimetric moisture content (r= 0.320) and mulch (r=0.346) (Table 1). In 2011 season, cowpea seed positively and weakly correlated with soil gravimetric moisture content (r=0.230). Seed yield was also positively and weakly correlated with mulch (r=0.234).

In 2010 cowpea seed yield positively correlated with soil gravimetric moisture content (r=0.320, p<0.05), mulch (r=0.346, p=.05). The 2011 season followed a similar trend as cowpea seed yield positively correlated with soil gravimetric moisture content (r=0.230, p=.05), positively and significantly correlated with soil organic matter (r=0.606, p=.05). These findings imply that though cowpea is drought tolerant, when mulch is applied it increases yield by managing soil moisture to make it readily available and this creates conducive soil atmosphere for active nodulation, reduced weed population, good water balance in leaves as a result of available soil moisture in addition to considerable organic matter added to the soil nutrient pool from the decayed grass mulch. These results are similar to those reported elsewhere by many authors such as [20,21,14,12,10].

3.5 Effect of Mulch on Cowpea Seed Yield

Mean seed yield decreased as the mulch rate decreased in 2010 and 2011 seasons (Table 4). Generally the yield values were highest on the 5 t/ha mulch (2.16 t/ha) plot followed by 3 t/ha mulch (2.09 t/ha) plot, the 1 t/ha mulch (2.08 t/ha) and the control (1.98 t/ha) plots in that decreasing order in 2010 season. A similar trend was observed in 2011. Mulch rate significantly (p=.05) and positively correlated with seed yield (r=0.563 in 2010 and r= 0.725 in 2011) (Table 5).

This finding implies that though cowpea is drought tolerant when mulch is applied it increases yield by managing soil moisture to make it readily available and this creates good water balance in the soil in addition to soil nutrient pool from decayed grass mulch. These results conform to reports by [21,14,12,10]. These results also suggested that a strong relationship exist between mulch and cowpea seed yield. This might be explained by the fact that mulch suppressed the growth of weeds by shading them from sunlight in order to prevent competition for available moisture and nutrient and this ensured that crops meet their water need for good yield. This observation is similar to earlier report by [10] that mulch prevent weeds impact on yield by more than 30% and fewer weeds found on mulch plots ensured that water and nutrient go straight to the plants to enhance yield. However, [22] found that uncontrolled weed like spear grass resulted in 92% reduction in maize grain yield. The result showed that increasing the rate of mulch application improved seed yield in cowpea.

Table 5. Correlation coefficient of mulch with cowpea seed yield in 2010 and 2011

Correlation (linear) of mulch	Correlation coefficient (r)	
	2010	**2011**
Seed yield	0.563*	0.725*

* *Significant (p=.05)*

4. CONCLUSION

It was found that grass mulch can be applied to improve soil physical condition.

There was a positive correlation between the cowpea seed yield and soil gravimetric moisture content.

The 5 t/ha mulch improved gravimetric and volumetric moisture contents, soil infiltration, sorptivity, residual soil moisture. This suggested that though cowpea is tolerant to water deficit to some extent, the use of 5 t/ha mulch for sustainable soil moisture management is important in areas of inadequate rainfall and poor soil physical condition.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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