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Article

Impact of Organic Amendments and Soil Mulching Applications on Soil Properties and Soybean Productivity

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Abstract: This study aims to evaluate the effect of organic amendments and soil mulching on soil properties and soybean productivity grown under a drip irrigation system. The experiment was conducted at the Faculty of Agriculture farm (Demo) at Fayoum University, Egypt, located at 29°17′006″N and 30°54′055″E in the SI 2023 and SII 2024 seasons. Four soil amendment treatments were assessed, i.e., zero (control), 20 t ha^{-1} of compost (C), 10 t ha^{-1} of vermicompost (V) and a mixture of both 10 t ha^{-1} of compost + 5 t ha^{-1} of vermicompost (CV), and two organic soil mulching (SM) rates of rice straw (M0 and M1; zero and 8 t ha^{-1}). The treatments were conducted using a randomized complete block arrangement (split-plot design) with three replicates. The results showed that the values of soil bulk density and hydraulic conductivity were significantly decreased by 5.56 and 10.98%, 12.35 and 31.44%, and 16.67 and 46.97% when applied to C, V, and CV, respectively, as compared with the control. On the other hand, there are significant increases in values of total porosity, water-holding pores, and useful pores by 0.43, 17.32, and 1.44%; 5.10, 26.45, and 5.66%; and 7.39, 33.19, and 8.28% when C, V, and CV are applied, respectively, as compared with the control. Soybean growth parameters and physiological attributes were significantly affected by the applied treatments. The application of CV+ SM8 significantly increased the values of weight 100 of seeds and seed and straw yield by 21.17, 6.11, and 24.29%, respectively, as compared with the control. It could be concluded that the combination of CV and SM_8 led to an improvement in soil properties and the productivity of soybean plants.

Keywords: Organic amendments, Soil mulching, Soil properties, Yield.

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1. Introduction

In Egypt, water conservation and increased crop productivity could result from the use of drip irrigation, especially in arid areas (Nouri et al., 2019). Organic amendments refer to materials incorporated into soil to enhance their characteristics and promote plant development. These amendments augment soil organic matter, leading to improved soil aeration, water penetration, and nutrient retention. Furthermore, they can serve as a source of plant nutrients, acting as organic fertilizers. The selection of a specific amendment depends on objectives, such as enhancing soil physical properties or ensuring long-lasting effects (Davis & Wilson, 2000). Su et al. (2022) recorded that diverse organic amendments can influence soil attributes, bacterial micro-biome, and plant growth. Notably, their influence on plant growth varies due to distinct mineralization rates in the soil. Organic matter, comprising plant and animal residues, significantly contributes to soil health, benefiting most garden and landscape plants. These amendments have the potential to enhance soil structure and elevate soil pH (Sun et al., 2021). Loper et al. (2010) illustrated that organic amendments can elevate concentrations of plant-accessible nutrients in soils, supplying essential nutrients to growing plants.

Compost is a type of organic amendment that is produced by the decomposition of organic matter, such as food waste, farmyard waste, and animal manure. Composting transforms organic matter into a stabilized state that can enhance soil for plant growth. Compost enhances the physico-chemical, and biological proerties of soil, including its structure, water retention, nutrient accessibility, and microbial activity (Kebede et al., 2023). The application of compost has been shown to increase crop productivity and crop quality due to its enhance the chemical and biological soil properties (Duong, 2013). Compost can enhance the stabilization and productivity of crops, as well as improve their quality, owing to its gradual nutrient release and availability in the soil. Kranz et al. (2020) and Elissen et al. (2023) found that compost can increase soil carbon and nitrogen content, some enzyme activities, and genetic diversity, which can enhance plant growth. It can also reduce bulk density, increase infiltration, hydraulic conductivity, water content and plant growth.

Vermicompost a product of earthworm digestion of organic materials, has been shown to have significant positive effects on soil properties and plant growth. Oyege & Balaji Bhaskar (2023) indicated that vermicompost improves soil quality, increases nutrient availability, enhances soil fertility, and boosts crop productivity. It also enhances soil aeration, water retention, and porosity, while reducing bulk density (Xu & Mou, 2016). Additionally, vermicompost can improve plant growth, delay leaf senescence, and enhance the nutritional value of crops. Its use in agriculture has been associated with improved soil fertility, both physically and chemically, leading to better crop yields. Overall, vermicompost is a valuable organic amendment that can promote sustainable agriculture by enhancing soil properties and supporting plant growth (Lim et al., 2015).

Rice straw mulching can maintain soil moisture, suppress weed growth, and improve soil physical properties (Ikhsan et al., 2023). It can also improve the soil environment and increase soil fertility (Cao et al., 2021). Rice straw mulching has been identified as a practice that enhances soil water content while concurrently reducing soil penetration resistance and crack volume (Paul et al., 2021). Furthermore, this mulching method has the potential to foster the establishment of soil microbial colonies and increase fungal and enzyme activity. These effects significantly contribute to the mineralization and release of soil nitrogen, promoting the transformation of ammonium and nitrate, and facilitating the absorption of soil nitrogen by plants (Yan et al., 2023).

Soybean (*Glycine max* L.), a crop widely cultivated globally for its economic and nutritional importance (Pagano & Miransari, 2016). Soybeans serve as a crucial source of food, protein, and oil, being the most widely cultivated oilseed crops worldwide with an annual production of 369.5 million tons. In Egypt, soybean cultivation occurs on a smaller scale, covering approximately 10,000 hectares (Coleman et al., 2021). Soybean productivity varies based on cultivation methods and varieties used. Singh et al. (2023) demonstrated that soybean seed yields ranged from 1.99 to 2.13 t ha^{-1} with the soybean crop intensification method, whereas conventional cultivation yielded from 1.47 to 1.63 t ha^{-1}. Soybean also recognized as an important crop for sustainable aboveground-underground plant-soil interactions (Mahmoud & El-Bably, 2017). The main objective of this study was to assess the impact of various organic soil amendments and organic surface mulching on specific soil parameters and the productivity of soybean cultivated under a drip irrigation method.

2. Materials and Methods

2.1. Field environmental conditions

The experiment was conducted at the Faculty of Agriculture farm (Demo) at Fayoum University, Egypt, located at 29°17 006″N and 30°54 055″E. The tested soil is located in an arid climate (Ponce et al., 2000). The soil, 0.5–0.80 m deep, is a sandy loam that defines as Typic Torripsamments, siliceous, and hyperthermic (Nachtergaele, 2001). Table 1 shows some of the experimental site's physical and chemical soil properties.

Table 1. Some initial physico-chemical characteristics of the experimental soil

Depth (cm)	Particle Size distribution, %			Texture class	ρ_b Mg m^{-3}	K_{sat} cm h^{-1}	TP	WHP	UP	ECe (dS/m) in soil paste extract	pH, in (1: 2.5) suspension	O.M %	N	P	K
	Sand	Silt	Clay				%						mg kg^{-1}		
0-30	77.43	12.30	10.27	SL	1.68	2.70	41.36	11.35	25.01	3.10	7.70	0.60	13.50	4.12	50.10

SL = Sandy loam ρ_b = bulk density, K_{sat}= hydraulic conductivity, (TP) % =Total porosity, (WHP) % = Water holding pores, (UP) % = Useful pores, ECe is the electrical conductivity, O.M = organic matter content.

2.2. Experimental design and treatment applications

Four soil amendments treatments were assessed [i.e., zero (control), 20 t ha^{-1} of compost (C), 10 t ha^{-1} of vermicompost (V) and a mixture of both 10 t ha^{-1} of compost + 5 t ha^{-1} of vermicompost (CV)] and two organic soil mulching (SM) rates of rice straw (M_0 and M_1; zero and 8 t ha^{-1}). These amounts of addition were determined based on previous studies and research.The treatments were conducted using a randomized complete block arrangement (split plot desigen) with three replicates (Table 2).

Table 2. Some chemical analysis of the used soil organic amendments (compost and vermicompost)

Amendment	Organic carbon	Total nitrogen	C / N Ratio	pH in (1: 2.5) suspension	EC (dS m^{-1}) in the extract	$CaCO_3$ %	K	P	Moisture content %
	%						g kg^{-1}		
Compost	15.50	1.70	9.12	7.76	2.80	1.60	4.50	3.30	35.50
Vermicompost	18.15	1.80	10.08	7.60	2.18	1.10	4.90	3.40	40.30

EC is the electrical conductivity.

Each plot had a 10 m long by 0.80 m row width with area 8 m^2. Soyabean seeds were planted manually on the 10th May in 1st and 2nd season, respectively, Soybean seeds were planted on both sides of the row spaced about 25 cm apart, Harvesting the soya bean plants was 120 days after planting for each season.The drip irrigation system was assigned at two lines and one dripper for each plant, the dripper discharge is 4 L of irrigation water per hour. The agronomic practices for commercial soybean crop production, including pest, weed, and disease control were followed as recommended.

2.3. Measurements

2.3.1. Some soil properties of the experimental field

Disturbed and undisturbed soil samples were initially collected from the experimental field at surface layer (0-30 cm) from each investigated and repeated after the conducted organic amendments and soil mulching.

2.3.1.1. Physical properties of the studied soils

measurements, determinations and calculations were conducted according to the methods and procedures outlined and described by (Klute, 1988; Jury & Horton, 2004).

2.3.1.2. Chemical properties of the studied soils

The measurements and calculations of some soil chemical properties were carried out using the techniques described by Page et al. (1982).

2.3.2. Morphological parameters, yield and yield components

At the end of the trial, 10 plants were randomly selected from each experimental plot and assessed for growth parameters. The fourth fully expanded leaves from the apex of the stem (and its internodes) that emerged imposition were collected per plant for morphological.

Plant height, stem diameter, leaves number/plant, leaf area and dry matter of plant were recorded at the end of the trial. Plant leaf area (cm^2) was measured as demonstrated by Wallace & Monger (1966) with some modifications. 10-20 leaf disks (10-20 cm^2) were then dried in an oven at 85 °C for 24 hours to ensure disks were dry (DDW). The following formula was used to compute total leaf area $plant^{-1}$.

$$\textbf{Total leaf area plant}^{-1} = (\textbf{LDW} \div \textbf{DDW}) \times \textbf{DA}$$

Where: LDW is the total leaf dry weight (g), DDW is the disks dry weight (g), and DA is the discs area.

2.3.3. Physiological measurements of the plant

2.3.3.1. Relative water content (RWC) of leaf discs was determined using the fresh weight, turgid weight, and dry weight of the leaf discs. The fresh weight (FW) of leaf discs was first measured. The leaf discs were then soaked in distilled water for 24 hours to allow them to become fully turgid. The water adhering to the leaf discs was removed by blotting with absorbent paper towels. The turgid weight (TW) of each sample was then measured. The leaf discs were then oven dried at 70°C for 72 hours until a constant dry weight (DW) was obtained. The RWC (%) was calculated using the following equation from Maxwell & Johnson (2000).

$$\text{RWC (\%)} = ((\text{FW} - \text{DW}) / (\text{TW} - \text{DW})) \times 100$$

Where: FW = Fresh weight of the leaf discs, DW = Dry weight of the leaf discs, TW = Turgid weight of the leaf discs.

2.3.3.2.The membrane stability index (MSI) was determined using a membrane thermo-stability assay based on the electrical conductivity (EC) of leaf tissue. Midribs were excised from leaf samples, and two sets of leaf discs were subjected to controlled heating: one at 40°C for 30 minutes (denoted as C_1) and another at 100°C for 10 minutes (denoted as C_2). The percentage membrane stability index (MSI, %) was calculated using the formula established by Premachandra et al. (1990):

$$\text{MSI (\%)} = [1 - (C_1 \div C_2)] \times 100$$

2.3.3.3. The relative chlorophyll index in soybeans was measured using a SPAD-502-2900 chlorophyll meter (SPAD meter).

2.3.4. Soybean yield

* Seeds yield and straw yield altogether were considered as biological yield.
* Harvest index denotes the ratio of seeds yield to biological yield multiplied by 100.
* The percentage of protein in seeds was calculated by multiplying the value of N by a factor 6.25, and the oil content of soybean seed was determined by Chemists (1984).
* The oil percentage was measured by grinding 10 g of seeds from each treatment, placing the ground samples in Whatman filter papers, and then sujecting them to extraction in a Soxhlet apparatus using 300 ml of petroleum ether (40-60 °C) as a solvent for 4-4.5 hours. After extraction, the samples were removed from the chiller, the oil was separated from the solvent, and the seed oil percentage was calculated using a specific equation:

Oil (%) = (initial seed weight - seed weight after oil extraction)/initial seed weight) ×100

2.4. Data analysis

The experimental data gathered over the two-year study period were analyzed statistically using the InfoSTAT software. Homogeneity of error variance was assessed according to the methodology outlined by Gomez & Gomez (1984). Statistical differences between groups were evaluated with Duncan's Multiple Range Test at a 5% significance level ($p \leq 0.05$).

3. Results

3.1. Effect of organic soil amendments and mulching on some soil physio-chemical properties

Soil physical and chemical properties as average values of the two successive seasons after harvest under the different treatments are presented in Tables 3 and 4. Data in Table 3 illustrates the effects of additional organic soil amendments and soil mulching on some soil physical properties. There was a positive effect in the values of bulk density, hydraulic conductivity, total porosity, water holding pores and useful pores when organic soil amendments and soil mulching were applied. The mean values of soil bulk density and hydraulic conductivity were significantly decreased by (5.56 and 10.98%), (12.35 and 31.44%) and (16.67 and 46.97) when application of compost (C), vermicompost (V) and a mixture of both compost with vermicompost (CV) respectively, as compared with control. Also, there are significant increases in the mean values of total porosity, water holding pores and useful pores by (0.43,17.32 and 1.44%), (5.10, 26.45 and 5.66%) and (7.39, 33.19 and 8.28%), when application of (C), (V) and (CV) respectively, as compared with control.

The soil mulching (M_1) treatment with rice straw (8 t h^{-1}) led to significant decreases in the mean values of bulk density and hydraulic conductivity by 10.83 and 13.64%, respectively, as compared with non-mulching (M_0). But there are significant increases in the mean values of total porosity, water holding pores and useful pores by 3.14, 6.43 and 2.47%, when soil mulching (M_1) used respectively, as compared with non-mulching (M_0). For the interaction between organic soil amendments and soil mulching treatments, the lowest values of soil bulk density and hydraulic conductivity were 1.20 Mg m^{-3} and 1.29 cm h^{-1}, respectively, at the compost with vermicompost blend treatment CV-blend and soil mulching (M_1). However, the highest values of total porosity, water holding pores and useful pores were 44.99, 16.11 and 28.21%, respectively.

Table 3. Effect of organic soil amendments and mulching on some soil physical properties at the end of experiment in (SI) 2023 and (SII) 2024 seasons

Treatment	Bulk density (Mg m^{-3})	Hydraulic conductivity (cm h^{-1})	Total porosity (TP%)	Water holding pores (WHP%)	Useful pores (UP%)
Season	**	**	NS	*	NS
S_1	1.53±0.03a	2.13±0.10a	42.71±0.30a	13.90±0.3b	26.56±0.20a
S_2	1.44±0.03b	1.97±0.12b	42.78±0.33a	14.05±0.3a	26.63±0.21a
Soil amendments	**	**	**	**	**
Control	1.62±0.03a	2.64±0.13a	41.41±0.40c	11.72±0.4d	25.61±0.30d
Compost (C)	1.53±0.03b	2.35±0.13b	41.59±0.38c	13.75±0.4c	25.98±0.27c
Vermicompost (v)	1.42±0.04c	1.81±0.14c	43.52±0.40b	14.82±0.4b	27.06±0.30b
CV-blend	1.35±0.05d	1.40 ±0.16d	44.47±0.43a	15.61±0.4a	27.73±0.30a
Mulch	**	**	**	**	**
M_0	1.57±0.02a	2.20±0.10a	42.09±0.30b	13.54±0.3b	26.27±0.20b
M_1	1.40±0.03b	1.90±0.12b	43.41±0.31a	14.41±0.3a	26.92±0.19a
Soil amendments*Mulch	**	**	**	**	**
Control×M_0	1.64±0.05a	2.73±0.20a	42.16±0.63e	11.39±0.68f	25.16±0.41e
Control×M_1	1.60±0.05b	2.55±0.20b	40.65±0.57g	12.06±0.64e	25.72±0.39d
C×M_0	1.58±0.05b	2.38±0.19c	41.12±0.61f	13.11±0.61d	26.05±0.38cd
C× M_1	1.49±0.04d	2.32±0.19c	42.05±0.57e	14.39±0.60c	26.24±0.37c
V×M_0	1.55±0.05c	2.09±0.20d	42.61±0.61d	14.55±0.62c	26.95±0.39b
V× M_1	1.30±0.06e	1.53±0.22e	44.42±0.65b	15.08±0.64b	27.16±0.39b
CV×M_0	1.50±0.05d	1.60±0.20e	43.95±0.59c	15.12±0.64b	27.25±0.43b
CV× M_1	1.20±0.07f	1.29±0.25f	44.99±0.69a	16.11±0.66a	28.21±0.40a

The values are presented as means ± SE. The symbols * and ** indicate significant differences at $p \leq 0.05$ and $p \leq 0.01$, respectively, while "ns" denotes nonsignificance at $p = 0.05$. Mean values within each column that are accompanied by different lowercase letters are considered significantly different according to Duncan's least significant difference test at $p \leq 0.05$.

Data in Table (4) illustrates the effects of additional organic soil amendments and soil mulching on some soil chemical properties. There are positive effects in the values of soil pH, ECe, O.M, N, P and K content in soil when organic soil amendments and soil mulching were applied. The mean values of soil pH and ECe, were significantly decreased by (0.92, 8.47%), (1.57, 14.92%) and (2.10, 21.02%), when compost (C), vermicompost (V) and a mixture of both compost with vermicompost (CV) applied, respectively, as compared with control. Also, there are significant increases in the mean values O.M, N, P and K contents in soil by (32.79, 9.27, 6.47 and 3.68%), (50.82, 24.24, 23.50 and 7.68%) and (55.74, 33.10, 33.81 and 10.60%) when (C), (V) and (CV) applied, respectively, as compared with control.

The soil mulching (M_1) treatment with rice straw (8 t h^{-1}) led to significant decreases in the mean values of soil pH and ECe by 0.79 and 7.69%, respectively, as compared with non-mulching (M_0). But there are significant increases in the mean values of O.M, N, P and K contents in soil by 5.00, 13.92, 16.59 and 5.18%, when soil mulching (M_1) used respectively, as compared with non-mulching (M_0). For the interaction between organic soil amendments and soil mulching treatments, the lowest values of soil pH and ECe were 7.42 and 2.29 ds m^{-1}, respectively, at the compost with vermicompost blend treatment (CV-blend) and soil mulching (M_1). But the highest values were O.M, N, P and K were 0.96, 21.29, 6.46 and 58.77%, respectively.

Table 4. Effect of organic soil amendments and mulching on some soil chemical properties at the end of experiment in (SI) 2023 and (SII) 2024 seasons

Treatment	Soil pH	ECe (dS m^{-1})	O.M %	N mg kg^{-1}	P mg kg^{-1}	K mg kg^{-1}
Season	**	*	**	NS	NS	NS
S_1	7.57±0.01a	2.68±0.07a	0.85±0.03a	16.82±0.46a	4.77±0.16a	54.47±0.53a
S_2	7.49±0.02b	2.57±0.07a	0.79±0.03b	17.15±0.57a	4.89±0.20a	54.57±0.58a
Soil amendments	**	**	**	**	**	**
Control	7.62±0.02a	2.95±0.09a	0.61±0.04c	14.56±0.58d	4.17±0.19d	51.68±0.69d
Compost (C)	7.55±0.02b	2.70±0.09b	0.81±0.04b	15.91±0.54c	4.44±0.18c	53.58±0.65c
Vermicompost (v)	7.50±0.02c	2.51±0.09c	0.92±0.04a	18.09±0.66b	5.15±0.24b	55.65±0.73b
CV-blend	7.46±0.02d	2.33±0.09d	0.95±0.04a	19.38±0.75a	5.58±0.27a	57.16±0.78a
Mulch	**	**	**	**	**	**
M_0	7.56±0.01a	2.73±0.07a	0.80±0.03b	15.88±0.42b	4.46±0.13b	53.14±0.50b
M_1	7.50±0.02b	2.52±0.07b	0.84±0.03a	18.09±0.55a	5.20±0.20a	55.89±0.57a
Soil amendments*Mulch	**	NS	**	**	*	**
Control×M_0	7.62±0.02a	3.05±0.14a	0.59±0.07h	14.03±0.95f	4.16±0.31d	51.16±1.10h
Control×M_1	7.62±0.02a	2.85±0.13a	0.64±0.06g	15.08±0.90e	4.19±0.31cd	52.20±1.06g
C×M_0	7.57±0.02b	2.70±0.13a	0.78±0.06f	15.54±0.89de	4.42±0.30cd	52.69±1.04f
C× M_1	7.52±0.02d	2.33±0.14a	0.83±0.06e	16.29±0.88d	4.46±0.30cd	54.48±1.01d
V×M_0	7.53±0.02c	2.79±0.14a	0.88±0.06d	16.48±0.93cd	4.59±0.32cd	53.18±1.08e
V× M_1	7.46±0.03f	2.61±0.14a	0.95±0.06b	19.69±1.08b	5.70±0.39b	58.11±1.16b
CV×M_0	7.51±0.02e	2.38±0.13a	0.94±0.06c	17.47±0.88c	4.70±0.30c	55.54±1.03c
CV× M_1	7.42±0.03g	2.29±0.13a	0.96±0.06a	21.29±1.22a	6.46±0.45a	58.77±1.22a

The values are presented as means ± SE. The symbols * and ** indicate significant differences at $p \leq 0.05$ and $p \leq 0.01$, respectively, while "ns" denotes nonsignificance at $p = 0.05$. Mean values within each column that are accompanied by different lowercase letters are considered significantly different according to Duncan's least significant difference test at $p \leq 0.05$. *EC is the electrical conductivity, O.M = organic matter content,

3.2. Effect of organic soil amendments and mulching on some morphological characteristics of soybean plants

Data in Table (5) illustrates the effects of additional organic soil amendments and soil mulching on some morphological characteristics of soybean plants. There are positive effects in the values of plant height (cm), stem diameter (cm), number of branches, number of leaves per plant and number of pods per plant^{-1} when organic soil amendments and soil mulching were applied. The mean values of plant height (cm), stem diameter (cm), number of branches, number of leaves and number of pods per plant^{-1}, were significantly increased by (20.28, 46.05, 10.53, 49.29 and 72.54%), (41.73, 73.15, 38.53, 66.17 and 102.66%) and (54.78, 111.47, 78.95, 101.76 and 188.57%) when (C), (V) and (CV) applied, respectively, as compared with control.

The soil mulching (M_1) treatment with rice straw (8 t h^{-1}) led to significant increases in the mean values of plant height (cm), stem diameter (cm), number of branches, number of leaves and number of pods per plant^{-1} by 7.58, 15.93, 19.61, 13.85 and 18.00%, respectively, as compared with non-mulching (M_0). For the interaction between organic soil amendments and soil mulching treatments, the highest values of plant height (cm), stem diameter (cm), number of branches, number of leaves and number of pods per plant^{-1} were 160.33, 28.85, 9.00, 157.67 and 317.33%, respectively, at the compost with vermicompost blend treatment (CV-blend) and soil mulching (M_1).

Table 5. Effect of organic soil amendments and mulching on some morphological characteristics of plant at the end of experiment in (S_I) 2023 and (S_{II}) 2024 seasons

Treatment	Plant height (cm)	Stem diameter (cm)	Number of branches per plant^{-1}	Number of leaves per plant^{-1}	Number of pods per plant^{-1}
Season	NS	*	**	NS	NS
S_1	128.63±4.56a	18.44±1.20b	5.33±0.34b	116.46±6.53a	195.58±15.14a
S_2	130.42±4.51a	20.32±1.18a	7.21±0.35a	118.33±6.50a	197.46±15.12a
Soil amendments	**	**	**	**	**
Control	100.25±6.36d	12.29±1.56d	4.75±0.52d	76.08±9.39d	102.92±20.94d
Compost (C)	120.58±5.77c	17.95±1.39c	5.25±0.46c	113.58±7.82c	177.58±18.87c
Vermicompost (v)	142.08±5.74b	21.28±1.37b	6.58±0.42b	126.42±7.88b	208.58±18.96b
CV-blend	155.17±6.20a	25.99±1.65a	8.50±0.49a	153.50±8.48a	297.00±21.13a
Mulch	**	**	**	**	**
M_0	124.79±4.53b	17.95±1.14b	5.71±0.37b	109.79±6.81b	180.29±14.96b
M_1	134.25±4.45a	20.81±1.21a	6.83±0.36a	125.00±6.04a	212.75±14.98a
Soil amendments*Mulch	*	NS	**	**	**
Control×M_0	95.33±9.57h	10.83±2.42a	4.00±0.66f	55.33±14.81g	79.33±32.25g
Control×M_1	105.17±9.05g	13.75±2.27a	5.50±0.68e	96.83±12.59f	126.50±29.90f
C×M_0	114.15±8.67f	16.72±2.14a	4.50±0.57f	112.50±12.10e	171.83±28.50e
C× M_1	127.00±8.38e	19.18±2.06a	6.00±0.59de	114.67±12.11e	183.33±28.33d
V×M_0	139.67±8.98d	21.10±2.28ba	6.33±0.58cd	122.00±12.86d	193.33±30.10d
V× M_1	144.50±8.59c	21.46±2.06ba	6.83±0.55c	130.83±12.23c	223.83±28.59c
CV×M_0	150.00±8.92b	23.14±2.24a	8.00±0.68b	149.33±12.86b	276.67±30.28b
CV× M_1	160.33±9.35a	28.85±2.54a	9.00±0.67a	157.67±13.29a	317.33±32.43a

The values are presented as means ± SE. The symbols * and ** indicate significant differences at $p \leq 0.05$ and $p \leq 0.01$, respectively, while "ns" denotes nonsignificance at $p = 0.05$. Mean values within each column that are accompanied by different lowercase letters are considered significantly different according to Duncan's least significant difference test at $p \leq 0.05$.

3.3. Effect of organic soil amendments and mulching on some physiological characteristics of plant

Data in Table (6) showed the effects of additional organic soil amendments and soil mulching on some physiological characteristics of soybean plants. There are positive effects on the values of RWC%, MSI% and SPAD when organic soil amendments and soil mulching were used. The mean values of RWC%, MSI% and SPAD were significantly increased by (32.52, 48.34 and 40.83%), (21.31, 34.92 and 20.16%) and (17.16, 22.78 and 9.37%) when soil amendments (C), (V) and (CV) were added respectively, as compared with control. The soil mulching (M_1) treatment with rice straw (8 t h^{-1}) led to significant increases in the mean values of RWC%, MSI% and SPAD by 7.87%, 2.72% and 3.96, respectively, as compared with non-mulching (M_0).

Data in Table (7) and Figure (1) showed the interaction between organic soil amendments and soil mulching treatments, the highest values of RWC%, MSI and SPAD were 84.57%, 60.64% and 56.35 respectively, at the compost with vermicompost blend treatment (CV-blend) and soil mulching (M_1).

Table 6. Effect of organic soil amendments and mulching on some physiological characteristics of plants in (S_I) 2023 and (S_{II}) 2024 seasons

Treatment	SPAD	MSI (%)	RWC (%)
Season	*	*	**
S_1	49.02±1.33b	50.15±1.64b	67.96±2.07b
S_2	50.90±1.29a	52.02±1.61a	69.83±2.06a
Soil amendments	**	**	**
Control	42.43±1.94c	40.38±2.33d	58.59±2.84d
Compost (C)	49.71±1.66b	49.58±2.04c	64.08±2.56c
Vermicompost (v)	51.47±1.66b	54.48±2.06b	70.40±2.49b
CV-blend	56.23±1.76a	59.90±2.22a	82.51±2.83a
Mulch	*	NS	**
M_0	48.99±1.39b	50.40±1.65a	66.29±2.08b
M_1	50.93±1.26a	51.77±1.59a	71.51±1.99a
Soil amendments*Mulch	*	NS	**
Control×M_0	41.60±2.89e	39.18±3.48a	54.22±4.25g
Control×M_1	43.25±2.68e	41.58±3.28a	62.96±3.89f
C×M_0	52.18±2.42bc	49.22±2.96a	61.22±3.85f
C× M_1	47.23±2.42d	49.94±2.91a	66.95±3.75e
V×M_0	53.80±2.62ab	54.04±3.18a	69.26±3.96d
V× M_1	49.13±2.37cd	54.91±2.94a	71.55±3.76c
CV×M_0	56.12±2.66a	59.17±3.23a	80.45±4.13b
CV× M_1	56.35±2.53a	60.64±3.22a	84.57±4.36a

The values are presented as means ± SE. The symbols * and ** indicate significant differences at $p \leq 0.05$ and $p \leq 0.01$, respectively, while "ns" denotes nonsignificance at $p = 0.05$. Mean values within each column that are accompanied by different lowercase letters are considered significantly different according to Duncan's least significant difference test at $p \leq 0.05$, (RWC)= Relative water content, (MSI) =The membrane stability index .

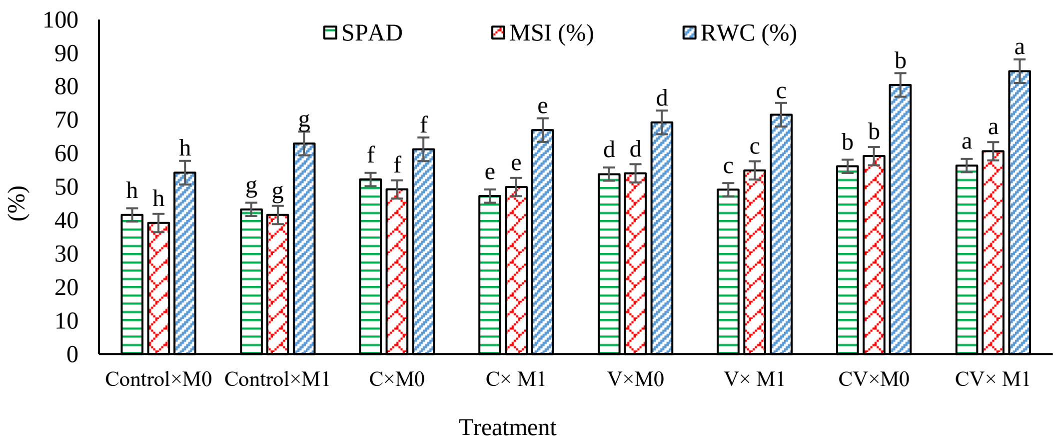

Figure 1. Showed the effect of organic soil amendments and mulching on SPAD, RWC= Relative water content, (MSI) =The membrane stability index.

3.4. Effect of organic soil amendments and mulching on weight of 100 seeds (g), seeds yield and straw yield

Data in Table 7 showed the effect of organic soil amendments and soil mulching addition on soybean crop yield. There are positive effects on the values of weight of 100 seeds (g), seeds yield and straw yield when organic soil amendments and soil mulching were applied. The mean values of weight of 100 seeds, seeds yield and straw yield were significantly increased by (2.63, 3.35 and 14.83%), (5.82, 25.00 and 27.84%) and (24.59, 73.48 and 48.02%) when soil amendments (C), (V) and (CV) were added, respectively, as compared with control.

The soil mulching (M_1) treatment with rice straw (8 t h^{-1}) led to significant increases in the mean values of weight of 100 seeds (g), seeds yield and straw yield by 6.57, 16.58 and 7.94%, respectively, as compared with non-mulching (M_0).

Data in Table 7 showed the interaction between organic soil amendments and soil mulching treatments. The values of weight of 100 seeds, seeds yield and straw yield were increased by 21.17, 6.11 and 24.29%, respectively, at the compost with vermicompost blend treatment (CV) and soil mulching (M_1).

Table 7. Effect of organic soil amendments and mulching on weight of 100 seeds, seeds yield and straw yield in (S_I) 2023 and (S_{II}) 2024 seasons

Treatment	W. of.100 seeds (g)	Seeds Yield (t h^{-1})	straw Yield (t h^{-1})
Season	**	**	**
S_1	16.36±0.36b	3.18±0.22b	18.60±0.64b
S_2	18.24±0.38a	5.05±0.23a	20.43±0.60a
Soil amendments	**	**	**
Control	15.98±0.50d	3.28±0.38c	15.91±0.86d
Compost (C)	16.40±0.45c	3.39±0.35c	18.27±0.77c
Vermicompost (v)	16.91±0.43b	4.10±0.32b	20.34±0.75b
CV-blend	19.91±0.56a	5.69±0.38a	23.55±0.86a
Mulch	**	**	**
M_0	16.75±0.36b	3.80±0.26b	18.77±0.63b
M_1	17.85±0.41a	4.43±0.28a	20.26±0.62a
Soil amendments*Mulch	**	**	NS
Control×M_0	15.40±0.68g	2.88±0.42g	15.27±1.23a
Control×M_1	16.56±0.70e	3.68±0.52e	16.54±1.20a
C×M_0	15.88±0.62f	2.97±0.37f	17.48±1.09a
C× M_1	16.91±0.62cd	3.81±0.43d	19.06±1.02a
V×M_0	17.05±0.64c	4.08±0.41c	19.52±1.14a
V× M_1	16.77±0.57de	4.11±0.36c	21.16±1.01a
CV×M_0	18.66±0.70b	5.26±0.50b	22.81±1.23a
CV× M_1	21.17±0.76a	6.11±0.44a	24.29±1.20a

The values are presented as means ± SE. The symbols * and ** indicate significant differences at $p \leq 0.05$ and $p \leq 0.01$, respectively, while "ns" denotes nonsignificance at p = 0.05. Mean values within each column that are accompanied by different lowercase letters are considered significantly different according to Duncan's least significant difference test at $p \leq 0.05$.

3.5. Effect of organic soil amendments and mulching on protein and oil yield

Data in Table (8) showed the effects of organic soil amendments and soil mulching addition on protein and oil yield of soybean crop. There was a positive effect on the values of protein (%), oil (%) and oil yield (t ha^{-1}) when organic soil amendments and soil mulching were applied. The mean values of protein, oil (%) and oil yield (t ha^{-1}) were significantly increased by (2.68, 1.08 and 1.18%), (7.02, 1.24 and 22.35%) and (12.54, 3.64 and 75.29%) when soil amendments (C), (V) and (CV) were added, respectively, as compared with control.

The soil mulching (M_1) treatment with rice straw (8 t h^{-1}) led to significant increases in the mean values of protein (%), oil (%) and oil yield (t ha^{-1}) by 2.77, 1.07 and 18.56%, respectively, as compared with non-mulching (M_0).

Data in Table (8) showed the interaction between organic soil amendments and soil mulching treatments. The values were of protein (%), oil (%) and oil yield (t ha^{-1}) were 50.69, 26.07 and 1.60%, respectively, at the compost with vermicompost blend treatment (CV-blend) and soil mulching (M_1).

Table 8. Effect of organic soil amendments and mulching on protein (%), oil (%) and oil yield (t ha^{-1}) at the end of experiment in (S_I) 2023 and (S_{II}) 2024 seasons

Treatment	Protein (%)	Oil (%)	Oil yield (t ha^{-1})
Season	**	**	**
S_1	46.35±0.50b	24.47±0.07b	0.78±0.06b
S_2	48.10±0.45a	26.34±0.13a	1.34±0.07a
Soil amendments	**	**	**
Control	44.74±0.70d	25.03±0.30d	0.85±0.11c
Compost (C)	45.94±0.61c	25.30±0.30c	0.86±0.10c
Vermicompost (v)	47.88±0.58b	25.34±0.28b	1.04±0.09b
CV-blend	50.35±0.64a	25.94±0.29a	1.49±0.11a
Mulch	**	**	
M_0	46.58±0.51b	25.27±0.19b	0.97±0.07b
M_1	47.87±0.47a	25.54 ±0.21a	1.15±0.08a
Soil amendments*Mulch	**	**	**
Control×M_0	43.63±0.97h	24.73±0.24h	0.73±0.11e
Control×M_1	45.86±0.94f	25.04±0.44g	0.97±0.15d
C×M_0	45.31±0.82g	25.63±0.24c	0.74±0.10e
C× M_1	46.57±0.84e	25.33±0.39e	0.98±0.13d
V×M_0	47.38±0.86d	25.48±0.32d	1.05±0.11c
V× M_1	48.37±0.79c	25.13±0.33f	1.04±0.10c
CV×M_0	50.02±0.97b	25.82±0.37b	1.37±0.14b
CV× M_1	50.69±0.90a	26.07±0.30a	1.60±0.13a

The values are presented as means ± SE. The symbols * and ** indicate significant differences at $p \leq 0.05$ and $p \leq 0.01$, respectively, while "ns" denotes nonsignificance at $p = 0.05$. Mean values within each column that are accompanied by different lowercase letters are considered significantly different according to Duncan's least significant difference test at $p \leq 0.05$.

4. Discussion

Organic soil amendments, such as compost, vermicompost, and organic mulching, play a critical role in modern agriculture by improving soil fertility, structure, and sustainability. While recent research has examined the individual impacts of these amendments on soybean productivity, limited attention has been given to their combined effects when integrated with organic surface mulching.

This study investigated the synergistic use of organic amendments (compost, vermicompost, and a compost-vermicompost blend) and organic mulching to optimize soil health and soybean growth in sandy loam soil, a substrate known for its poor water and nutrient retention. The application of these amendments significantly enhanced soil-water dynamics by increasing water-holding pore space and reducing hydraulic conductivity. Organic materials lowered soil bulk density, attributed to their lower density compared to native soil, thereby improving pore structure and hydraulic properties. These changes promoted better soil aeration, moisture retention, and aggregation stability.

Additionally, organic amendments reduced soil salinity, potentially by facilitating salt leaching, while simultaneously boosting organic matter content, cation exchange capacity, and essential nutrient levels (N, P, K). Soil pH also showed favorable adjustments. These findings align with studies by Kranz et al. (2020), Cao et al. (2021), Li et al. (2022), Chaudhari et al. (2021), Elissen et al. (2023), Ikhsan et al. (2023), and Kebede et al. (2023), underscoring the transformative potential of integrated organic practices in sustainable agriculture. The integration of soil organic amendments and organic mulching positively influenced soybean plants by enhancing their morphological, physiological, and biochemical responses, as well as improving yield and quality. Growth traits (i.e., plant height, stem diameter, number of branches, number of leaves, and number of pods) of soybean plants were demonstrated significant improvements following the application of compost, vermicompost, or a combination of both, alongside organic mulching (Table 6). These amendments and mulching materials inherently supplied substantial levels of nitrogen (N), phosphorus (P), and potassium (K) (Table 5), which promoted nutrient availability and uptake, thereby stimulating plant growth. These results align with findings by Singh et al. (2020), Villa et al. (2021), and Hao et al. (2023), who emphasized the role of organic inputs in optimizing soil fertility and crop performance.

In addition, the increase in plant growth in response to soil organic amendments and organic mulching could mainly be due to the ameliorative effect of soil organic amendments and organic mulching on soil physical properties (Table 4) by enhancing the capacity of soil to hold more water, which in turn improved the water uptake. Likewise, improved soil chemical characteristics including organic matter content and cation exchange capacity (Table 5) are reasonable for better plant growth. Hence, this distinctive performance of soybean growth features reflects the beneficial role of soil organic amendments and organic mulching. Multiple studies have validated these findings (Dsouza et al., 2018; Tang Li et al., 2019; dwi Wahyuni et al., 2022; Elissen et al., 2023).

The combined use of compost and vermicompost, particularly when blended and applied as a soil cover in agricultural systems, demonstrated notable enhancements in plant physiology and growth metrics such as leaf relative water content (RWC%), membrane stability index (MSI%), and chlorophyll levels (SPAD) relative to the control group (Table 7 and Figure 1). This integrative approach fosters beneficial changes in soil quality, nutrient accessibility, and moisture retention, which collectively improve plant vigor, stress resistance, and crop yields.

Organic amendments and mulching enhance soil structure and water retention, ensuring consistent water availability to plants. This mitigates water stress and sustains optimal hydration in plant tissues, directly boosting RWC%. Additionally, enriched microbial activity and nutrient cycling from organic inputs enhance plant resilience, stabilizing cellular membranes under stress conditions (reflected in higher MSI%). Furthermore, improved nutrient availability particularly nitrogen, phosphorus, and potassium supports chlorophyll synthesis, elevating SPAD values and photosynthetic efficiency. These mechanisms underscore the role of organic practices in optimizing plant health and productivity.

These findings align with prior research confirming that organic amendments and mulching strategies enhance soil-plant interactions, nutrient dynamics, and stress adaptability in crops (Abd El-Mageed et al., 2019; Tang Li et al., 2019; Cotrim et al., 2021; Qasim et al., 2023).

From the data in the Table (8) it conclude that organic soil amendments and mulching can positively influence soybean growth by improving soil fertility, nutrient availability, and creating a conducive environment for plant development. This can result in heavier 100 seeds, increased seed yield, and higher straw yield due to enhanced soil health, nutrient retention, and moisture conservation provided by these practices (Abd El-Mageed et al., 2018; da Silva et al., 2019; Mohammad, 2020; Akhtar et al., 2019; Awad et al., 2024). Table 9 showed that organic soil amendments and mulching can positively influence soybean crops by potentially increasing the protein content, oil content, and oil yield. These practices enhance soil fertility, improve nutrient availability, and create optimal growing conditions, leading to better protein and oil synthesis in soybean seeds and ultimately higher oil yield per hectare (Teame et al., 2017; Farhangi-Abriz et al., 2021; Junior et al., 2024; Rashmi et al., 2022; Song et al., 2024).

5. Conclusions

The findings of this study demonstrate that organic soil amendments (compost, vermicompost, or a compost-vermicompost blend) and organic mulching applied individually or synergistically effectively enhance soil physicochemical characteristics and boost soybean productivity in low-input agricultural systems. Among the tested treatments, the combined application of 10 t ha^{-1} compost + 5 t ha^{-1} vermicompost alongside 8 t ha^{-1} rice straw mulch emerged as the most effective strategy for optimizing soybean yield in the study region. This approach leverages the complementary benefits of organic amendments and mulching, improving nutrient availability, soil structure, and moisture retention while supporting sustainable crop production.

Declarations

Ethics approval and consent to participate

Consent for publication: The article contains no such material that may be unlawful, defamatory, or which would, if published, in any way whatsoever, violate the terms and conditions as laid down in the agreement.

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