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Response of hydro-physical properties of a Chromic Luvisol in Ghana to different methods of application of Mucuna pruriens as a soil amendments

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***Abstract*— *The study assessed the response of hydro-physical properties of Chromic Luvisol to different methods of application of Mucuna pruriens as a soil amendments in two separate experiments. A Randomized Complete Block Design (RCBD) with three replications was used with the following treatments: 7.04t/ha Mucuna pruriens as green manure (**GM**), 7.04t/ha Mucuna pruriens as live mulch (**LM**), 7.04t/ha Mucuna pruriens as in-situ mulch (**IM**) and a control plot which had no Mucuna pruriens as soil amendment. Data were collected on gravimetric (θ_g) and volumetric moisture content (θ_v), residual moisture storage(R), sorptivity(s), cumulative infiltration (I), bulk density (ρ_b), total porosity (f), aeration porosity (ξ_a), aggregate stability (ASt) and soil temperature, for assessment of hydro-physical properties of the soil. The results from the experiments indicated that Mucuna pruriens as live mulch used as amendment significantly reduce bulk density (ρ_b), increased total porosity (f) and aeration porosity (ξ_a) thus it gave significant improvement on those soil physical properties measured while Mucuna pruriens as in-situ mulch improved aggregate stability (ASt) and gave optimal soil temperature. In the assessment of soil volumetric moisture content (θ_v), residual moisture storage(R), sorptivity(s), cumulative infiltration(I), the study shows that Mucuna pruriens as in-situ mulch recorded the optimal values and was closely followed by Mucuna pruriens as live mulch.*

Keywords*— *Mucuna pruriens, live mulch, in-situ mulch, green manure, Chromic Luvisol.

I. INTRODUCTION

Most tropical soils are inherently low in nutrients and are prone to erosion, especially after deforestation and subsequent cultivation with conventional mechanical tillage (Hartmans *et al.*, 1982). Vargas- Ayala′ *et al.* (2002), noted that farmers in their response to combat hunger rather deplete the soil resources through continuous cropping, bush burning and environmentally unfriendly systems of farming. According to Nyakande *et al.* (1981), ecosystems need to be conserved so as to support plant and animal lives. To reverse this trend of loss of soil fertility and to increase food production, practices such as green manuring, mulching, composting, agro-forestry as well as the use of short-duration improved fallow leguminous plants have evolved for adoption (Whitehead, 1995).

Mucuna pruriens, commonly known as velvet bean is one of the herbaceous leguminous crop which has been used for mulching purposes is botanically known as *Mucuna pruriens* var utilis (Buckles *et al.*, 1998).The genus, *Mucuna*, is used to describe various species of annual and perennial legumes belonging to the Fabaceae family including the velvet bean (Buckles, 1995). According to Duke (1981) *Mucuna pruriens* is self-pollinating, hence natural out-crossing is rare. Bailey (1993) gives the gestation period (from flowering to dry seed harvest) of *Mucuna pruriens*as between 100-290 days. Gardener (1965) wrote that *Mucuna pruriens* grows well on a wide range of soil types including heavy clays provided they are well drained. Velvet bean thrives best with warm, moist conditions with plenty of rainfall (Chavez, 1993). Most *Mucuna* spp. exhibit reasonable tolerance to a number of abiotic stresses, including drought, low soil fertility, and high soil acidity, although they are sensitive to frost and grow poorly in cold, soils (Duke,1981; Hairiath, *et al*.1993). Gallagher *et al.* (1999) asserted that *Mucuna pruriens*, due to its vegetative cover, reduces the impact of the rain drop splashes which create soil crust and therefore enhances percolation. As a cover crop, Reijntes (1997) noted that, *Mucuna pruriens* helps to reduce the rate of run-off especially on hilly and sloppy areas and also reduces the rate of leaching and losses of mineral nutrients.

Although mulch farming has proven to be effective in controlling soil erosion and in improving soil properties, resource-poor farmers have always been reluctant to adopt conventional mulching, because of the large amount of labour needed to gather, transport and apply the mulch. The search for inexpensive and more attractive mulching methods has led to the development of *in-situ* and live mulch. Therefore, the objective of this work was to determine the influence of different methods of application of *Mucuna pruriens* as soil amendments on the hydro-physical properties of a Chromic Luvisol in Ghana.

II. MATERIALS AND METHOD

2.1 Study area

The experiment was carried out at the Multi-purpose nursery of the University of Education, Winneba, Mampong – Campus. Mampong lies at 457.5meters above sea level and falls within the transitional zone that is between the southern rain forest and Guinea Savannah belt of the North. Rainfall distribution in the area is bimodal and classified into major and minor rainy seasons. The major season commences from April to July and the minor season from early September to late November (Meteorological Service Department, Mampong, 2012). The soil is of the savannah Ochrosol type which belongs to the Bediesi series known as Chromic Luvisol in F.A.O/UNESCO classification, 1990 and derived from the voltaian sandstone (Soil Research Institute, 1999).

2.2 Treatments and design

There were four treatments and arranged in a Randomised Complete Block Design (RCBD) with 3 replications. These treatments were (i) *Mucuna pruriens* as green manure (ii) *Mucuna pruriens* as live mulch (iii) *Mucuna pruriens* as *in-situ* mulch and (iv) Control (no soil amendment)**.** Each plot measured 6m by 4m giving a total area of 24m^2 per plot. A path of 1m was left between each plot for easy movement. The demarcated field of 6m by 4m per plot was left for five months to be stable as it had recently been farmed on. The plots were all sprayed with an herbicide (Sunphosate with glyphosate as active gradient at a rate of 2.5L ha^{-1}) to control the weeds on them. Lining and pegging was done for planting of *Mucuna pruriens* at a planting distance of 0.8m by 0.8m. The plots with treatment (i), (ii) and (iii) were planted (mid-May, 2012) with *Mucuna pruriens* for the first experiment while for the second experiment the *Mucuna pruriens* was planted in mid-January, 2013.

***Mucuna pruriens* as green manure.** On this particular plot, the *Mucuna pruriens* which was at the flowering stage (a growth period of 120 days for maximum foliage) was incorporated into the soil using a hoe. The plot was left for three weeks to ensure that at least the decomposition of simple sugars had taken place and the heat produced during the initial stage of decomposition had reduced.

***Mucuna pruriens* as live mulch.** The *Mucuna pruriens* which was at the flowering stage (a growth period of 120 days for maximum foliage) was allowed to grow without any disturbance till the end of the experiment.

***Mucuna pruriens* as *in-situ* mulch.** The term *in-situ mulch* refers to the residues of dead or chemically killed cover crops which are used on the same land on which they were grown as mulch (Wilson *et al*,. 1982). On this plot *Mucuna pruriens* at the flowering stage (a growth period of 120 days for maximum foliage) was cut at the base with a knife. The *Mucuna pruriens* was then left on the plot as *in-situ* mulch.

Control (No *Mucuna pruriens*). This plot did not have any *Mucuna pruriens* planted on it from the inception of the experiments.

2.3 Determination of parameters

The dry bulk density was determined from soil cores collected at 0-15cm depth on the field with core sampler (Klute, 1986). Moisture content was determined on gravimetric and volume basis (Hillel, 1982) while residual moisture storage was obtained from the measurement of the gravimetric moisture content of the soil at the end of the experiment, using the method by Gardener (1965). Total porosity was calculated by the formula; $f = 1- \rho b/\rho s$ where f is total porosity, ρb is bulk density and ρs is particle density (2.65 g cm^{-1}) (Hillel, 1982). Air filled porosity was calculated by the formula, $af = f - \theta v$ where af is air filled porosity (Klute, 1986), f is the total porosity and θv is volumetric water content.

A modified wet sieving method was used to measure the aggregate stability (ASt) (Kemper and Rosenau, 1986). Twenty grams (20 g) of the aggregates were weighed unto a 0.25 mm sieve. The sieve was immersed in water contained in a basin and manually rotated gently for five minutes. The wet sieved aggregates were dried to a constant mass. Another 20 g sub sample was weighed and oven dried to a constant mass. After oven drying, the wet sieved aggregates were divided by the sub sample to give the aggregate stability, which was expressed as a percentage

Sorptivity was measured by dividing the first 5-minute cumulative infiltration by the square root of the time (Philip, 1957).The single ring infiltrometer method (Klute, 1986) was used to determine the cumulative infiltration in the flied.

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Soil temperature was determined by inserting a soil thermometer into the soil to a depth of about 5cm for 8 days. The readings were taken every 6:00 am, 12:00 noon and 6:00 pm for each day and recorded.

2.4 Data analysis.
The data collected on various parameters were subjected to analysis of variance using Genstat software programme 2013. The means were separated using Least Significant Difference (LSD) at 5% probability level.

III. RESULTS AND DISCUSSIONS

Results of initial analysis of hydro-physical soil properties of the area are presented in Table. 1

Table 1 Summary of initial hydro-physical soil properties

Soil property	value
Bulk density (ρ_b) (g/cm3)	1.6
Total porosity (f) (%)	40
Aeration porosity (ξ_a) (%)	29.26
Gravimetric moisture content (θ_g) (%)	6.71
Volumetric moisture content(θ_v) (%)	10.736
Degree of saturation (θ_s) (%)	26.84
Sand (%)	73.18
Silt (%)	16.54
Clay (%)	10.28
Texture	Sandy loam

Table 2 shows that *Mucuna* as live mulch recorded the least bulk density in both experiments while the control recorded the highest. It was significantly ($p<0.05$) different from the in-situ mulch and the control but not from the green manure. This could have been as result of the biological activity provided by the roots of the live *Mucuna pruriens* and the burrowing activity of earth worms since live *Mucuna pruriens* promotes earthworm activity. This confirms the assertion made by Houngnanadan *et al.* (2000), that the presence of live *Mucuna pruriens* in the soils as well as its biomass application to the soil provides favourable conditions for growth, survival and breeding of earthworms. The control recorded the highest bulk density and can be explained by the fact that it had the least volume of loose soil as it had no *Mucuna pruriens* on it and thereby less interference by biological or mechanical agents. Lower bulk densities are important productivity index in agriculture. According to Devis and Freitas (1970), the lower the bulk density the more productive the soil is, as it allows for easy root penetration.

Table.2: Influence of Treatments on Dry Bulk Density, Total Porosity and Air-Filled Porosity

	Dry Bulk Density(g/cm^3)		Total Porosity (%)		Air-Filled Porosity (%)	
	2012	2013	2012	2013	2012	2013
Control	1.567	1.550	40.88	44.51	28.00	26.21
Green manure	1.330	1.370	49.81	48.30	39.05	34.58
Live mulch	1.303	1.330	50.82	49.81	39.82	35.61
In-situ mulch	1.470	1.460	44.53	44.90	30.39	27.88
L S D (0.05)	0.0935	0.02825	3.523	1.067	3.667	2.008
C V (%)	2.0	0.4	2.3	0.4	4.6	2.2

The data (Table 2) revealed that *Mucuna* as live mulch recorded the highest total porosity in both experiments. This trend could have been as results of the burrowing activities of the roots of live *Mucuna pruriens* and earthworm. The result affirms Akinsanmi (1994), assertion that high total porosity of soil is a result of high organic matter obtained from *Mucuna pruriens* fallow. And also according to Devis and Freitas (1970) *Mucuna pruriens* fallows produce crumb structure which facilities soil cultivation and growth of roots of crop plants, as it permeates the soil with roots and pores, and are able to loosen, break up and process the soil**.** The control recorded the least total porosity in both experiments (Table 2). This might be explained with the fact that the control recorded the highest bulk density therefore had more compaction hence less pores. It could also be that, it had fewer disturbances as it had no *Mucuna pruriens* on it.

From the results of the experiments (2012 and 2013), it was observed that the *Mucuna* as live mulch had the highest air-filled porosity ,this could have been as result of it recording the least bulk density (Table 2) therefore least compaction, highest total porosity and coupled with one of the lowest volumetric moisture content. This trend in air-filled porosity is common knowledge, in that the moisture content of the soil is a principal determinant of the content of soil air. This affirms Hodgson and Macleod (1989) that air-filled porosity of a soil increases with decreasing moisture content. It also conforms to Brady (1990) that the moisture content of the soil principally determines the content of soil air, since the soil pores not filled with water are occupied by air. The control also recorded the least air-filled porosity in both experiments. This might be attributed to it recording the least aggregate stability (Table 3), highest bulk density and therefore the least porosity. This affirms (Brady, 1990) that Soil texture, bulk density and aggregate stability are among the soil properties that influence soil aeration.

Table.3: Influence of Treatments on Aggregate Stability

	Aggregate Stability (%)	
	2012	2013
Control	41.82	41.20
Green manure	41.16	41.64
Live mulch	43.74	44.71
In-situ mulch	51.68	52.77
L S D (0.05)	6.50	5.932
C V (%)	4.0	3.8

Stability of soil aggregates is defined as the ability of soil aggregate to resist disruption when outside forces (usually associated with water) are applied (USDA-NRCS, 2008). The results of the experiment (Table 3) shows that in both experiments the *Mucuna* as *in-situ* mulch recorded aggregate stability values that were significantly ($p<0.05$) higher than all the other treatments. This trend could be attributed to the fact that *Mucuna* as *in-situ* mulch had its surface cover with *Mucuna pruriens* throughout the experiment and therefore it provided protection against the full impact of raindrop. Gallagher *et al.* (1999) asserted that *Mucuna pruriens*, due to its vegetative cover, reduces the impact of the rain drop splashes which create soil crust and therefore enhances percolation. The result could also be due to the decomposition of the *Mucuna* which helped to stabilize the soil aggregate. This confirms Van-Camp *et al*. (2004) that organic matter from organic materials stabilizes soil structure by at least two different mechanisms: by increasing the inter-particle cohesion within aggregates and by enhancing their hydrophobicity, thus decreasing their breakdown. In experiment two (2013) the control recorded the lowest aggregate stability. It might have been as results of the control being bare throughout the experiment and had no protection from the full impact of the raindrop. However *Mucuna* as green manure recorded the lowest aggregate stability in experiment one, might be due to the mechanical forces operating on the soil surface during the incorporation of the *Mucuna pruriens* and tillage could cause significant soil loosening which causes the destruction of soil aggregates (Aksakal and Oztas, 2010)

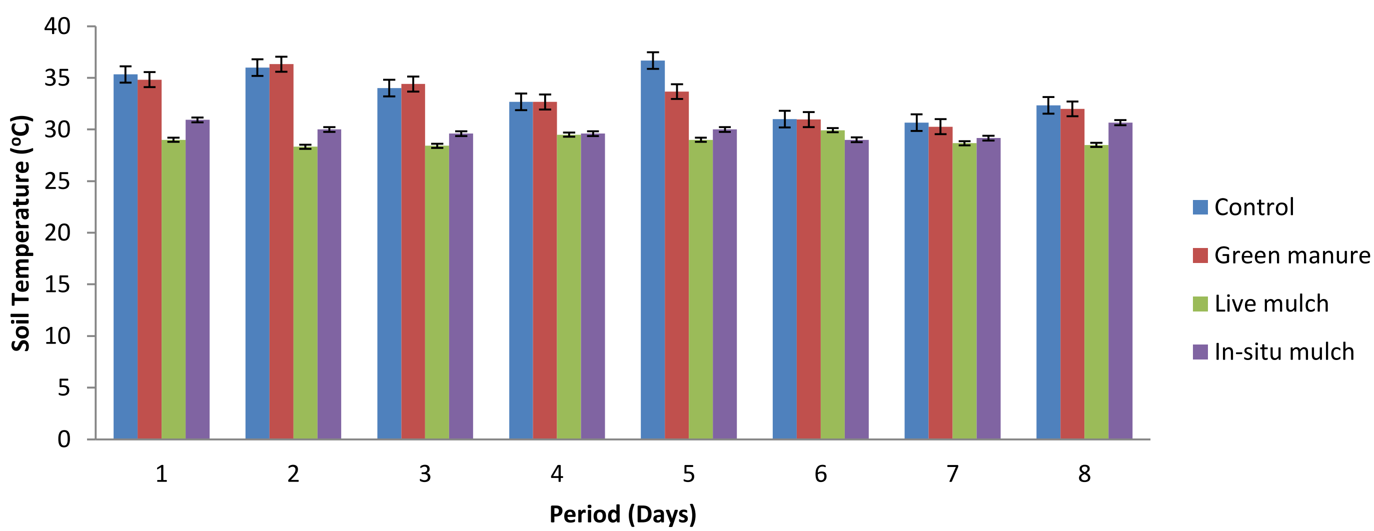

Fig.1: Daily Soil temperatures reading of treatments (2012)

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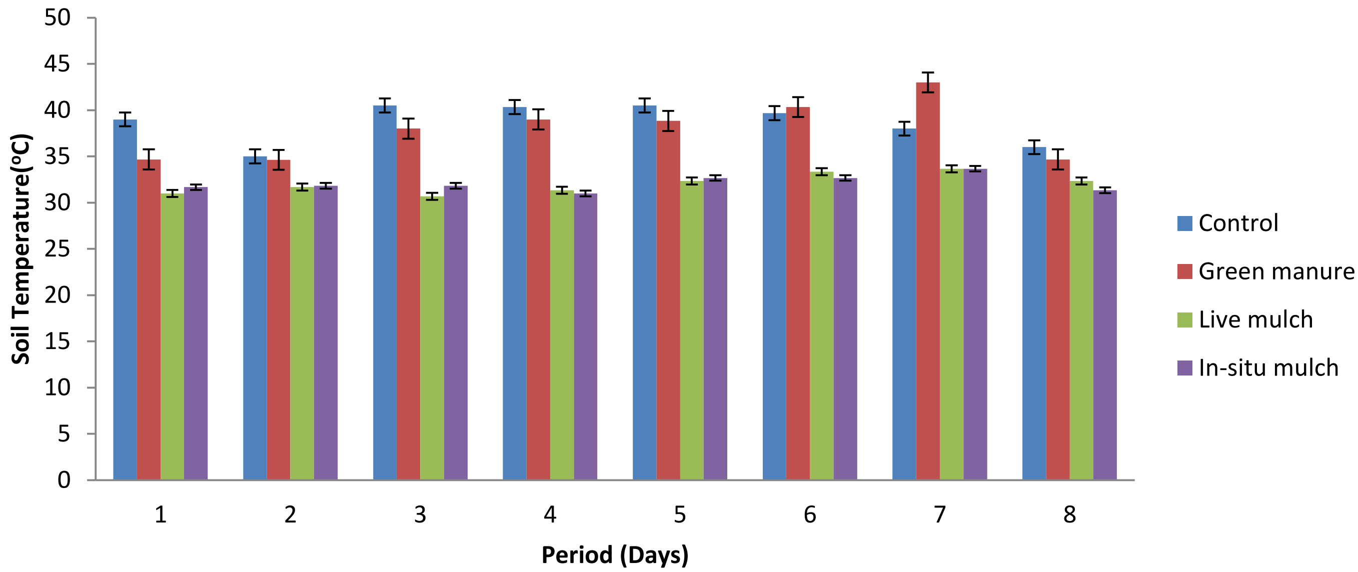

Fig.2: Daily Soil temperatures reading of treatments (2013)

By the fifth day of measuring daily temperature(Figure 1) *Mucuna* as live mulch recorded the lowest temperature (29^0 C).However, it was not significantly ($p<0.05$) different from *Mucuna* as *in-situ* mulch(30^0C) but they were both significantly($p<0.05$) different from *Mucuna* as green manure (33.67^0C)and the control(36.67^0C) in experiment one. A similar trend was observed in the second experiment (2013), where by the seventh day of measuring daily temperature, *Mucuna* as live mulch (33.67°C) and *Mucuna* as *in-situ* mulch (33.67°C) recorded the lowest temperature which was significantly ($p<0.05$) different from *Mucuna* as green manure (43^0C) and the control (38^0C) in experiment two. This trend (Figure 1 and 2) could be attributed to the fact that, both *Mucuna* as live mulch and *Mucuna* as *in-situ* mulch had *Mucuna* giving a protective cover and thus reducing the effect of direct sunshine and hence leading to lower temperatures. This affirms the assertion of Parson (1996), that *Mucuna pruriens* is a successful cover crop because it exerts certain influence on the soil, protecting the soil surface from direct heat of the sun, keeping the soil cool and warm in the extremes of the weather. Organic mulch maintains more uniform soil temperature by acting as an insulator that keeps the soil warm during cool spells and cooler during the warm month of the year (Ameroso, 2010).Generally the low temperature recorded by *Mucuna* as live mulch and *Mucuna* as *in-situ* mulch could be that they recorded the highest gravimetric moisture content (Table 4). This conforms to Raison (1986) who after series of trials in Australia, reported that soil temperatures reduced as the soil water content increased.

Table.4: Influence of Treatments on Soil Moisture

	Gravimetric Moisture Content (g/g)		Volumetric Moisture Content (cm^3/cm^3)		Residual Moisture Content (cm)	
	2012	2013	2012	2013	2012	2013
Control	8.13	9.87	12.74	15.29	1.93	2.26
Green manure	8.22	10.03	10.93	13.74	1.61	2.06
Live mulch	8.44	10.93	11.00	14.53	1.65	2.18
In-situ mulch	9.61	11.66	14.14	17.03	2.12	2.55
L S D (0.05)	NS	1.468	2.272	1.983	0.3449	0.3102
C V (%)	3.3	2.0	5.0	2.4	4.9	1.9

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Table 4 indicates that the *Mucuna* as *in-situ* mulch recorded the highest volumetric moisture content in both experiments with the control recording the lowest. This result could be attributed to the fact that *Mucuna* as *in-situ* mulch and the live mulch had a ground cover which reduced water loss through evaporation. A similar trend was observed by Akubundu *et al*, (2000) that *Mucuna pruriens* plant serves as a ground cover to prevent loss of water through evaporation and decreases soil run off and thus keeping the soil moist.

Erenstein (2002) also observed that there was a reduction in runoff, evaporation and increased infiltration for effective soil water storage for crop's water requirement after mulching.

The high residual moisture content (Table 4) recorded by *Mucuna pruriens* as *in-situ* mulch in both years could be attributed to the fact that the *Mucuna pruriens* on that plot reduced the contact between the soil and dry air and this reduced the water loss into the atmosphere through evaporation from sunshine and desiccating winds (Olabode *et al.*, 2006). It also conforms to Agyenim-Boateng and Safo (1999) in an experiment conducted on *Mucuna pruriens* as a cover crop that there was improved moisture content of the soil; from 9.4% to between 10.30% and 11.40%. Hartfield *et al*.(2001) in farming matters found 34-50% reduction in evaporation and a considerable decrease of soil temperature as results of the ground cover protection by mulch (*Mucuna pruriens* as *in-situ* mulch).The trend observed might have been as a result of the low temperatures recorded by *Mucuna pruriens* as *in-situ* mulch (Figure1 and Figure 2).This conforms to Srivastava (1992) who observed that low temperature leads to a low evaporative demand and increases the scope for excess soil water conditions. The lower the temperature, the lower the evaporation losses and the more moisture retention for cultivated crop. The highest residual moisture content recorded by *Mucuna pruriens* as *in-situ* mulch could be attributed to the highest gravimetric and volumetric moisture content recorded (Table 4) as antecedent moisture is key to residual moisture content.

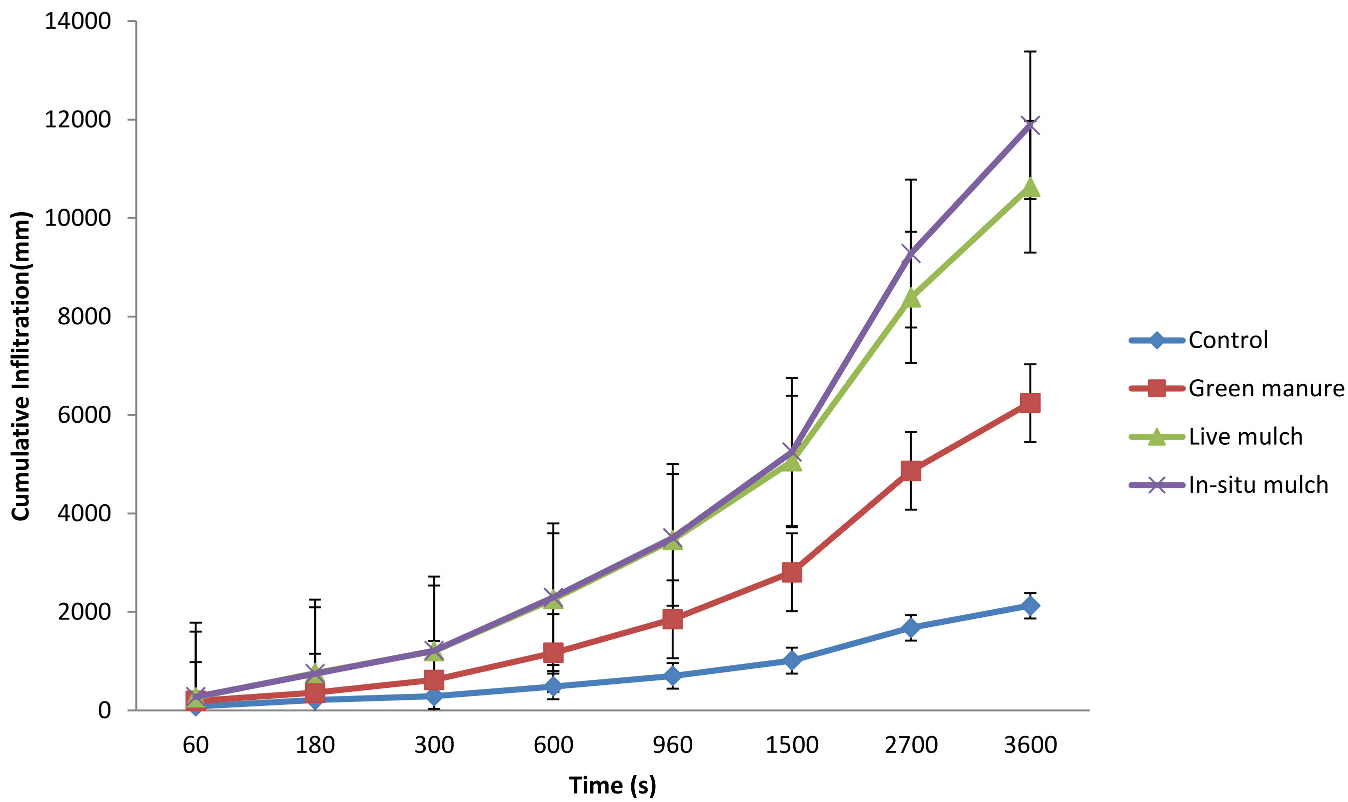

Fig.3: Cumulative infiltration curves for treatments (2012)

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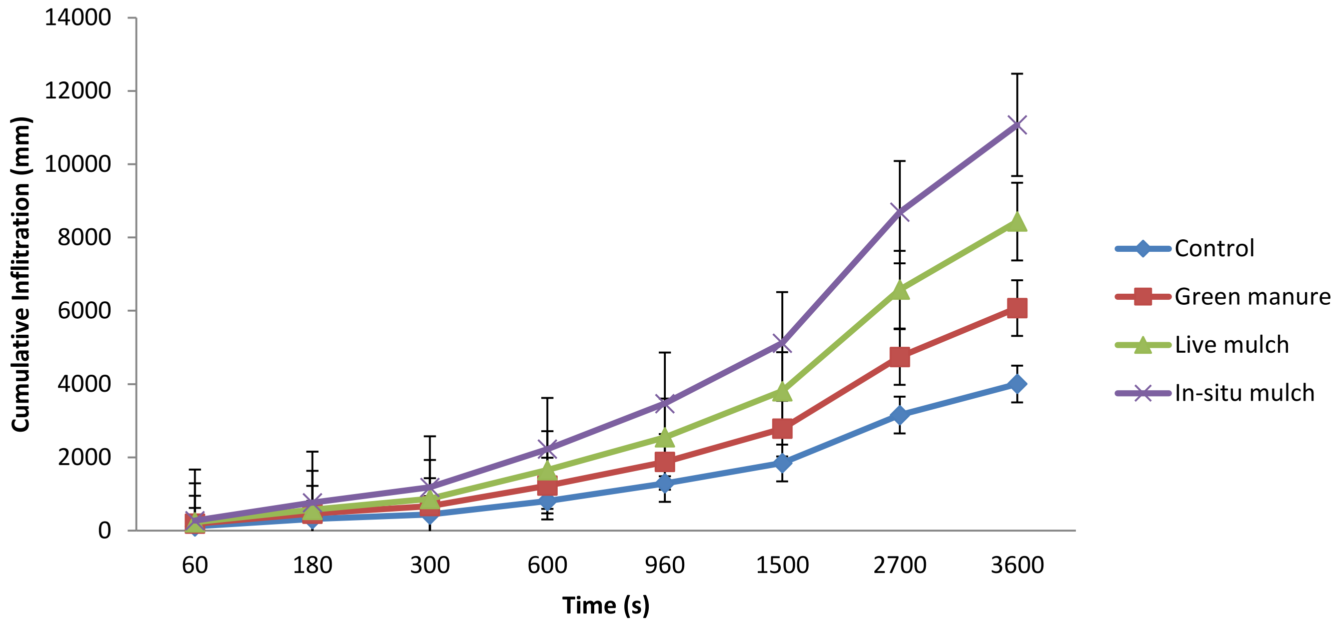

Fig.4: Cumulative infiltration curves for treatments (2013)

The results (Figure 3 and 4) of the experiment showed that, by the hour mark, *Mucuna pruriens* as *in-situ* mulch recorded the highest cumulative infiltration amount in both experiments with the control recording the least value. *Mucuna pruriens* as *in-situ* mulch was significantly different from *Mucuna pruriens* as green manure and the control but not significantly different from *Mucuna pruriens* as live mulch in the first experiment. This findings could also be attributed to the fact that *Mucuna pruriens* as live mulch plot recorded the highest Total porosity and air-filled porosity (Table 2) and likely to have more macro pores for good water infiltration. This confirms that it is not only antecedent water that influences infiltration but other factors like structure, texture porosity and tillage Jury *et al*. (1991). These findings are very important as infiltration influence runoff and time of ponding. The temporal distribution of soil moisture controls numerous catchment processes including runoff generation, groundwater recharge, ET, soil respiration, and biological productivity (Williams *et al*., 2009).

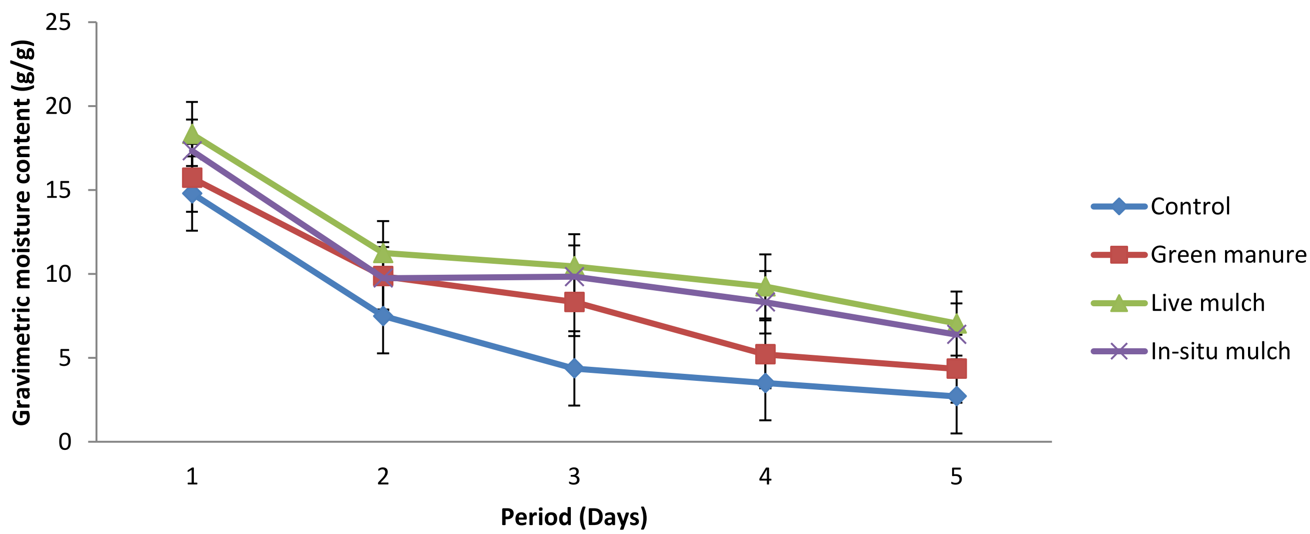

Fig.5: Influence of mucuna on soil drying (2012)

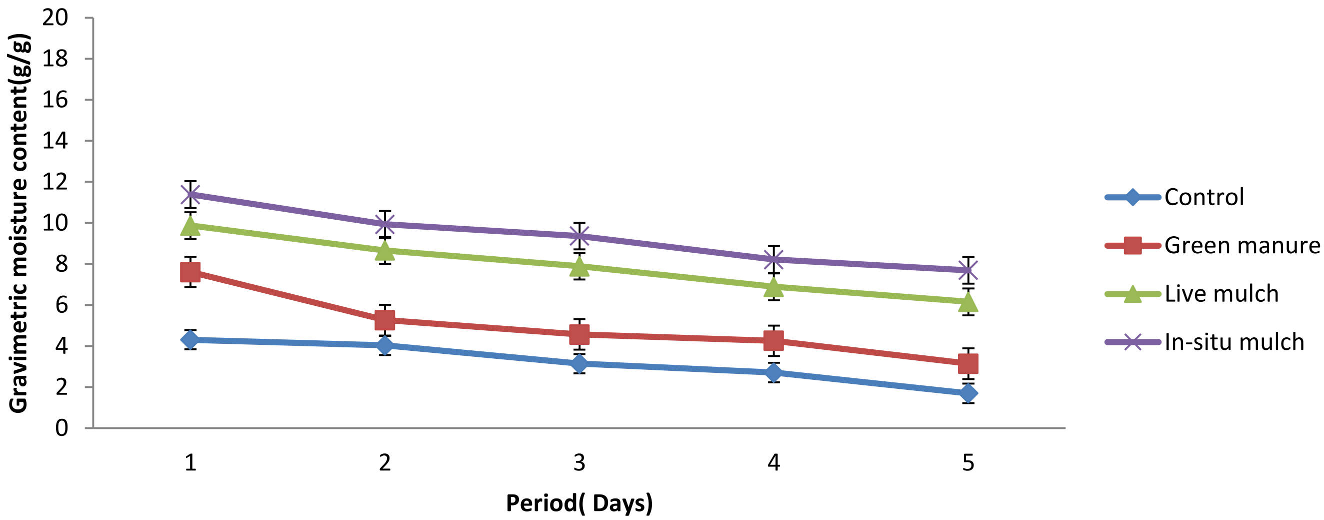

Fig.6: Influence of mucuna on soil drying (2013)

It was observed that, *Mucuna pruriens* as live mulch scored the highest gravimetric moisture content value (7.05) after the five days of studying soil drying in experiment one (2012) with the control scoring the lowest (2.71). In 2013 the in-situ mulch recorded the highest value (7.69) while the control again recorded the least value (1.70). The observation above could be attributed to the fact that the treatment *Mucuna pruriens* as *in-situ* mulch and *Mucuna pruriens* as live mulch had mulch which reduced water loss by evaporation and reduced direct impact of sunshine on the surface of the soil. It could also be attributed to the low temperature recorded by *Mucuna pruriens* as *in-situ* mulch as low temperatures also reduces soil moisture loss. This affirms Parson (1996) assertion that *Mucuna pruriens* is a successful cover crop because it exerts certain influence on the soil, protecting the soil surface from direct heat of the sun, keeping the soil cool and warm in the extremes of the weather.

Table.5: Influence of Treatments on Sorptivity

	SORPTIVITY(mm/s) 2012			SORPTIVITY (mm/s) 2013		
	S60	S180	S300	S60	S180	S300
Control	10.3	15.6	16.7	14.84	25.72	25.40
Green manure	24.7	27.9	35.7	24.73	37.82	42.02
Live mulch	34.2	56.5	69.4	29.46	42.60	50.95
In-situ mulch	35.7	55.5	70.1	35.27	56.76	67.80
LSD	7.77	16.02	20.35	8.8	11.12	12.18
CV	7.3	6.8	4.8	9.2	6.5	4.1

Sorptivity is a measure of the soils ability to absorb water. Generally *Mucuna pruriens* as *in-situ* mulch recorded the highest sorptivity value followed by the live mulch in both experiments with the control recording the lowest sorptivity value (Table 5). This could be attributed to *Mucuna pruriens* as live mulch and *Mucuna pruriens* as *in-situ* mulch were better drained with higher porosity and therefore, likely to have more macro pores and the greater ability to absorb and conduct initial water during infiltration. Also the Mucuna treatment had a protective ground cover by the *Mucuna pruriens* and therefore reduced the impact of raindrop and splash which in turn reduced soil compaction, reducing the surface sealing and increasing porosity, reducing surface runoff and increasing infiltration, and readily making soil water available to the plant. This assertion is supported by Chancellor (1977) and Olabode *et al*. (2006). The reverse is true for the control plot which recorded the lowest sorptivity value. This was supported by Jury *et al*. (1991), that besides,

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antecedent moisture, sorptivity is influenced by porosity and pore size distribution, aggregate stability, bulk density, permeability.

IV. CONCLUSION AND RECOMMENDATION

Mucuna pruriens as *in-situ* mulch, *Mucuna pruriens* as live and *Mucuna pruriens* as green manure as soil amendments improve gravimetric (θ_g) and volumetric moisture content (θ_v), residual moisture storage(R), sorptivity (s), cumulative infiltration(I) with *Mucuna pruriens* as *in-situ* mulch recording significantly ($p \leq 0.05$) higher values while the control recorded the least values in the above mentioned parameters. The soil bulk density (ρ_b), total porosity (f) and aeration porosity (ξ_a), were significantly improved by *Mucuna pruriens* as live and *Mucuna pruriens* as green manure as they were significantly ($p \leq 0.05$) higher than *Mucuna pruriens* as *in-situ* mulch and the control in both years. *Mucuna pruriens* as *in-situ* mulch in both years was significantly higher in aggregate stability (ASt) than all the other treatments while there was no significant difference amongst them. Soil temperature was steadily reduced by *Mucuna pruriens* as live and *Mucuna pruriens* as *in-situ* mulch with each been significantly different from the control in the first and second year respectively. From this results, the application of *Mucuna pruriens* as *in-situ* mulch, *Mucuna pruriens* as live as soil amendments is recommend as the most effective soil conservational technology for improvement soil hydro-physical properties.

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