Original Research Article

EFFECTS OF LAND PREPARATION METHOD AND ORGANIC SOIL AMENDMENT ON SOIL PROPERTIES, GROWTH AND YIELD OF MAIZE (*ZEA MAYS*).

Abstract

Maize (*Zeamays* L.) is an important food crop popular in Kenya and its production has a direct influence to nutrition and economic security. The high demand for this food crop has resulted to innovation of new farming practices to increase its production. Therefore, this experiment was set up at Meru University Demonstration Farm in randomized complete block (RCBD)split plot design. Two land preparation methodswere used conservational and conventional (CA and CT). The organic amendments were 2.5t ha^{-1} BSF, 5.5t ha^{-1} BSF, 8.5 t ha^{-1} BSF, 2.5 t ha^{-1} BSF + Biochar, 5.5 t ha^{-1} BSF + Biochar, 2.5 t ha^{-1} BSF + Trichoderma 125g ha^{-1}, 5.5 t ha^{-1} BSF + Trichoderma 125g ha^{-1}, 5t ha^{-1} FYM, 100kgN ha^{-1} DAP and control. Data collected was on soil bulk density, soil moisture, vegetative growth and yields. There was significance ($p<0.05$) difference between the two land preparation method on soil moisture retention. Organic amendments influenced the soil moisture retention and soil bulk density reduction significantly ($p<0.05$). Plots with 8.5 t ha^{-1} BSF and 100kgN ha^{-1} DAP increased the vegetative growth by 37%, application of Trichoderma increased the vegetative growth by 7%. CA increased the vegetative growth by 6% and 4% as compared to CT. 8.5 t ha^{-1} BSF increased the vegetative growth by 21% and 19%. CA increased the yields by 6% in S1 and 14% in S2 compared to CT. Trichoderma increased the yields of maize by 12% and 11%. Increase in maize yield and vegetative growth is due to increased soil moisture condition in CA. Addition of BSF manure and biochar improved the soil moisture retention, reduced soil bulk density and improvement in soil nutrient content which led to an increase in growth and yield.

Key words: Biochar, Black soldier fly manure, Maize vegetative growth, Maize yield, Soil moisture, Soil bulk density, Trichoderma.

1. Introduction

Maize (*Zea mays* L.) is an important food crop popular in Kenya and its production has a direct influence to nutrition and economic security. In 2020-2021 maize production in Kenya was about 85% of total cereal production of which it declined by about 550,000 metric tons which was as a result of increased cost of inputs, uneven rainfall distribution and drought. However,this impact contributed to a decline in maize consumption rate from 4-5 million metric tons to 3 million metric tons which amounts for 30% decrease (World Food Program 2022).The government of Kenya has laid strategies to subsidize farm inputs to increase maize production in Kenya(Central Bank 2023).Even though the use of subsidized chemical fertilizer not only will increase maize crop production in Kenya but also alters the soil pH, soil bulk density, decreased organic matter, soil macro and micro biodiversity, thereby bringing hazards to soil and environmental (Pahalvi*et al*., 2021). Therefore, there is a need for utilization of readily available organic manure to increase maize production in order to conserve soil health and environment.

Organic manure is a potential source of plant nutrients for increasing maize*(Zea mays)* production (Kandil *et al*., 2020). Organic soil amendment has a potential of improving soil water up to 8% (Singh *et al*., 2021).Cattle manure being one of the sources of organic plant nutrients has been found to be having a capacity to enhance maize productiveness, improved soil pH and increased nitrogen supply, which increased maize yield up to 45% (Eleduma*et al*., 2020). In Kenya cattle manure is a common organic fertilizer used by farmers at the rate of 5 t to 15 t ha^{-1} for maximum maize yield production (Aluoch *et al*., 2022). However, the full benefits have not been realized due to limited use and scarcity of cattle manure. On other hand, black soldier fly manure (BSFM) *(Hermetia illucens L.)* is gaining its popularity globally as a source of organic soil enricher and this has been found to increase maize yields up to 7% (Lalander *et al.*, 2019 and Beesigamukama *et al*., 2020). Due to its special mouth parts and intestinal enzymes, black soldier fly larvae have a capacity to breakdown the biological wastes and successful decomposition (Cho *et al*., 2020). High nutrient contents in decomposed black soldier fly manure improves soil physiochemical and biological properties and this has been found to increase maize yield up to 60% (Tanga *et al*., 2022; Agustiyani *et al*., 2021). In Kenya BSF is a new phenomenon however, the BSF materials are available to limited extent on maize production.Tanga *et al*. (2022) found that 7.5 t ha^{-1} BSF increased maize yield by 17% than other organic fertilizer. Biochar has gained popularity in improving soil health due to its porous nature and carbon-rich material, which enhances soil fertility and structure (Liu *etal*., 2019). The porous structure of biochar retains water in the soil, leading to improved soil moisture conditions, which has been found to increase maize yield up to 8.4% and 50% harvest index (Barus *et al*., 2023; Cong *et al*., 2023; Islam *et al*., 2018). The rates for biochar application of up to 15 t ha^{-1} has been found to increase maize yield by 14% when amended with chemical fertilizer (Mosharrof*et al*., 2022).Perhaps combining biochar and other practices of production can lead to improved maize yields and enhanced soil physiochemical property. Currently the practices in Kenya is the rates given for cattle manure alone (Muriithi *et al*., 2022).Therefore, there is a desirable need to use various mixtures of manure from different sources. In Kenya, application rates need to be addressed to achieve maximum maize yields

Conservation soil tillage practices, such as reduced tillage and no tillage, improve water use efficiency by preventing soil damage and preserving soil water (Wang and Shangguan, 2015). Switching to no-tillage farming improves water infiltration and reducedevaporation (Ranaivoson *et al*., 2019). No-tillage and reduced tillage techniques increases the effectiveness of water usage and lower evapotranspiration in cereals (Guo *et al*., 2019; Liu *et al*., 2020). Zero-tillage method has been found to conserve soil moisture up to 32%, which has been found to increase maize yields up to 17% (Khaemba *et al*., 2017;Wang*et al*., 2021). In Kenyathe common method of land preparation being used is conventional tillage method, minimum tillage and ridging method to enhance moisture conditions in semi-humid regions (Kiboi *et al*., 2021). Therefore, new methods of land preparation in Kenya needs to be used to improve soil moisture conditions and increase maize production.

Trichoderma asperellum is a species of fungi belonging to the genus Trichoderma. Trichoderma has been found to be biofertilizer to support soil organic matter decomposition, which leads to an increase in maize growth and yield up to 20% per hector (Syamsiyah *et al*., 2023). It has also been found to increasephosphate absorption rate by 19% which was found to increase plant growth by 41.1% (Bononi *et al*., 2020). *Trichoderma spp* has been shown to improve root growth and development due to excretion of auxins and gibberellins which are plant growth regulators (Palegio *et al*., 2017).In Kenya *Trichoderma spp* is used as a beneficial fungus to inhibit mycotoxin fungi affecting maize (Mwatabu *et al*., 2023). Therefore, there is limited information on Trichoderma effects on maize production in combination with different organic source of manure to increase maize yields.The main objective of this study was to evaluate the effects of land preparation method and organic amendments and on soil physical properties, growth and yield of maize.

2. Materials and Methods

Experimental site

The experiment was carried out in Meru University of Science and Technologydemonstration farm, Kenya, on a latitude $0^{o}08’16’$N, longitude $37^{o}42’33’$E, 1420m above sea level. Experiment wasdoneduring June-October 2022 (S1) and November - March 2023 (S2).

Experimental design and treatments

The experiment was laid out in randomized complete block split-plot designreplicated three times with the main plots having two land preparation methods (basin and conventional) and organic amendments (2.5 t ha^{-1} Black Soldier Fly (BSF) (T1), 5.5 t ha^{-1} (T2), 8.5 t ha^{-1} (T3), 2.5 t ha^{-1} BSF + 3t ha^{-1} Biochar (T4), 5.5 t ha^{-1} + 3t ha^{-1} Biochar (T5), 2.5 t ha^{-1} BSF + 125g ha^{-1} *Trichoderma asperellum* (T6), 5.5 t ha^{-1} + 125g ha^{-1} *Trichoderma asperellum* (T7), 5t ha^{-1} Farm Yard manure (FYM) (T8), 250kg ha^{-1} DAP (T9) and control (T10)) as sub-plots.

Land Preparation and Planting

The experiment was out in the field with experimental plots measuring 2m length by 2m wide with a part of 1m. For basin land preparation method basin holes of 35cm long by 15cm wide and 15cm deep was made with an inter-spacing of 90cm and intra-spacing of 25cm. The holes were three quarter filled with the mixture of soil and manure (BSF and FYM)before sowing the seeds. For conventional land preparation method, the land was tilled to fine tilt using a jembe and a fork jembe and the planting holes was made at a spacing of 75cm by 25cm.

Duma 43SC (SeedCo East Africa LTD) maize variety was planted two seeds per basin hole. *Trichoderma asperellum* (DUDUTECH Company Limited, Kenya) was diluted in water using the recommended mixing ratios and drenched into the planting holes. Organic by-products black soldier fly (BSF) manure was obtained from Black Soldier Fly Sanitation Project in Meru University of Science and Technology, decomposed Farm Yard Manure (FYM) obtained from Meru University Farm and DAP and CAN from Yara East Africa. Three litter metallic container was three quarter filled with rice husks and closed tightly. It was heated to red hot using wood fuel for 2 hours and then container was left to cool down and the ready biochar was taken to the field.

Data Collection

Growth parameters

Three weeks after sowing, three maize plants were randomly selected and tagged from each treatment for the determination of growth parameters. Data on plant height, plant stem girth and chlorophyll index were measured at an interval of two weeks. Plant height was measured from the ground level using a tape measure (cm), stem diameter was measured 20cm from the ground level using Vernier caliper (mm). On the other hand, chlorophyll index was measured using chlorophyll meter(SPAD-502Plus) by measuring the top most second leaf. The number of leaves were determined byhand counting of fully developed leaves. Maize was harvested when they had attained physiological maturity (green maize). Then, the total yields were determined by weighing the harvested cobs per plot using a weighing balance.

Soil parameters

Soil moisture was measured using digital Moisture meter (DSMM500). Soil moisture level was being measured before watering the soil to field capacity.Soil bulk density was determined using core ring method.

Soil samples for bulk density were collected on the hole of each plot using a steel core ring cylinder of diameter 4.5cm and 5cm height.Steel ring was pushed into the soil to a depth of 15cm. Soils around the ring ware excavated without disturbing, excess soils were removed using a using a sharp knife and plant roots were cut off. Soils were placed in a khaki bag and oven dried for 24hrs at 105^{o}C. Then dry weight (g) was determined using an analytical weighing scale (FA2004E(N)). The volume (cm^3) of steel core ring cylinder was used to calculate the soil bulk density using the formulae (Jurgensen *et al*., 1999):

Soil Bulk Density(gcm^{-3}) = Weight of dry soils (g)/Volume (cm^3)

Statistical Analysis

Collected data was analyzed using general linear model procedure Statistical Agricultural Software (SAS 2005) and least significance difference (LSD) was used to determine the mean difference between treatments. Least significance difference test was employed to differentiate at 5% levels of significance.

3. Results and Discussions

Effects of land preparation method and organic amendment onsoil moisture

There was no significant interaction between land preparation method and the organic amendment on soil moisture content. Land preparation method had a significant effect ($p<0.05$) on moisture content (table 1). In both seasons conservational land preparation method recorded the higher soil moisture content from 35 DAS to 77 DAS than conventional land preparation method (table 1). This results can be explaining by the fact that in conservational land preparation method there was minimum soil disturbance which resulted to an increase of 4% and 2% soil moisture content in S1 and S2 respectively. Increase in soil moisture in conservational land preparation was due to reduced soil disturbance which maintained the soil structure and soil water percolation. This is in agreement with Wang *et al*.(2021) and Zhang *et al*. (2022) who found that conservational land preparation method increased soil moisture content significantly by 8%, 4.4% and 8.5%.

There was a significance difference ($p<0.05$) between the different levels of BSF on soil moisture content in both seasons. 8.5 t BSF recorded the higher soil moisture content as from 21 DAS to 77 DAS in both seasons (table 1). Then it was followed by 5.5 t BSF and 2.5 t BSF in both seasons in which they were not significantly different. This shows that increased soil moisture could be due to increased organic matter added through increase of BSF manure level. 8.5 t BSF increased the soil moisture by 8% and 10% in S1 and S2 respectively. This is because hydrophilic nature of organic matter enhanced soil moisture molecules preventing water from easily draining through the soil (Leelamanie and Karube 2009). Bhanwaria *et al*. (2022), found that on application of 5t ha^{-1} vermicomposting manure increased soil moisture content by 33 kPa and 1500 kPa compared to control.

Biochar application had a significant difference($p<0.05$) on soil moisture content (table 1). At 21 DAS to 77 DAS 5.5 t BSF + Biochar recorded higher soil moisture than 5.5t BSF in both seasons. Then it was followed by 2.5 t BSF + Biochar recorded higher soil moisture content than 2.5 t BSF in both seasons (table 1). This explains that on amendment of biochar in combination with 5.5 t BSF and 2.5 t BSF increased soil moisture by 6% and 11.5% in S1 and S2 respectively. 2.5 t BSF increased soil moisture content by 3% and 4% in S1 and S2 respectively. The porous nature of biochar enhanced the improvement of soil moisture content, making it an effective soil amendment for improving soil moisture holding capacity. This is line withKatterer*et al*. (2019), who found that on addition of biochar it influencedsoil moisture content significantly ($p=0.029$) in Fallow + Biochar as compared to bare fallow soil. Biochar amendment has been found to improve soil moisture content by 9.1% and 26% (Elsaeed*et al*., 2021; Wang *et al*., 2021).

Trichoderma application had no significant effect on soil moisture content. Controlrecorded the lowest moisture content from 21 DAS to 77 DAS in both seasons (table 1). had no significant difference with the chemical applied fertilizer (table 1). 5t FYM increased soil moisture by 8% and 11.7% in S1 and S2 than control which was not significantly different from 5.5 t BSF. Other studies found that, organic matterhave shown to increase soil moisture at an average of 8.9%, 9.1% and 13% respectively (Singh *et al*., 2021, Wang *et al*., 2021 and Lepsch *et al*., 2019).

Table 1: Effects of land preparation method and organic amendment on soil moisture for maize planted at MUST Demo farm during June-October 2022 (S1) and November 2022-March 2023 (S2).

	Soil Moisture (%)									
	Days after sowing (DAS) June-October 2022 S1					Days after sowing (DAS) November 2022-March 2023 S2				
Land Preparation method	**21DAS**	**35DAS**	**49DAS**	**63DAS**	**77DAS**	**21DAS**	**35DAS**	**49DAS**	**63DAS**	**77DAS**
Conservation	16.6a	16.6a	16.6a	16.9a	16.9a	17.5a	17.4a	18.3a	17.7a	18.1a
Conventional	16.3a	16.4b	16.1b	15.8b	16.2b	17.3a	16.9b	17.5b	17.0b	17.7b
LSD	0.3	0.2	0.2	0.4	0.1	0.4	0.2	0.2	0.1	0.2
P	ns	0.0431	<.0001	<.0001	<.0001	ns	0.0026	<.0001	<.0001	0.004
Organic Amendment	**21DAS**	**35DAS**	**49DAS**	**63DAS**	**77DAS**	**21DAS**	**35DAS**	**49DAS**	**63DAS**	**77DAS**
2.5 t BSF	15.9de	16.6ab	16.0cd	15.7de	16.2cd	17.3b	16.9d	17.4de	16.7de	17.4d
5.5 t BSF	16.0cde	16.7ab	16.1bc	16.0cd	16.5bc	17.7b	17.7b	17.2cd	17.6d	17.5bc
8.5 t BSF	19.3a	17.1a	17.8a	16.9ab	17.8a	19.5a	19.1a	19.9a	18.6a	19.5a
2.5 t BSF+Biochar	16.6bc	16.6ab	16.5b	16.9abcd	16.7b	17.7b	17.7b	19.3b	17.6b	18.1b
5.5 t BSF+Biochar	17.2b	16.8ab	18.2a	17.8a	17.5a	18.9a	19.6a	19.6ab	19.1a	19.7a
2.5 t BSF+Trichoderma	15.9cde	16.5b	16.1bc	16.3bcd	16.5bc	17.5b	17.1d	17.1e	17.1cd	17.2bcd
5.5 t BSF+Trichoderma	16.5cd	16.6b	16.1bc	16.8bc	16.5bc	74.9b	18.0b	17.7bc	17.7d	17.3bc
5t Farm Yard Manure	16.2cde	16.5b	16.4bc	16.4bcd	16.5bc	17.4b	17.4bcd	18.2c	17.6b	18.0bc
Control	14.6f	15.4c	15.0e	14.9e	15.2e	14.7d	14.2e	15.8g	15.4f	15.9f
DAP + CAN	15.8e	16.4b	15.6d	15.7de	16.0d	15.7c	14.7e	16.4f	16.4e	16.9e
LSD	0.7	0.4	0.5	0.9	0.4	0.8	0.5	0.4	0.4	0.5
P	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
CV	3.8	2.2	2.4	4.8	2.1	3.9	2.6	2.2	2	2.5

Means with different letters down the column indicates significant difference at 5% significant level. CV Coefficient Variability, LSD: Least Significance Difference, BSF; black soldier fly and ns indicates no significant differences.

Effects of land preparation method and organic amendment onsoil bulk density

There was no significant interaction between land preparation method and organic soil amendment on soil bulk density. Land preparation method had no significance effect ($p>0.05$) on soil bulk density in both seasons (Fig 1a and Fig 1c). Conservational land preparation method recorded average soil bulk density means of 0.8g/cm^3 which was not significantly different with conventional land preparation method. This shows that land preparation method had no significant influence on soil bulk density.This is in agreement with Afzalinia and Dehghanian(2021),Singh*et al*.(2021) andWang *et al*. (2022) who found that land preparation method has no significance influence on soil bulk density.

There was significant ($p<0.05$) effect on soil bulk density in both seasons on amendment of BSF manure. 8.5 t BSF recorded the lower soil bulk density than 5.5 t BSF and 2.5 t BSFin both seasons (Fig1b and Fig 1d).This implies that on increasing the levels of BSF organic manure enhances soil porosity and soil aeration BSF reduced the soil bulk density by 14% and 25% than 5.5 t BSF and 2.5 t BSF in S1 and S2 respectively. It has been found that organic soil amendment reduces soil bulk density by 10%, 11% and 6% respectively (Loss *et al*., 2022; Wang *et al*., 2020; Seyedsadr*et al*., 2022).

Similarly, addition of biochar resulted in a significance effect ($p<0.05$) on soil bulk density in both seasons. Combination of 5.5 t BSF + Biochar recorded lower soil bulk density than 5.5 t BSF in both seasons respectively. Similarly, 2.5 t BSF + Biochar recorded lower soil bulk density than 2.5 t BSF in both seasons respectively (Fig 1b and Fig 1d). This is attributed to the porous nature of biochar and black soldier fly manure led to a decrease in soil bulk density by 12% in both seasons respectively. Biochar has been found to reduced soil bulk density by 7.6% and 12% (Takova*et al*., 2020; Omondi *et al*., 2016). Phuong *et al*. (2020), found that fallow rice -rice + Rice husk biochar and fallow rice -rice + compost decreased the soil bulk density significantly ($p<0.05$) in top soil layer.

In both seasons there was no significant difference ($p>0.05$) on amendment of Trichoderma on soil bulk density (Fig 1b and Fig 1d). Control recorded the highest soil bulk density of 0.9g/cm3 which was not significantly different with chemical applied fertilizer plots. Organic amendments reduced the soil bulk density up to 33% as compared to control in both seasons (Fig 1b and Fig 1d). Organic amendment has been found to reduce soil bulk density by 19%, 24% and 13.3% (Latif *et al*., 2021; Ozlu*et al*., 2019; El-Nagar and Mohamed 2019).

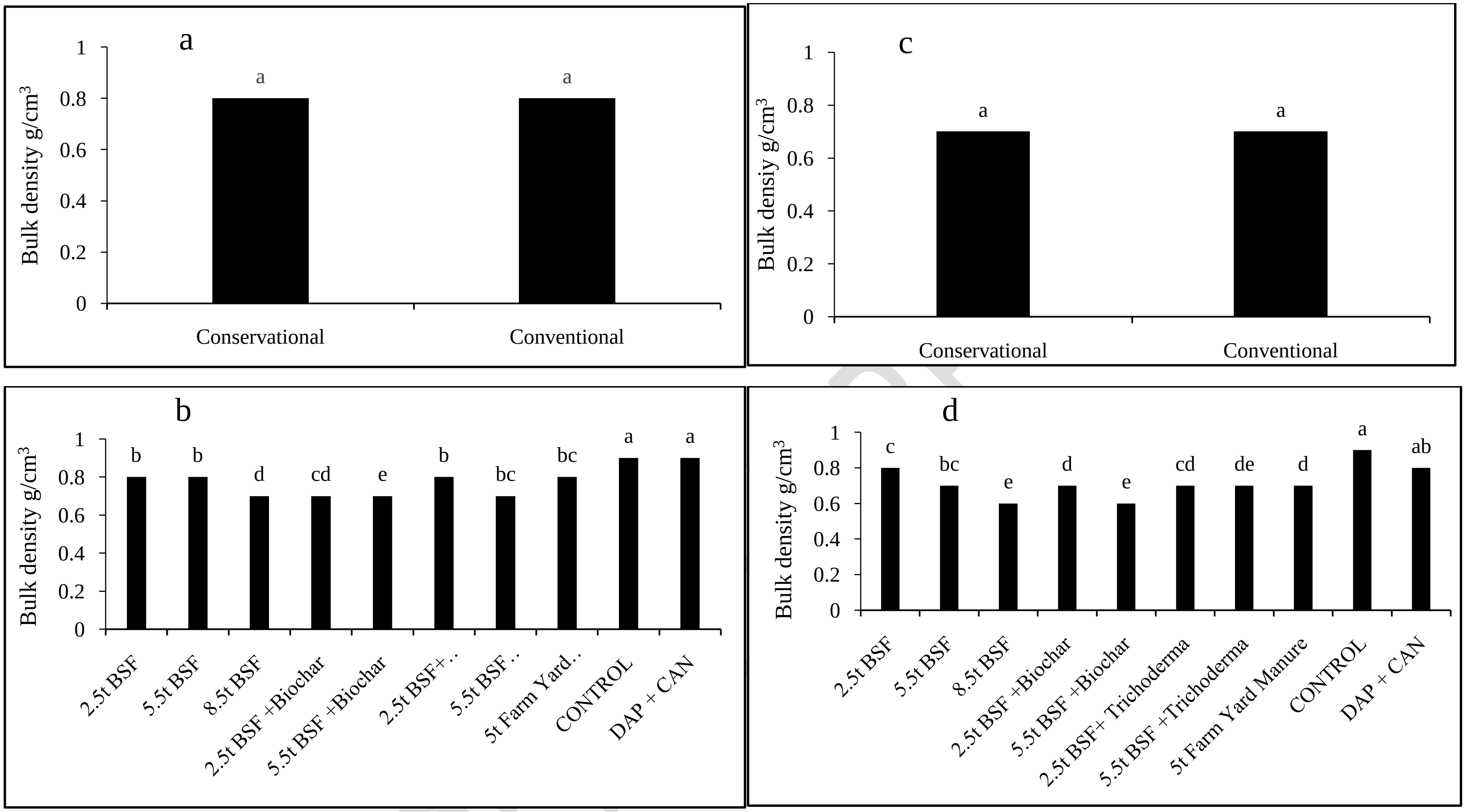

Figure 1: Effects of land preparation method and organic amendment on soil bulk density (g/cm^3) during June-October 2022 (a & b) season one and November 2022-March 2023 (c & d) season two.

The vertical bars represent the least significance difference (LSD) at p=0.05.

Effects of land preparation method and organic amendment onmaize plant height

There was no significance interaction between land preparation method and organic amendment on maize plant height (table 2). Land preparation method has no significant effect ($p>0.05$) on maize plant height in both seasons at 35 DAS to 63 DAS in both seasons. At 91 DAS in S1 and 63 DAS to 91 DAS in S2 there was significant effect on maize plant height. Conservational land preparation method maintained the higher maize plant height from 21DAS to 91 DAS than conventional land preparation method (table 2). This shows that conservational land preparation method minimizes soil moisture loss due to minimum soil disturbance which lead to an increase in maize plant height by 6% and 5% in S1 and S2respectively. This is in line withDong*et al*. (2022)who found that conservational tillage method increased maize plant height up to 19%. Similarly, Isola *et al*. (2021), found that zai pit method of land preparation increased the maize plant height by 3% compared to conventional tillage method.

Use of different levels of BSF amendments resulted in significance difference ($p<0.05$) in both seasons on maize plant height (table 2). At 21 DAS to 91 DAS 8.5 t BSF recorded higher maize plant height followed by 5.5 t BSF and 2.5 t BSF in both seasons (table 2). This shows that increasing the level of BSF application rate increases maize plant height 22% and 12% than 5.5 t BSFrespectively. 5.5 t BSF increased maize plant height by 9% and 8% in S1 and S2respectively. This could be attributed to increased organic matter applied which enhanced moisture retention and reduced soil bulk density.The higher maize plant height is associated with BSF frass fertilizer application compared to the control treatment in previous studies (Beesigamukama *et al*., 2020; Tanga *et al*., 2022).

Combination of biochar and BSF has no significance effect ($p>0.05$) on maize plant height in both seasons. At 63 DAS to 91 DAS 5.5 t BSF + Biochar maintained higher plant heights than 5.5 t BSF in both seasons (table 2). 2.5 t BSF maintained higher maize plant height as from 49 DAS to 91 DAS in both seasons. This shows that amendment of biochar and BSF increased maize plant height by 8% and this could be due to increased soil moisture conditions and reduced soil bulk density. This is line withLi *et al*. (2022) and Ndiate*et al*. (2021), who found that application of biochar led to an increase in maize plant height by 30.92% and 3.3%respectively.

Application of Trichoderma influenced maize plant height significantly ($p<0.05$). at 35DAS to 91 DAS 5.5 t BSF + Trichoderma recorded higher maize plant height than 5.5 t BSF. Then followed by 2.5 t BSF + Biochar which maintained high maize plant height than 2.5 t BSF (table 2). This explains the fact that *Trichoderma spp.* applied with BSF has significant influence on maize plant growth and this could be due to enhanced root development and nutrient absorption. 5.5 t BSF + Trichoderma increased maize plant height by 14% and 7% in S1 and S2respectively. 2.5 t BSF + Trichoderma increased maize plant height by 8% in both seasons. Trichoderma have been found to increase maize plant height by 23%, 19% and 12.5% respectively (Syamsiyah *et al*., 2020; Doni *et al*., 2016; Khadka and Uphoff 2019).

In S1 and S2 control recorded the least maize plant height as from 21 DAS to 91 DAS (Table 2). At 21 DAS to 91 DAS chemical applied fertilizer and 8.5 t BSF plots doubled the plant height than control in both seasons (table 2). In 5t FYM maize plant height was 25% and 28% higher than control respectively. Chemical applied fertilizer plots recorded the highest maize plant height and this is because there was instant nutrient absorption and uptake as compared to organic amended soils. Application of DAP inorganic fertilizers has been found to increase maize plant height by 13% respectively(Naomi and Nurmalasari, 2021).

Table 2: Effects of land preparation method and organic amendments on maize plant height planted at MUST Demo farm during June-October 2022 (S1) and November 2022-March 2023 (S2).

	Plant Height (cm)											
	Days after sowing (DAS) June-October 2022 S1						Days after sowing (DAS) November 2022-March 2023 S2					
Land Preparation method	**21DAS**	**35DAS**	**49DAS**	**63DAS**	**77DAS**	**91DAS**	**21DAS**	**35DAS**	**49DAS**	**63DAS**	**77DAS**	**91DAS**
Conservation	7.7a	18.3a	37.2a	63.5a	88.8a	120.4a	14.2a	32.0a	78.9a	175.3a	205.8a	207.4a
Conventional	6.9b	17.8a	36.5a	63.0a	87.9a	112.8b	12.9b	31.9a	78.8a	162.4b	193.1b	197.8b
LSD	0.4	0.9	1.9	2.7	3.6	5.9	0.5	1.2	1.4	1.9	2	1.9
P	0.0021	ns	ns	ns	ns	0.0134	<.0001	ns	ns	<.0001	<.0001	<.0001
Organic Amendment	**21DAS**	**35DAS**	**49DAS**	**63DAS**	**77DAS**	**91DAS**	**21DAS**	**35DAS**	**49DAS**	**63DAS**	**77DAS**	**91DAS**
2.5 t BSF	7.8ab	17.2bc	40.8b	60.4c	85.7d	111.0ed	14.1b	31.5de	76.5c	161.6d	183.5g	184.9h
5.5 t BSF	8.0ab	19.1ab	38.7b	60.6c	86.2d	112.1ed	14.9ab	33.4bdc	79.4bc	173.8c	201.8de	203.2ef
8.5 t BSF	8.7a	21.0a	47.8a	78.1b	103.9b	142.6b	15.7a	34.8abc	88.1a	191.9a	227.9b	229.7b
2.5 t BSF+Biochar	6.6dc	19.2ab	31.4de	58.0c	80.7de	105.8e	9.9e	29.7e	77.1c	164.8d	190.3g	192.5g
5.5 t BSF+Biochar	7.5bc	18.3b	37.7bc	59.6c	94.6c	122.4cd	13.9bc	32.4cde	80.8b	173.6c	205.5d	208.0d
2.5 t BSF+Trichoderma	7.4bc	15.9c	33.4cd	59.1c	81.1de	108.0e	13.0cd	30.8de	77.8bc	169.6c	197.5e	200.2f
5.5tBSF+Trichoderma	7.6b	18.4b	39.4b	63.2c	99.1bc	131.7bc	14.4b	35.9ab	85.8a	181.9b	215.4c	217.8c
5t Farm Yard Manure	6.3d	17.2bc	28.7ef	59.2c	73.1e	101.7e	12.8d	31.9de	78.8bc	171.8c	203.3d	206.1de
Control	5.5d	13.4d	25.0f	43.1d	62.0f	75.1f	12.7d	23.2f	58.9d	107.3e	136.3h	148.2i
DAP + CAN	7.8ab	21.0a	45.8a	91.5a	117.3a	156.0a	14.1b	36.1a	85.6a	191.8a	232.8a	235.1a
LSD	1	2.2	4.3	6	8.2	13.3	1.02	2.7	3.1	4.4	4.5	4.3
P	<.000	<.000	<.000	<.000	<.000	<.0001	<.000	<.0001	<.000	<.000	<.0001	<.0001

	1	1	1	1	1		1		1	1		
CV	17.52	15.1	14.5	11.7	11.4	14.1	9.3	10.3	4.9	3.2	2.7	2.6

Means with different letters down the column indicates significant difference at 5% significant level. CV Coefficient Variability, LSD: Least Significance Difference, BSF; black soldier fly and ns indicates no significant differences.

Effects of land preparation method and organic amendment onChlorophyll index

There was no significant interaction between land preparation method and organic amendment on maize chlorophyll index. Land preparation method had no significant effect ($p>0.05$) on maize chlorophyll index (table 3). At 21 DAS to 91 DAS conservational land preparation method recorded the higher maize chlorophyll index than conventional land preparation method (table 3). This shows that conservational land preparation method increases maize chlorophyll index by 2% and this could be due increased moisture content and reduced soil bulk density. Similarly, Munyao *et al*. (2019) and Guo *et al*. (2023), found that conservational land preparation method increased chlorophyll index by 50% and 17.5% respectively.

There was significance difference($p<0.05$) between different levels of BSF on maize chlorophyll index in both seasons (table 3). At 21 DAS to 91 DAS 8.5 t BSF recorded higher maize chlorophyll index followed by 5.5 t BSF and 2.5 t BSF in both seasons (table 3). Increase in the maize chlorophyll index in 8.5 t BSF could be due to improved soil moisture conditions and reduced soil bulk density which increased chlorophyll index by 13% and 4% than 5.5 t BSFrespectively. 5.5 t BSF increased chlorophyll index by 4% and 5% than 2.5 t BSF in S1 and S2 (table3)respectively.This is in line with Beesigamukama *et al*. (2020) andFuertes-Mendizábal*et al*. (2023), who found that maize chlorophyll index was increased by 4%, 9% and 85% which was associated with high nitrogen presence in the frass fertilizer

There was no significance ($p>0.05$) difference on amendment of biochar in both seasons on chlorophyll index (table 3). At 21 DAS and 91 DAS 5.5 t BSF + Biochar recorded higher chlorophyll index than 5.5 t BSF. Similarly, 2.5 t BSF + Biochar recorded higher maize chlorophyll index than 2.5 t BSF in both seasons (table 3). This shows that combination of BSF and biochar increases maize chlorophyll index by 10 % and 3 % in S1 and S2respectively. This is in line with Sun *et al*., (2022) who found that chlorophyll index was influenced significantly ($p<0.05$) on amendments of biochar. Other studies found an increase in maize chlorophyll index by 21% and 37% respectively(Feng *et al*., 2021; Minhas *et al*., 2020).

Amendment of Trichoderma influenced the maize leaf chlorophyll index significantly ($p<005$) in both seasons (table 3). At 21 DAS to 91 DAS 5.5 t BSF + Trichoderma recorded higher maize chlorophyll index than 5.5 t BSF. 2.5 t BSF + Trichoderma maintained higher maize chlorophyll index than 2.5 t BSF in both seasons (table 3). Combination of Trichoderma spp and BSF increases maize chlorophyll index 6% and 5% in S1 and S2respectively. Increase in chlorophyll index could be due to increased nutrient absorption and moisture conditions. De Araújo*et al*. (2023), found that Trichoderma increased chlorophyll content up to 42.5µg.cm^2. Other studies have found that Trichoderma increased maize chlorophyll by 13% and 20%respectively (Oliveira *et al*., 2022; Mahato and Neupane 2017).

Organic amendment influenced maize chlorophyll index significantly ($p<0.0001$) in both seasons (table 3). At 21 DAS to 91 DAS control maintained lower maize chlorophyll index than organic amendments. In both seasons 8.5 t BSF had no significance difference on maize chlorophyll index with chemical fertilizer. 5t FYM was11% and 24% higher maize chlorophyll index than control. BSF frass fertilizer has been found to improve maize chlorophyll index due its nutrient content (Beesigamukama *et al*. 2020; Fuertes-Mendizábal*et al*. 2023).

Table 3: Effects of land preparation method and organic amendments on maize chlorophyll index planted at MUST Demo farm during June-October 2022 (S1) and November 2022-March 2023 (S2).

	Chlorophyll index (SPAD values)											
	Days after sowing (DAS) June-October 2022 S1						Days after sowing (DAS) November 2022-March 2023 S2					
Land Preparation method	**21DAS**	**35DAS**	**49DAS**	**63DAS**	**77DAS**	**91DAS**	**21DAS**	**35DAS**	**49DAS**	**63DAS**	**77DAS**	**91DAS**
Conservation	28.4a	31.7a	34.3a	37.5a	33.1a	32.4a	31.6a	35.6a	37.1a	47.6a	47.0a	44.6a
Conventional	26.94b	31.3a	35.1a	37.0a	33.2a	32.5a	31.3a	35.4a	37.4a	47.1a	46.3a	44.2a
LSD	1.2	0.9	1	0.7	1.6	1.6	0.6	0.4	0.3	0.8	0.9	0.5
P	0.0208	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Organic Amendment	**21DAS**	**35DAS**	**49DAS**	**63DAS**	**77DAS**	**91DAS**	**21DAS**	**35DAS**	**49DAS**	**63DAS**	**77DAS**	**91DAS**
2.5 t BSF	27.8c	31.0c	35.9bdc	35.2e	31.7cd	30.3d	31.2bc	34.9d	36.0d	47.1c	46.3c	42.6d
5.5 t BSF	26.7dc	32.5bc	34.8cde	37.1cd	32.6abc	31.7bdc	32.7a	36.2c	36.6cd	47.7c	47.0bc	45.0c
8.5 t BSF	30.6ab	35.9a	37.6ab	38.0bc	37.6a	36.4a	32.6a	37.9b	40.9a	50.3ab	50.0a	47.0b
2.5 t BSF+Biochar	26.0dc	31.3c	33.4e	39.6b	31.8cd	31.2cd	30.8c	33.6e	37.1c	47.7c	46.9bc	43.8d
5.5 t BSF+Biochar	27.0dc	32.3bc	34.9cde	36.1de	35.7ab	35.2ab	31.3bc	36.1c	38.1b	48.4bc	48.5ab	45.5c
2.5 t BSF+Trichoderma	28.7bc	31.1c	33.7ed	37.2cd	30.7d	30.3d	31.4abc	34.9d	36.7cd	48.2c	47.bc	45.5c
5.5 t BSF+Trichoderma	31.5a	33.6b	37.1abc	36.8cde	36.8a	36.3a	31.8abc	36.9c	40.1a	49.0abc	48.5ab	47.3b
5t Farm Yard Manure	24.9d	26.6d	33.4e	37.4cd	32.4bcd	31.2cd	32.4ab	35.2d	36.5cd	47.9c	47.0abc	46.1bc
Control	21.4e	26.4d	27.6f	33.1f	26.5e	25.5e	28.3d	29.6f	30.7e	36.2d	34.9d	33.1e
DAP + CAN	31.9a	34.1ab	38.4a	41.9a	38.1a	37.5a	32.0abc	39.5a	40.0a	50.7a	49.8a	48.6a

LSD	2.7	2	2.2	1.7	3.6	3.6	1.3	0.9	0.8	1.9	2.1	1.2
P	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
CV	12.3	7.9	8.1	5.6	13.5	13.7	4.9	3.4	2.9	5.1	5.4	3.4

Means with different letters down the column indicates significant difference at 5% significant level. CV Coefficient Variability, LSD: Least Significance Difference, BSF; black soldier fly and ns indicates no significant differences.

Effects of land preparation method and organic amendment onmaize stem diameter

There was no significant interaction between land preparation method and organic amendments on maize stem diameter. Land preparation method had no significance effect ($p>0.05$) on maize stem diameter in both seasons (table 4). At21 DAS to 91 DAS conservational land preparation method recorded higher maize stem diameter than conventional land preparation method in both seasons (table 4). This states that conservational land preparation increases maize stem diameter by 3% and this could be due to reduced soil disturbance and improved soil moisture.Studies shows that zero tillage increases maize stem diameter by 6.6% and 3% respectively(Crespo *et al*., 2022; Yerli *et al*., 2023).

In both seasons there was significance effect($p<0.05$) on application of different levels of BSF on maize stem diameter (table 4). At 21DAS to 91DAS 8.5 t BSF recorded higher maize stem diameter than 5.5 t BSF (table 4). 5.5 t BSF still recorded higher maize stem diameter than 2.5 t BSF. This explains that increasing the level of 8.5 t BSF amendment increases maize stem diameter by 7% and 17% in S1 and S2respectively (table 4). 5.5 t BSF increased maize stem diameter by 8% in S2respectively. The increase in maize stem diameter could be due to increased level of BSF which is suggested that composted BSF frass fertilizer contains 2.5% N available for plant growth (Tanga *et al*., 2022). Other studies show that maize stem diameter increased by 28% and 26% respectivelyon amendments of BSF fertilizer (Anyega *et al*., 2021; Tanga *et al*., 2022)

In both seasons there were no significance difference ($p>0.05$) on amendment of biochar on maize stem diameter (table 4). At49 DAS to 91DAS maize planted on 5.5 t BSF + Biochar recorded higher stem diameter than 5.5 t BSF (table 4). 2.5 t BSF + Biochar recorded higher maize stem diameter than 2.5 t BSF. This shows that combination of biochar and BSF increases maize stem diameter by 4% and 2% in S1 and S2respectively. Other studies have found that biochar increased maize stem diameter by 8.2%, 5% and 2% respectively(Khan *et al*., 2022; Rahayu *et al*., 2022; Yang *et al*., 2020).

In both seasons there was significance effect ($p<0.05$) on application of Trichoderma on maize stem diameter (table 4). At 49 DAS to 91DAS 5.5 t BSF + Trichoderma recorded higher than 5.5 t BSF (table 4). It was then followed by 2.5 t BSF + Trichoderma recorded higher 2.5 t BSF. This illustrate that combination of *Trichoderma spp* and BSF enhanced nutrient absorption whichincreased maize stem diameter by 7% and 17% than 5t BSF in S1 and S2respectively(table 4). 2.5 t BSF also increased maize stem diameter by 9% and 18% in S1 and S2respectively. Studies have shown that application of Trichoderma led to an increase in stem diameter by 23%, 42% and 27.3%respectively (Symasiyah*et al*., 2023; Abdelmoaty *et al*., 2022; Lopez-Valenzuela *et al*., 2019).

Organic amendment influenced the maize stem diameter significantly ($p<0.0001$) in both seasons (table 4). At 21 DAS to 91 DAS chemical fertilizer applied plots recorded higher maize stem diameter than control in both seasons (table 4). 5t FYM recorded 8% and 23% higher maize stem diameter than control in S1 and S2respectively. This was not significantly different from 5.5 t BSF. Increase in maize stem diameter might be due to instant nutrient availability in chemical applied fertilizer. Naomi and Nurmalasari, (2021), found that DAP fertilizer increased maize plant height by 9%respectively.

Table 4: Effects of land preparation method and organic amendments on maize stem diameter planted at MUST Demo farm during June-October 2022 (S1) and November 2022-March 2023 (S2).

	Stem Diameter (mm)											
	Days after sowing (DAS) June-October 2022 S1						Days after sowing (DAS) November 2022-March 2023 S2					
Land Preparation method	**21DAS**	**35DAS**	**49DAS**	**63DAS**	**77DAS**	**91DAS**	**21DAS**	**35DAS**	**49DAS**	**63DAS**	**77DAS**	**91DAS**
Conservation	2.6a	6.0a	13.3a	18.8a	25.0a	26.5a	5.2a	13.7a	27.8a	31.2a	34.2a	34.5a
Conventional	2.5a	5.5b	12.7a	17.8b	24.7a	25.7b	4.9b	13.1b	26.4b	31.0a	34.3a	34.2a
LSD	0.2	0.3	0.8	0.5	0.7	0.7	0.19	0.5	0.5	0.4	0.5	0.4
P	ns	0.0077	ns	0.0002	ns	0.0406	0.006	0.042	<.0001	ns	ns	ns
Organic Amendment	**21DAS**	**35DAS**	**49DAS**	**63DAS**	**77DAS**	**91DAS**	**21DAS**	**35DAS**	**49DAS**	**63DAS**	**77DAS**	**91DAS**
2.5 t BSF	2.4bc	5.9de	11.8de	17.1e	25.3cd	26.6cd	5.2bc	12.8b	24.2e	28.6e	30.8f	29.3e
5.5 t BSF	2.8b	6.9b	12.9cd	17.1e	25.0cd	26.1cd	5.2bc	13.8b	26.4d	30.2d	33.1e	32.1d
8.5 t BSF	3.3a	7.7a	16.3ab	20.1b	27.6ab	28.7ab	5.9a	16.1a	31.5ab	35.2a	39.2b	39.0b
2.5 t BSF+Biochar	2.2cd	4.7fg	11.8de	17.1e	23.8de	25.0de	4.2d	13.1b	24.4e	28.9e	31.1f	29.8e
5.5 t BSF+Biochar	2.4bc	6.7bc	14.7bc	18.9cd	26.0bc	27.2bc	5.3bc	13.9b	26.7d	30.4d	33.1e	32.4d
2.5tBSF+Trichoderma	2.5bc	5.4ef	11.6de	18.3d	24.4cd	25.7cd	5.0bc	13.2b	28.0c	32.5bc	35.2d	35.8c
5.5tBSF+Trichoderma	2.8ab	6.4bcd	14.4c	19.7bc	27.5ab	28.7ab	5.5b	15.4a	30.6b	33.4b	37.9c	39.0b
5t Farm Yard Manure	2.5bc	4.4g	10.4e	16.7e	22.5e	23.8e	5.0bc	13.1b	29.1c	32.0c	36.0d	36.3c
Control	1.8d	3.5h	8.3f	14.8f	20.5f	21.8f	4.3d	6.5c	17.9f	24.0f	25.5g	27.8f
DAP + CAN	2.8b	6.1cde	17.7a	23.0a	28.8a	30.1a	5.2bc	15.4a	32.1a	36.0a	40.8a	41.8a
LSD	0.5	0.6	1.8	1.1	1.7	1.7	0.4	1.2	1.1	1	0.9	1
P	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
CV	24.4	14.6	17.3	7.5	8.6	8.2	10.3	10.8	5.1	4.1	3.7	3.5

Means with different letters down the column indicates significant difference at 5% significant level. CV Coefficient Variability, LSD: Least Significance Difference, BSF; black soldier fly and ns indicates no significant differences.

Effects land preparation method and organic amendment on maize yields

In both season there were no significance interaction between land preparation method and organic amendment on maize yields. Land preparation method had no significance ($p>0.05$) difference on maize yields in both seasons (Fig 2a and Fig 2c). Conservational land preparation method recorded higher maize yields than conventional land preparation in both season (Fig 2a and Fig 2c). This shows that conservational land preparation method increases maize yields by 6% and 14% respectively. Thiswas attributed by reduced soil bulk density and increased soil moisture content.Conservational and preparation method have been found to increase maize yield by 10.4%, 11%, 10.8% and 38% respectively (Li *et al*., 2022; Bai *et al*., 2022; Wang *et al*., 2021; Singh *et al*., 2021).

There was significance ($p<0.05$) difference in application of different levels of BSF on maize yield in both seasons (Fig 2b and Fig 2d). In both seasons 8.5 t BSF recorded higher maize yield than 5.5 t BSF and 2.5 t BSF (Fig 2b and Fig 2d). This illustrates that increasing the level to 8.5 t BSF increased the maize yields by 19% and 15% in S1 and S2 respectively. This could be due to increase in organic nutrients in BSF manure. 5.5 t BSF increased maize yields by 17% and 4% in S1 and S2 respectively. BSF frass fertilizer has been found to increase maize yields by 11.1% and 23% respectively(Beesigamukama *et al*., 2020;Quilliam *et al*. 2020;Tanga *et al*. 2021)

Amendments of biochar had no significant effect($p>0.05$) on the maize yields in both seasons (Fig 2b and Fig 2d). In S1 and S25.5 t BSF + Biochar recorded higher maize yield than 5.5 t BSF. It was the followed by 2.5 t BSF + Biochar which recorded higher maize yields than 2.5 t BSF. This states that combination of BSF and biochar enhances soil moisture conditions and reduced soil bulk density which has been found to increase maize yields. 5.5 t BSF + Biochar increased 7% and 2% in S1 and S2 respectively. 2.5 t BSF increased maize yield by 3.4% and 4% in S1 and S2 respectively. This is in line with Islam *et al*. (2018) and Katterer*et al*. (2019), who found that rice husk biochar increased maize growth and yield significantly ($p<0.05$). Kang *et al*. (2021), found that application of biochar increased the maize corn productivity up to 29.3% respectively.

Application of Trichoderma influenced the maize yield significantly ($p<0.05$) in both seasons (Fig 2b and Fig 2d). In both season 5.5 t BSF + Trichoderma recorded higher maize yields than 5.5 t BSF. It was followed by 2.5 t BSF + Trichoderma which recorded higher maize yield than 2.5 t BSF (Fig 2b and Fig 2d). This illustrates that combination of BSF and *Trichoderma spp* increases nutrient absorption and maize plant growth which was found to increase maize yield. 5.5 t BSF + Trichoderma increased maize yield by 4% and 12% in S1 and S2 respectively. 2.5 t BSF + Trichoderma increased maize yield by 28% and 4% in S1 and S2 respectively. Trichoderma has been found to increase maize plant growth and yield by 40%, 18% and 31% respectively (Worlu *et al*., 2022; Nmom*et al*., 2023; Syamsiyah *et al*., 2023).

Organic amendment had a significanceeffect ($p<0.0001$) on maize yields in both seasons (Fig 2b and Fig 2d). In S1 and two chemical fertilizer applied plots and 8.5 t BSF was three times higher than control in S1 and double in S2 respectively (Fig 2b and Fig 2d). In S1 and S2maize yields in 5t FYM was double higher than control respectively. Researchers have found that NPK inorganic fertilizers increases maize yields with the range 14.3%, 5%, 6% and for FYM amendment increased by 28% respectively(Li *et al*.,2022, Dahlin *et al*., 2021, Weib*et al*., 2021 and Zhang *et al*., 2021).

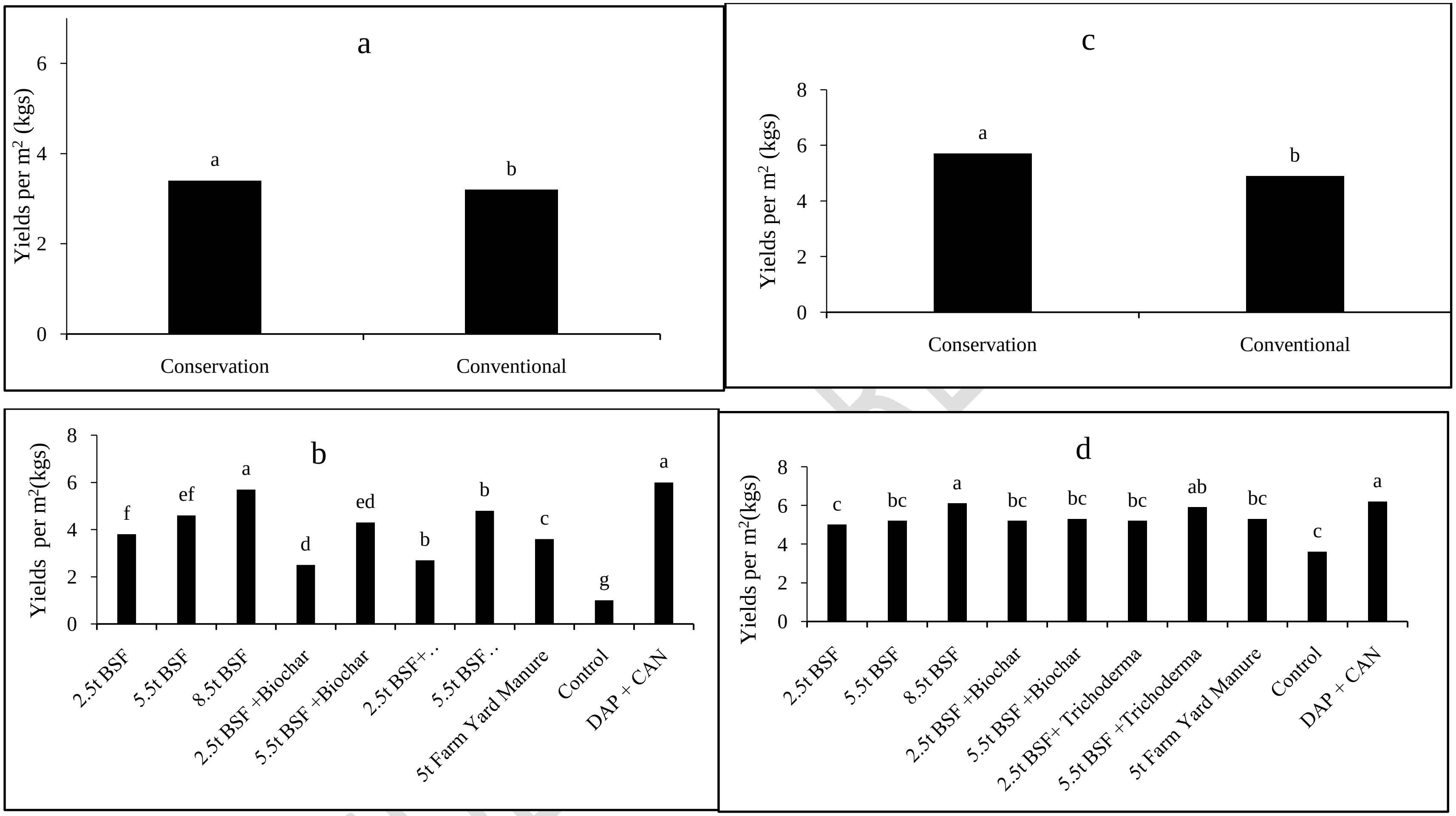

Figure 2: Effects of land preparation method and organic soil amendment on maize yield during June-October 2022 (a & b) season one and November 2022-March 2023 (c & d) season two.

The vertical bars represent the least significance difference (LSD) at 5% significant level.

Conclusion

Conservation land preparation consistently maintained higher soil moisture due to reduced soil disturbance, resulting in increased soil moisture content compared to conventional land preparation methods. Similarly, the application of Black Soldier Fly (BSF) manure significantly influenced maize yields. This improvement in yields was attributed to enhanced soil fertility resulting from the application of BSF manure. On the other hand, the application of biochar demonstrated a significant improvement in soil moisture retention and reduced soil bulk density, showcasing its potential in enhancing soil water conservation and soil bulk density reduction.

In addition, application of *Trichoderma spp*, particularly in combination with Black Soldier Fly (BSF), significantly influenced maize yields in both seasons. The synergistic effects of 5.5 t BSF + Trichoderma and 2.5 t BSF + Trichoderma were evident, resulting in higher maize yields compared to their respective BSF-only. These findings highlight the potential of the combined use of BSF and *Trichoderma spp* in enhancing nutrient absorption and promoting maize plant growth, ultimately leading to substantial increases in maize yield.

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