International Journal of Recycling of Organic Waste in Agriculture (2023) Special Issue: 61-73
Doi: 10.30486/ijrowa.2022.1956047.1450

ORIGINAL RESEARCH

Spinach powder as soil conditioner enhances physiochemical properties of soil and growth characteristics of *Solanum melongena*

Hifza Javed, Shazia Iram*, Barira Bilal, Tehreem Tassawar

Received: 27 April 2022 / Accepted: 24 December 2022 / Published online: 25 December 2022

Abstract

Purpose (i) To evaluate the efficacy of spinach in dry powdered and liquid form as a sustainable substitute for chemical fertilizers; (ii) To analyze and compare the morphological and yield-related parameters of *Solanum melongena* plants using spinach powder and compost as compared to the control treatment.

Method In a pot experiment, *Solanum melongena* seeds were sowed in soil mixed with spinach powder and compost while the control pots were without any amendment to the soil. The spinach -amended soil, compost-amended soil, and control soil sample were compared in terms physiochemical characteristics like pH , EC ,TDS, organic matter , nutrients i.e. nitrogen , phosphorus, potassium ,calcium ,magnesium and heavy metals. While, plant morphological traits plant height, root length, numbers of flowers and fruits were recorded.

Results The pH of spinach-amended soil was slightly alkaline before plantation as compared to control soil. The nitrogen, phosphorus, and potassium content in spinach dry powder was 15%, 36% and 49%, respectively. The organic carbon content was 56% with moderate amount of micronutrients like calcium, magnesium and iron. Spinach powder-amended soil significantly improved the plant morphological characteristics like stem height, root length and able to produce more flowers and mature fruits as compared to compost-amended soil and control soil.

Conclusion The use of spinach in powder and liquid concoction was a suitable alternative to chemical fertilizers. It was able to deliver all major macro- and micronutrients to soil thus improving the fertility and has significant impact on plant growth and yield.

Keywords Plants fertilizers, Soil fertility, Organic amendments, Food security, Sustainable approach

Introduction

Agriculture is a source of economic growth and livelihood of millions of people around the globe but due to unsustainable practices it can lead to various environmental and health hazards (Naveed et al. 2020). The main issue is the soil pollution arising partially due to the excessive use of pesticides and chemical fertilizers that is mutually affecting the terrestrial and aquatic ecosystems (Schellberg et al. 2008). The unbridled increase in human population has burdened the food resources especially for the developing countries. The susceptibility of the already strained agriculture sector, which is battling pests or pest-borne diseases, low yield, pollution, water scarcity and other issues to fulfil the population's food demand is exacerbated by

✉ Shazia Iram shaziairam@fjwu.edu.pk

Laboratory of Mycology and Ecotoxicology, Department of Environmental Sciences, Fatima Jinnah Women University, Rawalpindi, Pakistan

global climate change. The poor countries have to put massive amount of fertilizer to increase the yield or to make soil suitable for the cultivation of particular crop. The downside of this situation is degradation of natural environment and soil interrelated environmental problems such as loss of soil fertility, soil degradation, desertification, and soil erosion. In order to reduce the environmental degradation, sustainable strategies for agricultural improvement can provide a better option for reducing environmental degradation and increasing the yield of the cropping system. Organic fertilization is the ancient method to enhance soil qualities and yield that is both economical and has long term benefit for the overall improvement of physiochemical characteristic of soil (Doan et al. 2015). Soil conditioners are used for preserving and improving soil fertility and basic macronutrients i.e. nitrogen, phosphorus and potassium (NPK), as well as essential micronutrients such as calcium (Ca), copper (Cu), magnesium (Mg), manganese (Mn), zinc (Zn) etc. (Millmier et al. 2000). By definition, the soil conditioner is the amendment which improves physical qualities of soil and its processes (Rossi et al. 2020). The main function of a soil conditioner is to enhance water holding capacity and permeability, percolation, soil aeration, organic content, cation exchange capacity, maintaining soil pH, and improving microbial community structure in agricultural soil. Many organic sources of soil conditioner such as vermiculite, compost, farmyard manures, biochar, bone meal, blood meal, coir, sewage sludge and sawdust are used to boost plant physiological and yield characteristics and enhance the soil's nutritional profile. Composting from food waste, manures, and sewage sludge is feasible solution for improving soil quality, but it has disadvantages like leachate, odor, or heavy metals contamination. A more direct approach is the use of plant growth promoting enzymes procured from organic sources. One such source is spinach (*Spinacia oleracea*) that is grown all over the world due to its high nutrition value. Spinach is rich in rubisco enzyme short for Ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco; EC 4.1.1.39), an abundant plant protein which helps in the absorbance of nutrients from soil and also responsible for the conversion of inorganic carbon into organic form (Chapman et al. 1988). Rubisco enzyme increases photosynthesis by increasing the photorespiration process. As both processes are directly proportional to one other, the plants absorb more carbon dioxide from the environment while also releasing a large amount of oxygen. Such carbon dioxide to oxygen conversion leads to the carboxylation and oxygenation reactions which is the main objective of rubisco manipulation (Jucovic et al. 2008). The use of plant enzyme as soil conditioner, decrease the excessive use of fertilizer while improving soil physiochemical properties. In this research, spinach was selected as an alternative source to fertilize soil and its effect on soil physiochemical properties was evaluated. Moreover, spinach powder and liquid mixture was used and the effects on the growth characteristics of the *Solanum melongena* (eggplant) were evaluated.

Material and methods

Preparation of spinach powder

Spinach (*Spinacia oleracea*) was brought from the local market (10 kg). The leaves were chopped from stems, thinly cut, and thoroughly washed with distilled water. Leaves were wrapped in aluminum foil and placed in the oven at 60°C to get the dry powder. After 72 hours, leaves were crushed in the blender which was then passed through sieve U.S Mesh #20 removing coarse particle to get fine powder. The final powder was approximately 1.5 kg which was used as the soil amendment and liquid fertilizer.

Pot experiment setup

Seeds and compost for *Solanum melongena* were bought from a nursery in Islamabad, Pakistan. For setting up the pot experiment, 9 kg soil was mixed with

1 kg of spinach powder and filled in 10 pots of seven-inch diameter. Similarly, 9 kg of soil was mixed with 1 kg of compost and control soil without any amendment and was filled in pots. The spinach powder amendment, compost and control were applied to 10 pots for each treatment. Each pot was sowed with five seeds initially and after two weeks of germination, only two healthy seedlings were allowed to grow. After four weeks of plantation, the liquid spinach mixture was sprayed. For this, 100 g of fine spinach powder was mixed in 1 L distilled water and left for overnight. Then it was filtered with cheese cloth layered three times to get filtrate without powder residue. This concoction was sprayed in three doses, one at three weeks of seed germination, one at flowering stage and one after the fruit emerged. This liquid fertilizer was sprayed on the downward side of *Solanum melongena* leaves and soil was covered with cardboard sheet cut around base of the stem (Iram et al. 2019).

Plant morphological analysis

The *Solanum melongena* plants morphological characteristics were observed during the experiment, i.e. number of flowers per plant and fruits. The plant height was measured with measuring tape from the base of the stem to the top. After harvest, the root length was measured. The leaves were plucked from the plants and the fresh weight was recorded and then dried at 105°C to measure the dry weight (Zahid et al. 2015).

Physiochemical analysis

EC, pH and TDS measurement

The EC (electron conductivity), pH and TDS (total dissolved solid) were measured by dissolving 1 g powder or soil in 50 ml of deionized water in a 100-ml beaker. The soil/spinach powder was mixed on a magnetic stirring plate for 15 minutes. This mixture was left for 1 hour to reach the equilibrium of dissolved salts. Then, a Crison MM 40 $^{+}$ multimeter probe was inserted in the beaker to note the readings of pH, EC and TDS.

Moisture content analysis

For soil moisture analysis, 100 g of wet soil was oven dried at 105°C in a porcelain dish. After 24 hours, the dish was weighed to note the difference. The calculation of moisture content was evaluated from following formula; Percentage moisture content %

$$= \frac{\text{weight of wet soil} - \text{weight of dry soil}}{\text{weight of dry soil}}$$

For spinach powder moisture analysis, the same procedure was followed except the temperature for drying was kept at 55°C. So, the organic matter destruction due to volatilization at higher temperature (SU et al. 2014) was minimized.

Organic carbon determination

Walkey (1947) method was used to determine the organic matter content of spinach powder and soil. Briefly, 1 g of dried spinach powder was taken in 500 ml conical flask then 10 ml of 1 N potassium dichromate ($K_2Cr_2O_7$) and 20 ml sulphuric acid (H_2SO_4) were poured. After cooling the mixture, 200 mL of water and 10 mL of phosphoric acid were added with 1 mL of diphenyl indicator to obtain violet blue solution. The sample was then titrated with a 0.5 M ferrous ammonium sulphate $9(NH_4)_2Fe\,(SO_4)_2{\cdot}6H_2O$) solution until it turned green and carbon percentage was evaluated according to the formula described by (De Vos et al. 2007). All chemicals used in this study were of analytical grade.

Heavy metal analysis

To determine the heavy metals lead (Pb), nickel (Ni), cdmium (Cd), chromium (Cr) and calcium (Ca), iron (Fe), magnesium (Mg), nitric–perchloric acid digestion was performed (Hseu 2004). Briefly, 1 g of soil was mixed with 10 ml of concentrated nitric acid in a

250-ml Erlenmeyer flask on a hotplate. The mixture was heated for 40 minutes at boiling temperature and cooled afterwards. Then, 5 ml of 70% $HClO_4$ was added to the flask and heated gently till white fume appeared. Small aliquots of distill water were added to release more fumes until it completely subsided. This solution was cooled, filtered and diluted to 50 ml in a volumetric flask with distilled water. An atomic absorption spectrophotometer (AA-7000) was used to determine the concentration of micronutrients and heavy metals (Iram et al. 2019).

Potassium analysis

Potassium was analyzed by atomic absorption spectroscopy and extraction method was di-acid digestion as described for heavy metal analysis.

Phosphorus analysis

A method described by Nafiu (2006) was followed. Breifly, in a conical flask, 5 g of sample with a teaspoon of sample was shaked with 100 ml of 0.5 M sodium bicarbonate ($NaHCO_3$) at pH 8.5. After 30 minutes, the material was filtered using Whatman filter paper No.2. The filtrate was analyzed for phosphorus with ascorbic acid method at 880 nm on UV-VIS spectrophotometer.

Nitrogen analysis

The nitrogen content in the sample was used to identify the protein (Sáez-Plaza et al. 2013). The Kjeldahl technique was used to determine the total nitrogen. About 2 g of sample was placed in a digestive tube with 4.15 g of potassium sulphate, 0.35 g copper sulphate and 15 ml sulphuric acid. The digesting flask was heated by mantle at 100-150^{o}C for 60 minutes under a fume hood, and the liquid was changed greenish in color after cooling the mixture turned blue. For distillation, 75 ml distilled water was added into the flask with water and 30 ml sodium hydroxide (NaOH) solution. Then, the flask with sample was condensed and collected in a flask through the discharge end. To this mixture, methylene red indicator dissolved in 50 ml distilled water was added. This mixture was diluted with NaOH solution until pink color appeared.

Statistical analysis

The data was analyzed using Microsoft Excel 13 and IBM SPSS Statistics 20 software. One-way Analysis of Variance (ANOVA) with a 95% confidence level was used to determine the effect of soil amendments on the growth of *Solanum melongena*. The means of replicate experiment and treatment were expressed as means of variance with significant difference expressed at $p < 0.05$ probability in all of the evaluated parameters in Tables 3 and 4.

Results and discussion

Characteristics of spinach powder

The pH of dried spinach powder was slightly alkaline with EC 83.3 µS/cm. The total dissolved solids in spinach powder was 178 mg/l, while the organic carbon was 46%. The spinach powder has moisture content of 56% as shown in Table 1. The NPK (nitrogen, phosphorus, potassium) content of this powder indicated it as a rich source of macronutrients required for any organic fertilizer. The nitrogen constituted 15%, whereas phosphorus and potassium were 36% and 49%, respectively (Fig. 1). The micronutrient calcium was 63.21 g/kg, iron was 15.35 g/kg while a good concentration of magnesium 6.89 g/kg was found in spinach powder. Overall, the physiochemical properties of spinach powder were comparable to the International Agricultural Soil Standards as shown in Table 1. In the study by Oyewusi et al. (2021), they co-composted chicken manure and saw dust using passively-aerated method. Chicken manure is high in NPK and micronutrients like calcium and magnesium. The final composted product showed pH 8.17, moisture content was 49.92%, nitrogen 1.82% while Ca , Mg were 10.12 g/kg ,1.41 g/kg. The phosphorus in the compost was

8.18 g/kg. Similarly, this study demonstrated that, the chemical and physical profile of the spinach powder is at par with any other organic fertilizer constituting all major micro and macronutrients necessary for rejuvenating depleting soils and providing bioavailable nutrients for plant growth and productivity.

Table 1 Physical and chemical analysis of dried spinach and comparison with international agricultural soil standards

Parameters	Average mean values of spinach powder	International Agricultural Soil Standards (Naseem et al. 2012)
pH	8	4-8.5
EC µS/cm	83.3	4
TDS mg/l	178.0	2564
Moisture Content%	56	NGVS
Organic Carbon%	46	>0.86
Nitrogen g/kg	40.23	NGVS
Phosphorus g/kg	95	>7
Potassium g/kg	131.5	>80
Calcium g/kg	63.21	7-500
Magnesium g/kg	6.89	0.02-10
Iron g/kg	15.36	NGVS

NGVS: No guideline value set

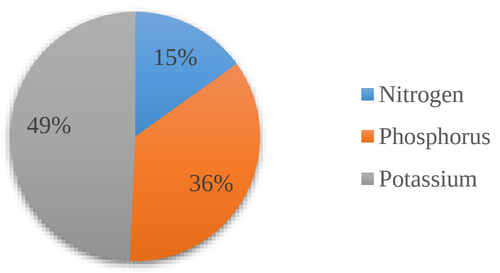

Fig. 1 Percentage of macronutrients NPK in spinach powder

Heavy metal concentrations in the dried spinach powder were examined to determine the source of secondary pollution (Table 2). The results revealed that heavy metals such as Cd, Ni, Cr, and Pb were found to be under permissible limit of European Union guidelines and thus making it a good source of organic fertilizer without inducing the risk of secondary pollution. Organic amendments have been shown to reduce cadmium concentration, whereas certain amendments have been shown to increase cadmium concentration in soil. This variation is due to the different types of raw materials utilized to make fertilizers (McGrath et al. 2000). Some heavy metals form chelates with organic elements of soil organic matter, which has been seen in prior investigations. Since soil has a great attraction for metals and allows for cation exchange with them, metal complexes occur in the soil medium. The addition of organic molecules to the samples resulted in a decrease in Pb concentration. The use of compost and spinach in the soil has been shown to reduce heavy metal concentrations such as lead, nickel, chromium, and cadmium (Shyamala and Belagali 2012).

Table 2 Average value of heavy metals in spinach powder and comparison with European Union (EU) maximum permissible limits for soil

Heavy Metals	Average Mean Value (mg/kg)	EU limits for soil (mg/kg) (Eissa and Negim 2018)
Cadmium (Cd)	0.4	3
Nickel (Ni)	20.73	NGVS
Chromium (Cr)	2.39	150
Lead (Pb)	1.32	300

NGVS: No guideline value set

Physiochemical properties of soil after amendments

The spinach powder and compost were added to the soil while control soil did not receive any amendments. The results in Table 3 show the statistical summary of fertilizer amendments before and after plantation of plants. The *p* value is 0.003 ($p < 0.05$) so the result is highly significant. The spinach powder and compost had significant impact on the soil physiochemical properties before the plantation and after plantation. The pH of spinach amended before plantation was raised to 9.5 but to after plantation the pH was lowered to 8.0. This showed that soil has undergone some changes at the chemical level which lowered the pH. One possible explanation is that nitrogen rich fertilizer underwent nitrification by soil bacteria and in the process hydrogen ions were released which increased the acidity thus resulting in the lowering of pH and increased yield output (Vasak et al. 2015; Han et al. 2020).

The EC values ranged for spinach amended soil before plantation was 62.4 mg/l and the compost soil had 69.6 mg/l which was nearly reduced to half after plantation. Except for the control soil samples, all soil supplemented with compost or spinach powder had higher EC and TDS values.

According to Datta et al. (2019), the secretion of organic acids by the breakdown of organic matter caused a similar rise in conductivity. The electrical conductivity critical limit should not exceed 4.0 dS/m. The TDS value increased as a result of the usage of organic and chemical fertilizers, which could be due to an increase in salt concentration. According to Mane et al. (2011), the TDS content in the treated soil pots was different, and there was a definite increase in TDS value due to the higher salt concentrations. The high moisture content was observed from the initial plantation stage to the harvest stage. In comparison to compost soil, spinach-amended soil had the highest percentage value of moisture content (53.67%) before planting. The moisture content of amended soils ranged from 26.67% to 33.33% after planting, as shown in Table 3. Moisture content was found to be significantly different in the early plantation and after harvesting. Soil moisture content was kept high in the current study at the early plantation stage, as a preparation for sowing seeds. According to previous research, the increased moisture content value was caused by the decreased soil compressibility and the nitrification by soil microorganism increased the aggregate stability (Edwards et al. 2000). Organic carbon in spinach-supplemented soil was 53.67%, while in compost amended soil the organic carbon percentage was 46.67% as compared to control soil containing 40 % of organic carbon. The average value of organic carbon in all amended soils increased significantly after plantation (Table 3).

Table 3 Statistical evaluation of the physicochemical parameters for control and experimental soils treated with spinach powder and compost

Parameters	Sample	Replicate 1	Replicate 2	Replicate 3	Mean	Standard Deviation
pH	Spinach Soil (BP)	9.8	9.5	9.2	9.5	±0.3
	Spinach Soil (AP)	8	8.1	8	8.0	±0.05
	Compost Soil (BP)	8.8	8.5	8.3	8.53	±0.25
	Compost Soil (AP)	8.2	8	8	8.07	±0.11
	Control Soil (BP)	8.6	8.3	8.5	8.47	±0.15
	Control Soil (AP)	7.9	7.6	7.2	7.57	±0.35
EC (us/cm)	Spinach Soil (BP)	65.3	60	62	62.4	±2.68
	Spinach Soil (AP)	36.4	35	32	34.47	±2.25
	Compost Soil (BP)	73.8	65	70	69.6	±4.41
	Compost Soil (AP)	34.1	32	32	32.7	±1.21
	Control Soil (BP)	30	29	32	30.33	±1.53
	Control Soil (AP)	24.1	22	23	23.03	±1.05
TDS (mg/l)	Spinach Soil (BP)	53	54	51	52.66	±1.53
	Spinach Soil (AP)	23.3	22	21	22.1	±1.15
	Compost Soil (BP)	45	40	50	45	±5
	Compost Soil (AP)	21.8	20	22	21.27	±1.10
	Control Soil (BP)	83.3	75	78	78.77	±4.20
	Control Soil (AP)	15.45	14	13	14.15	±1.23
Moisture Content (%)	Spinach Soil (BP)	56	52	53	53.67	±2.08
	Spinach Soil (AP)	28	26	26	26.67	±1.15
	Compost Soil (BP)	46	45	42	44.33	±2.08
	Compost Soil (AP)	35	32	33	33.33	±1.53
	Control Soil (BP)	48	42	46	45.33	±3.05
	Control Soil (AP)	32	31	34	32.33	±1.52
Organic Carbon (%)	Spinach Soil (BP)	46	42	43	43.67	±2.08
	Spinach Soil (AP)	54	52	55	53.67	±1.53
	Compost Soil (BP)	40	38	39	39	±1
	Compost Soil (AP)	48	46	46	46.67	±1.15
	Control Soil (BP)	36	34	35	35	±1
	Control Soil (AP)	40	38	35	37.67	±2.52

Analysis of variance

Source	Degrees of Freedom (DF)	Sum of Squares (SS)	Mean Square (MS)	F-Stat	*P*-Value
Between Groups	4	4816.7741	1204.193	5.133	0.003
Within Groups	25	5864.824	234.593		
Total	29	10681.5981			

(BP: Before Plantation, AP: After Plantation)

Macro and micronutrient content after soil amendments

The use of organic material and chemical fertilizers is the cause of increased organic content in soil. By delivering good nutritional values, these amendments promoted microbial activity in any type of soil. The organic amendments were beneficial in terms of long term availability of nitrogen, potassium and phosphorus to the soils and productivity is greatly enhanced even beyond the cultivation season (Antoniadis et al. 2015). Table 4 summarizes the statistical variation of the treatments and their effects on the mineral content of soil. The spinach powder-amended soil in comparison to compost and control treatment had significant impact on the soil macro and micronutrients. The treatments of amendments before and after plantation showed significant differences between the treatments groups (p value = 0). The nitrogen concentration in spinach before plantation was 39.5 g/kg and after plantation it reduced to 31.3 g/kg. In the current study, the content of nitrogen in soil at the early phases of plantation was high. A spike in concentration was caused by the utilization of organic resources and chemical fertilizers. This treatment may have caused the organic nitrogen conversion from spinach by naturally occurring bacteria in the soil resulting in a quick increase in readily available nitrogen. The potassium and phosphorus content in spinach amended soil before plantation was 131 g/kg and 246.7 g/kg, respectively. But, potassium concentrations in amended and control soils were significantly lowered after plantation because plants took up all of the available P and K in soil.

Organic amendments have the potential to affect the soil qualities and directly enhance their physical and chemical properties, spinach- and compost-amended soils have higher concentrations of calcium and magnesium than control soil. In previous studies, larger concentrations of these micronutrients were found in compost and organic amendments (Bashir et al. 2021). In comparison to control soil, the highest calcium level was found in spinach or compost treated soils with 62.81 g/kg and 65.67 g/kg, respectively, before plantation. All treated soils, except for the control soil, had a considerable concentration of calcium at the early plantation stage. Similarly, magnesium concentration in both compost and spinach powder amended soil was relatively same before plantation. After the plant growth, both calcium and magnesium were readily available to eggplant. Plants use micronutrients only in specific amounts and remainder is left in soil (Han et al. 2020). Furthermore, the bioavailability of micronutrients in soils is highly dependent on pH. According to USDA Natural Resources Conservation Service (1998), the calcium and magnesium are highly bioavailable at soil with pH 7.8. In this study, the soil pH was in range of 7.9 to 8.2 in organic amendments and control after the plantation of crop (Table 3). The pH had significant impact on the arability of Fe in soil. Iron is more available to plants in acidic soils and neutral soil at pH 7 has 50% less solubility of iron. At pH 8, it becomes even reduced due to the formation of iron hydroxide (Fageria and Nascente 2014; Gondal et al. 2021). In this study the spinach-amended soil has soluble form of iron as compared to compost soil. Since the pH in all treatment soil was around 8, so it has significant impact on the availability of iron (Table 4).

Solanum melongena morphological analysis

To compare the growth rates of *Solanum melongena* in spinach- and compost-enhanced soils, different morphological parameters were assessed, such as the height of the plant, root length, stem width, number of flowers, and number of fruits were evaluated in comparison to control soil (Fig. 2).

Table 4 Variations in the mineral content of the control and treated soil samples and statistical significance evaluation

Parameters	Sample	Replicate 1	Replicate 2	Replicate 3	Mean	Standard Deviation
N_2 (g/kg)	Spinach Soil (BP)	40.23	39	39.5	39.5	±0.62
	Spinach Soil (AP)	32	30	32	31.3	±1.15
	Compost Soil (BP)	35	34	34	34.3	±0.58
	Compost Soil (AP)	30	29	30	29.6	±0.58
	Control Soil (BP)	32	31	33	32	±1.00
	Control Soil (AP)	30	29	29.5	29.5	±0.50
K (g/kg)	Spinach Soil (BP)	131.5	130	131.5	131	±0.9
	Spinach Soil (AP)	44	44	46	44.7	±1.15
	Compost Soil (BP)	68	67	68	67.7	±0.57
	Compost Soil (AP)	39	36	39	38	±1.7
	Control Soil (BP)	85	83	85	84.3	±1.2
	Control Soil (AP)	18	18	17	17.7	±0.57
Mg (g/kg)	Spinach Soil (BP)	8.8	8.3	8.1	8.4	±0.25
	Spinach Soil (AP)	6.1	5.9	6.3	6.1	±0.05
	Compost Soil (BP)	7.9	7.2	7.5	7.5	±0.35
	Compost Soil (AP)	6.3	6.2	5.5	6	±0.05
	Control Soil (BP)	4.2	4.1	3.4	3.9	±0.05
	Control Soil (AP)	2.1	2.2	2.5	2.3	±0.05
p (g/kg)	Spinach Soil (BP)	247.16	247.16	246	246.7	±0.67
	Spinach Soil (AP)	77.5	77.5	75	76.6	±1.44
	Compost Soil (BP)	158	158	154	156.7	±2.31
	Compost Soil (AP)	77	75	77	76.3	±1.15
	Control Soil (BP)	108	104	108	106.7	±2.31
	Control Soil (AP)	75	73	72	73.33	±1.53
Fe (g/kg)	Spinach Soil (BP)	15.36	15.36	14	14.91	±0.78
	Spinach Soil (AP)	10	8	10	9.33	±1.15
	Compost Soil (BP)	22	21	22	21.67	±0.58
	Compost Soil (AP)	20	19	20	20	±1.00
	Control Soil (BP)	19	17	16	17.33	±1.52
	Control Soil (AP)	15	14	15.3	14.44	±0.51
Ca (g/kg)	Spinach Soil (BP)	63.21	63.21	62	62.81	±0.70
	Spinach Soil (AP)	16	16	15	15.67	±0.58
	Compost Soil (BP)	66	66	65	65.67	±0.58
	Compost Soil (AP)	16	13	14	14.33	±1.53
	Control Soil (BP)	15	14	13	14	±1.00
	Control Soil (AP)	14	11	12	12.33	±1.53

Analysis of variance

Source	Degrees of Freedom (DF)	Sum of Squares (SS)	Mean Square (MS)	F-Stat	***P*-Value**
BG	4	43801.187	10950.296	7.742	0.0004
WG	24	33945.793	1414.408		
Total	28	77746.981			

BP: Before Plantation, AP: After Plantation; BG: Between Groups, WG: Within Groups

Fig. 2 Pot experiment showing *Solanum melongena* growth under (a) control treatment. (b) Spinach amended soil producing healthy plant with more number of mature fruits

In the current study, all the experiment findings showed that spinach-amended soil had a higher fertility level than compost-augmented soil and control soil. In contrast with control soil, different results (stem width, root length, number of fruits & flowers) stayed more noteworthy in spinach powder-adjusted soil as shown in Figs. 3, 4 and 5.

The average stem height of plant grown in soil supplemented by spinach powder was 113 cm. While the plants grown in compost-amended soil had mean height 98.7cm as compared to control which was 94 cm (SD= 0.6). Both compost- and spinach-amended soil had SD=1. In terms of the stem width and the root length, there was not significant difference comparing the treatments with the control (Fig. 3). These findings suggested that the bio-fertilizers showed the maximum plant height because of their capacity to produce growth-promoting chemicals and providing an ideal microclimate, which might have helped in plant development (Baiyeri et al. 2016). The addition of bio-compost supported the yield of various vegetables, as indicated by Rahman et al. (2013).

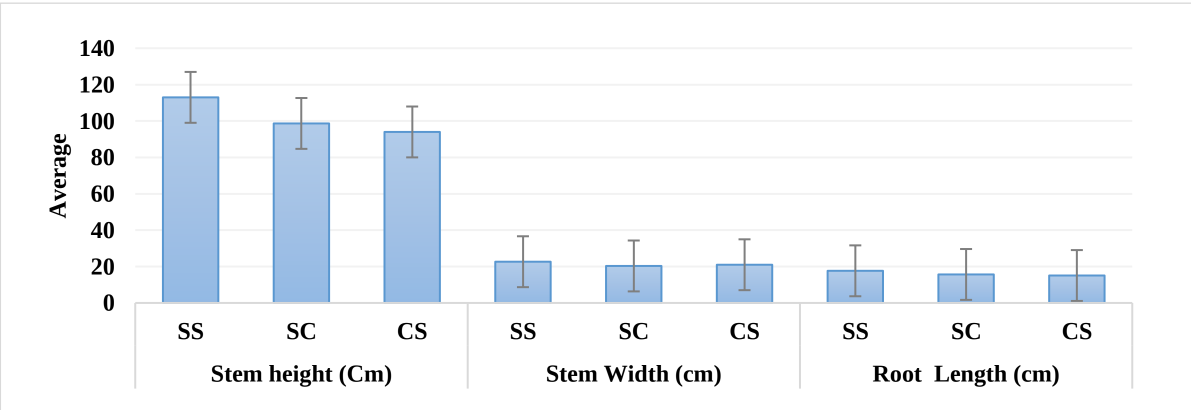

Fig. 3 *Solanum melongena* grown under different organic amendments with the average stem height, width and root length

SS: Spinach amended Soil; SC: soil amended with compost; CS: Control Soil

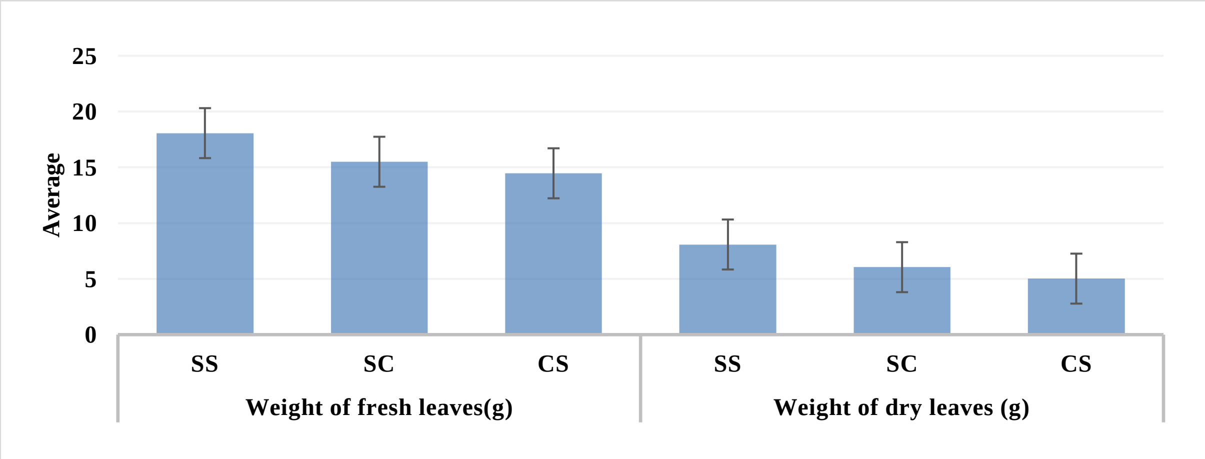

Fig. 4 The average dry and fresh weights of *Solanum melongena* leaves under different organic amendments

SS: Spinach amended Soil; SC: soil amended with compost; CS: Control Soil

The fresh and dry weights of leaves were slightly better with plants grown in spinach-amended soil (Fig. 4). The fresh weight of leaves from spinach-powdered pots was 18.1 g (SD=1.1) and dry weight of 8.2 g was recorded. For compost soil, the average fresh weight of leaves was 14.9 g (SD= 0.8).

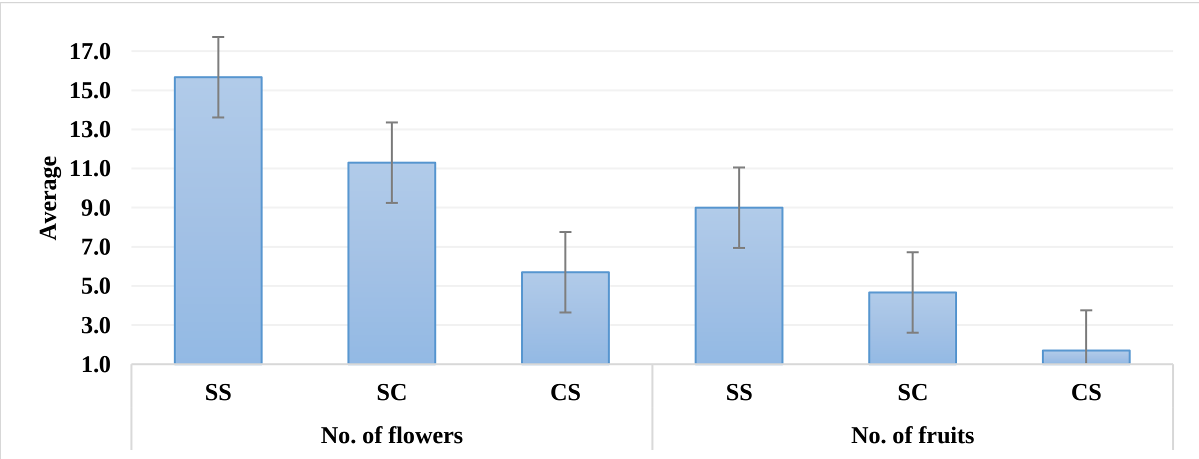

Fig. 5 Average number of flowers and ripe fruits of *Solanum melongena* cultivated under different organic conditions compared to controls

SS: Spinach amended Soil; SC: soil amended with compost; CS: Control Soil

The spinach powder and liquid fertilizer application during different growth stages has significant effect on the flower and fruit production (Fig. 5). The average number of flowers were 15.7 which matures into 9 fruits per plant (SD= 1). So, spinach is overall beneficial for the growing plant as it is evident from Table 1 that spinach powder was rich in potassium and phosphorus. Potassium is an important macronutrient which is the activator for various plant enzymes, protein synthesis and photosynthesis. It improves the plant basic metabolism at cellular levels which is evident from healthy yields (Xu et al. 2020).The control and compost-amended soil had better flower production but the yield was significantly less due to poor nutrient availability. Spinach's higher organic matter substance and nutritional value made it an optimal developing substrate for a wide range of plants. Moreover, the rubisco chemical found in spinach goes about as a photosynthesis catalyzer and upholds plant development. Spinach is a cost-effective and highly nutritive vegetable which is grown across the globe. The spinach powder is sustainable option for improving soil physiochemical properties and adding nutritive value to crops as compared to chemical fertilizers.

Conclusion

The present study demonstrated that the spinach powder is a potential soil conditioner and fertilizer at par with many organic fertilizers. The spinach powder was able to deliver all the major and minor nutrients to the plant growth and yield enhancement. The spinach powder not only was rich in NPK but it was also a great source of plant enzyme and major protein in which the rubisco acted as a photosynthesis catalyzer. The results showed that spinach powder has increased soil fertility and improved its physiochemical attributes as compared to compost and control soil samples. The results were statistically highly significant ($p \leq 0.05$). Moreover, the morphological and yield related results illustrated that spinach powder had significant impact on the growth of *Salonum melongena* in spinach-supplemented as compared to compost and control soil samples. The minimal use of chemical fertilizer combined with environmentally friendly approach such as the use of spinach powder as a soil conditioner can be beneficial for long-term sustainability of agroecosystem. This approach is cost effective and advantageous for small scale farmers and kitchen gardeners. Further research is needed to unravel the potential of spinach powder and its bioactive enzymes for the growth of crops.

Acknowledgements All authors would like to acknowledge Fatima Jinnah Women University, Rawalpindi Pakistan for the research activities.

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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