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Influence of Different Soil Application Methods of *Mucuna puriens* on Soil Chemical Properties and Maize Yield in Ghana

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Authors' contributions

This work was carried out in collaboration between all authors. Author BYO under the supervision of authors K. Agyarko and E. K. Aseidu designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors MA, KK, E. K. Amponsah and K. Atakora performed the statistical and managed the analyses of the study and also did the literature search. All authors read and approved the final manuscript.

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ABSTRACT

Damaged and depleted soils need to be rebuilt, improved and used efficiently to support permanent agriculture. Generally there have been several attempts to use cover crops as soil amendments to improve soil management and conservation while improving soil productivity. This experiment was conducted between December 2011 and December 2013 at the multipurpose nursery of the University of Education, Winneba, Mampong Campus, Ghana to determine the growth and yield response of maize and some soil chemical properties to *Mucuna pruriens* as soil amendments. The treatments used were; *Mucuna pruriens* as green manure, *Mucuna pruriens* as live mulch, *Mucuna*

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pruriens as *in-situ* mulch and control (no *Mucuna pruriens*) laid out in a randomized complete block design (RCBD) with 3 replications. The growth and yield parameters of maize measured were plant height, stem girth, leaf area index (LAI), 100 seed weight, mean cob weight and grain yield. Organic carbon and organic matter, soil pH, total nitrogen (N), available phosphorus (P), exchangeable potassium (K) and cation exchange capacity (CEC) were measured for soil chemical properties. The study showed that *Mucuna pruriens* as *in-situ* mulch recorded the highest grain yield and cob weight followed by *Mucuna pruriens* as green manure, *Mucuna pruriens* as live mulch and the control. Although *Mucuna pruriens* as live mulch recorded higher levels of the soil's chemical properties, it did not give the best growth and yield performance of maize (test crop) probably as a result of its allellopathic effects and the competition between the live *Mucuna pruriens* and the maize plant for space, water and nutrients.

Keywords: Green manure; in-situ mulch; live mulch; Maize; Mucuna pruriens.

1. INTRODUCTION

The key problem of tropical agriculture is the steady decline in soil fertility, which is closely related to the duration of soil use. According to Mulumba and Lal [1] damaged and depleted soils need to be rebuilt, improved and used more efficiently if they are to support permanent agriculture.

This calls for soil conservation practices which aim at protecting the soil from erosion, maintaining satisfactory levels of plant nutrients, with a realistic soil management measures playing a supporting role [2].

Maize (*Zea mays* L.) is a major cereal crop in West Africa, accounting for slightly over 20% of the domestic production in the sub-region [3]. It is one of the most important cereals in Ghana, which is cultivated in all the agro-ecological zones [4]. Maize yield averaged 4.9 t ha^{-1} globally in 2009 [5]. However, yields in major maize growing areas in the developing world remains low and is about 3.1 t ha^{-1} [6]. Yields in the United States for example have increased remarkably from an average of 1.6 t ha^{-1} in the early 1930's to the current approximated yield of 9.5 t ha^{-1}, whereas yields presently obtainable in Ghana hover around 1.7 t ha^{-1} [5,7]. The significant importance of maize for both animals and man calls for its improvement both in quality and quantity. Poor soil quality and poor soil health have led to reduced yield [8]. In Ghana, maize is produced predominantly by small holder resource poor farmers under rain-fed conditions [9].

Low soil fertility and low application of external inputs are the two major reasons that account for low productivity in maize [10,11]. The soils of the major maize growing areas in Ghana are low in organic carbon (<1.5%), total nitrogen (<0.2%), exchangeable potassium (<100 mg kg^{-1}) and available phosphorus (<10 mg kg^{-1}) [10,11]. Soil fertility depletion in smallholder farms is the fundamental biophysical root cause for declining per capita food production in sub-Saharan Africa.

To reverse the trend of loss of soil fertility and to increase food production, practices such as green manuring, mulching, composting, and agro-forestry as well as the use of short duration improved fallow leguminous plants have evolved for adoption [12]. Food and Agricultural Organization programmes on integrated plant nutrition system recommend the use of nitrogen-fixing plants into fields to improve soil nutrient status, so as to increase crop productivity. This would break the vicious cycle of poverty, low input agriculture and soil degradation in many developing countries [13]. Intensive farming according to Grant and Okigbo [14] relies on the provision of additional nitrogen through inorganic fertiliser or by growing leguminous plants as fallows that have symbiotic relationship with nitrogen-fixing bacteria.

Mucuna pruriens has been identified as one of the species of high potential for soil fertility improvement. The potential of the crop as *in-situ* mulch, live mulch and green manure on growth and yield of maize is uncommon among farmers. The study therefore sought to determine the effect of different methods of application of *Mucunapruriens* on some soil chemical properties, growth and yield of maize.

2. MATERIALS AND METHODS

2.1 Study Area

The experiment was carried out at the Multi-purpose nursery of the University of Education, Winneba, Mampong – Campus. Mampong (07°04'N, 01°24'W) lies at 457.5 meters 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 [15]. The soil is of the savannah Ochrosol type which belongs to the Bediesi series known as Chromic Luvisol in F.A.O/ UNESCO classification [16] and derived from the voltaian sandstone.

2.2 Treatments and Experimental 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 6 × 4m giving a total area of 24 m^2 per plot. A path of 1 m was left between each plot for easy movement. The demarcated field of 6 by 4 m per plot was left for five months to be stable from the last farming. The plots were all sprayed with an herbicide (Sunphosate with glyphosate as active gradient at a rate of 2.5 l ha^{-1}) to control the weeds on them. Lining and pegging was done for the planting of *Mucuna pruriens* at a planting distance of 0.8 × 0.8 m. The plots with treatment (i), (ii) and (iii) were planted with *Mucuna pruriens* for the first experiment in mid- May 2012 while for the second experiment the *Mucuna pruriens* was planted in mid-January 2013.

2.2.1 *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 the decomposition had taken place and the heat produced during the initial stage of decomposition had reduced.

2.2.2 *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.

2.2.3 *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. 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.

2.2.4 Control (No *Mucuna pruriens*)

This plot did not have any *Mucuna pruriens* planted on it from the inception of the experiments.

2.3 Planting of Maize

Maize variety (Obatanpa) was planted (with planting distance of 0.7×0.4 m) at the same time on all the four treatments, thus three weeks after incorporation of mucuna into the soil on the *Mucuna pruriens* as green manure plot. Three seeds were planted per hill and thinned to two plants a week after germination.

2.4 Determination of Parameters

The soil chemical properties measured were, pH [17], Org C and Org Matter [18], CEC [19], Available P [20], N [21].and K- using the Gallenkamp Flame photometer. The growth parameters of the test crop (maize) monitored and measured included, Plant Height, Stem Girth and Leaf Area Index (LAI).The procedure recommended by Sexana and Sing [22] was used in estimating the leaf area index. Data on Cob Weight, 100 seed weight and Grain Yield were measured.

2.5 Initial Soil Properties

The average bulk density, total porosity and air-filled porosity were 1.50 g/cm^3, 43% and 27.1% respectively (Table 1).

The average organic carbon and organic matter were 1.12% and 1.93% respectively, while the cation exchange capacity and pH of the soil were 5.447 Cmol kg^{-1} and 5.720 respectively.

2.6 Data Analysis

The analysis of variance (ANOVA) procedure was carried out using the GenStat Statistical Package. Means were separated using the Least Significant Difference (LSD) at 5% significant level ($p < 0.05$).

Table 1. Summary of initial soil physical and chemical properties

Soil property	Value
Bulk density (g cm^{-3})	1.50
Total porosity (%)	43.00
Air-filled porosity (%)	27.10
Org. C (%)	1.12
Org. M (%)	1.93
CEC (Cmol kg^{-1})	5.45
pH	5.72

3. RESULTS AND DISCUSSION

3.1 Effect of Soil Application Methods of *Mucuna pruriens* on Some Soil Chemical Properties

The influence of treatments on soil pH, OC%, OM%, N%, Available P, Exchangeable K and CEC was indicated (Table 2). All the *Mucuna pruriens* treated soil recorded significantly lower soil pH values and higher OC%, OM%, N%, Available P, Exchangeable K and CEC values than the control. It is widely recognised that the additions of organic materials to soils affect the physical and chemical properties. This was therefore reflected in the lower values of the chemical properties observed in the control treatment where no additions of organic materials were made. Among the *Mucuna pruriens* treated soil, *Mucuna pruriens* as live mulch recorded the highest values of OC%, OM%, N%, Available P and Exchangeable K, while the *in-situ* mulch treatment had the highest values for CEC and the lowest soil pH. The values of the parameters recorded between the *Mucuna pruriens* as live mulch and the *in-situ* mulch treatments were statistically the same.

As compared to the Green manure treatment, where the *Mucuna pruriens* plants were mixed with the soil, there was no mixing of organic materials with the soil under the *Mucuna pruriens* as live mulch and the *in-situ* mulch treatments, and hence the observed higher values of the soil's chemical properties in the latter treatments. Soil tillage has been found to affect soil properties. Alam et al. [23] in a study on tillage practices found the total N, P, K, and S in their available forms to be highest under zero tillage. No-till systems have greater soil microbial biomass and enzymatic activity, which is attributed to favourable physical and chemical conditions for microbial activities [24]. Microbes improve soil quality by cycling nutrients and thus influence the release of soil nutrients which might be the reason behind the higher values of the soil's chemical properties in the *Mucuna pruriens* as live mulch and the *in-situ* mulch treatments. The *Mucuna pruriens* as live mulch treatment compared to the other treatments recorded higher values of the soil's properties probably as a result of the numerous benefits of the live plants, such as preventing soil erosion, allowing symbiotic nitrogen fixation, conserving nutrients in the top soil layer, increasing biodiversity and release of root exudates in the soil which might have increased soil microbial population and activities and thus release of more nutrients in the soil [25,26,27].

3.2 Effect of Soil Application Methods of *Mucuna pruriens* on Maize Plant Height

There was a steady increase in the height of maize plant for all treatments from the first week after planting to tasseling (Figs.1 and 2).

Mucuna pruriens as *in-situ* mulch recorded the highest plant height in both experiments (2012 and 2013). This might be due to the fact that *Mucuna pruriens* as *in-situ* mulch plot recorded high quantity of nitrogen when treatments were chemically analysed (Table 2). This assertion is in conformity with the findings of Akinyosaye [28] that, moderate to high nitrogen supply to the plants promotes vegetative growth and in this case can be equated to the high plant height. The results also confirm the findings of Tweneboah [29] that, adequate quantities of nitrogen promote leaf growth reflected in the increase of plant height. The highest plant height recorded by *Mucuna pruriens* as *in-situ* mulch could be explained by its record of high levels of the soil's chemical properties assessed (Table 2).

Although *Mucuna pruriens* as live mulch treatment recorded the highest nitrogen, highest potassium, and highest phosphorus, it recorded the least plant height. This might be attributed to the alleopathic property of *Mucuna pruriens* which leads to the suppression and inhibition of plant growth [30,31].

3.3 Effect of Soil Application Methods of *Mucuna pruriens* on Leaf Area Index

Mucuna pruriens as green manure recorded the highest leaf area index in both experiments

Table 2. Treatments effects on some soil chemical properties

Treatment	pH		Org. C (%)		Org. M (%)		Total N (%)		Avail. P (mg kg^{-1})		Exch. K (Cmol kg^{-1})		CEC (Cmol kg^{-1})	
	2012	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**
Control	5.66	5.72	1.01	1.31	1.74	2.26	0.09	0.11	12.53	14.12	0.17	0.14	4.97	5.45
Green manure	5.96	5.81	1.14	1.54	1.97	2.63	0.13	0.14	18.71	19.46	0.22	0.20	5.82	5.86
Live mulch	5.12	5.22	1.67	1.77	2.89	3.22	0.19	0.19	32.85	30.04	0.29	0.25	6.30	6.73
In-situ mulch	5.01	5.17	1.66	1.69	2.86	2.85	0.17	0.17	27.56	25.80	0.26	0.22	6.31	6.82
LSD $_{(0.05)}$	0.38	0.15	0.11	0.12	0.19	0.29	0.02	0.04	5.70	4.19	0.04	0.03	0.33	0.23
C V (%)	0.50	1.50	4.60	3.40	4.60	3.80	4.90	5.90	2.20	2.90	5.60	1.90	1.30	1.10

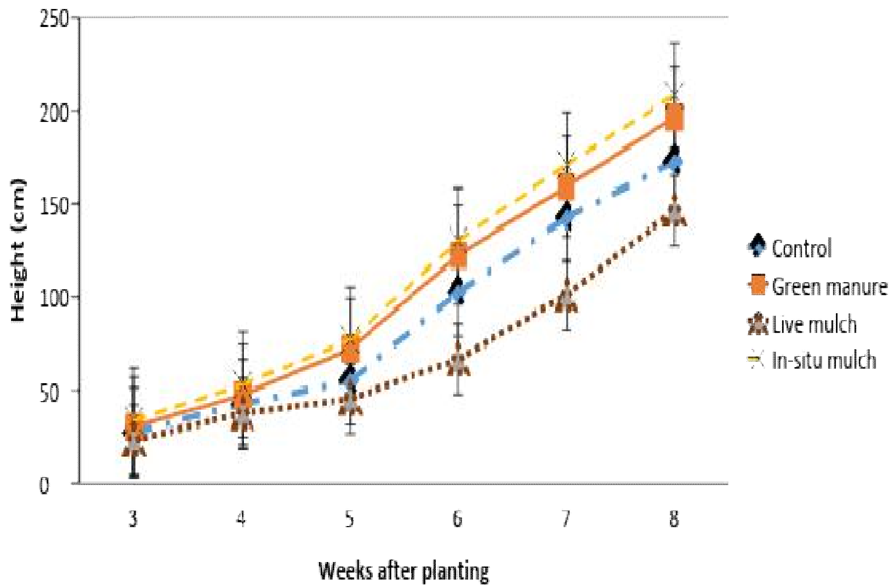

Fig. 1. Changes in plant height as affected by treatments (2012)

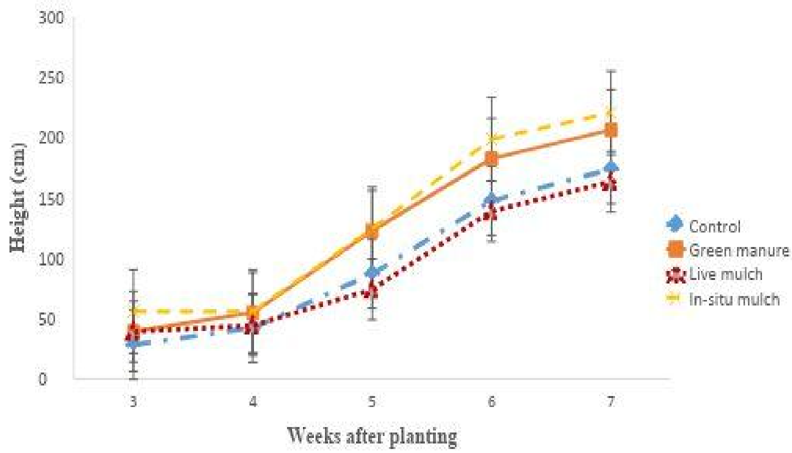

Fig. 2. Changes in plant height as affected by treatments (2013)

(2012 and 2013) (Table 3) whereas the control with no *Mucuna pruriens* application recorded the lowest values in both experiments. *Mucuna pruriens* as green manure was significantly different from the Control and *Mucuna prurien* as live mulch but not significantly different from *Mucuna pruriens* as *in-situ* mulch. This could be due to the fast release of soil nutrients in the *Mucuna pruriens* as green manure treatment which enhanced plant growth and consequently leaf enlargement. This is in conformity with Houngnandan et al. [32] who stated that *Mucuna pruriens* had a low C:N ratio and so decomposed easily and faster. Also *Mucuna pruriens* is known to have N-rich leaves that decompose rapidly in tropical environment with the subsequent release of N in the soil [3]. *Mucuna pruriens* incorporation into a Haplic Acrisol enabled greater growth and yield of crops [33].

Table 3. Mean leaf area index

Treatments	Leaf area index	
	2012	**2013**
Control	2.22	2.37
Green manure	3.29	3.30
Live mulch	2.06	2.09
In-situ mulch	3.26	3.24
$LSD_{(0.05)}$	0.41	0.31
CV(%)	3.90	4.60

Mucuna pruriens as live mulch recorded the lowest values of leaf area index in both experiments, which could be attributed to the allelopathic properties of the *Mucuna pruriens* plant [30,31].

3.4 Effect of Soil Application Methods of *Mucuna pruriens* on Stem Girth of Maize

Mucuna pruriens as green manure treatment recorded the highest stem girth values in both experiments (Figs. 3 and 4). *Mucuna pruriens* as live mulch plot recorded the lowest values of stem girth in both experiments. The same reasons for the trend in leaf area index could be attributed to the results observed in the stem girth.

3.5 Effect of Soil Application Methods of *Mucuna pruriens* on Maize Yield

The influence of *Mucuna pruriens* treatments on yield parameters of maize showed that generally, *Mucuna pruriens* as *in-situ* mulch recorded the highest 100 seed weight, cob weight and grain yield of maize, with the control which received no kind of *Mucuna pruriens* application recording the lowest value in both experiments (Table 4). This trend recorded by *Mucuna pruriens* as *in-situ* mulch could be explained by the high expression of parameters assessed for soil's chemical properties (Table 2). Which positively affected the growth of the maize plants and thus leading to the highest yield of maize observed.

Though *Mucuna pruriens* as live mulch recorded the highest levels of the parameters of the soil's chemical properties, maize yield parameters, especially the cob weight and the grain yield under the two experiments were significantly lower than all the *Mucuna pruriens* treated soil and significantly the same as the yields from the

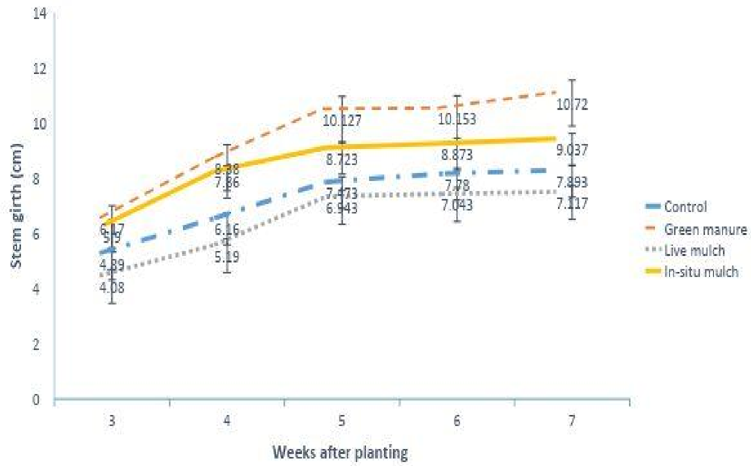

Fig. 3. Changes of maize stem girth as affected by treatments (2012)

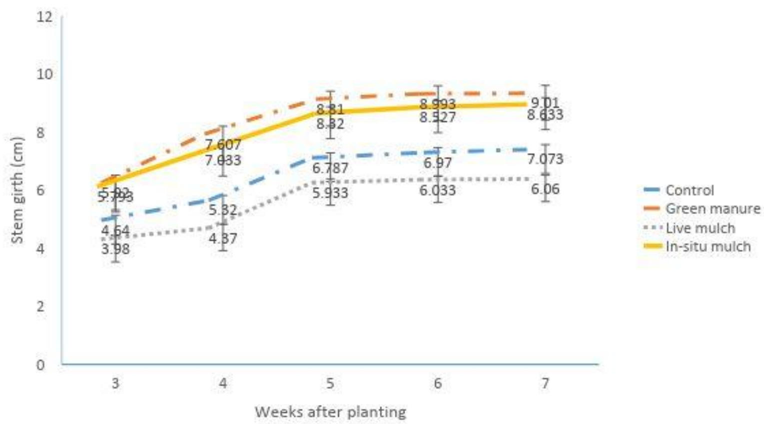

Fig. 4. Changes of maize stem girth as affected by treatments (2013)

Table 4. Influence of treatments on yield parameter

Treatments	100 seed weight (g)		Maize gran yield (kg ha^{-1})		Mean cob weight (g)	
	2012	2013	2012	2013	2012	2013
Control	36.60	31.53	2653.00	2561.00	109.50	77.73
Green manure	40.50	35.58	3258.00	3264.00	138.30	107.20
Live mulch	42.90	38.23	2882.00	2827.00	109.50	89.00
In-situ mulch	46.60	41.96	3431.00	3447.00	151.50	124.93
L S D $_{(0.05)}$	7.05	6.77	313.90	338.10	21.77	12.03
C V (%)	2.30	3.20	2.10	3.10	4.10	5.90

control treatment. This could be attributed to the allelopathic properties of the *Mucuna pruriens* plants and the competition between the maize and the live Mucuna plant which affected the growth of the maize plants negatively [30,31] and subsequently the yield of the maize crop.

It was observed that maize yield like some other parameters measured differed from year to year. This was because the rainfall distribution in the study area is bimodal and classified into major and minor rainy seasons. Therefore, the growth period of the maize plant happens to have fallen under different raining seasons and hence the year in which the growth period of the maize fell under the major raining season had marginal higher yields than the year under which the growth period fell under the minor raining season where the rainfall was relatively for a shorter period and of low intensity and frequency.

However, the yield of maize for the minor raining season was greater than that of the major raining season this can also be attributed to the fact that higher amount of rainfall encouraged the vigorous growth of *Mucuna pruriens* as live mulch which in turn outcompeted the maize.

4. CONCLUSION

In the present study, out of three treatments of *Mucuna pruriens viz.,* as green manure, , as live mulch and as *in-situ* mulch, the green manure treatment significantly improved the soil chemical properties and productivity of maize, Significantly the highest yield was recorded in the *in-situ* mulch method followed by the green manure method. Non-significant difference in yield was found between the control and the live mulch treatments. Even though the live mulch treatment recorded the highest values for the chemical properties of the soil, it did not record the highest yield of maize; this might be attributed to the allelopathic effects of live *Mucuna pruriens* plants.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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