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ORIGINAL ARTICLE

Municipal sewage sludge, aquatic weed compost on soil enzymatic activity and heavy metal accumulation in Kale (*Brassica oleracea* L.)

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Abstract

Enormous quantities of organic wastes such as sewage sludge (SS) and aquatic weed compost (AWC) are produced in large quantities on the banks of Dal Lake Kashmir. It is a challenging task for authorities to manage them properly. Therefore, the study's purpose was to evaluate these organic wastes agricultural use potential. The experiment was laid out in a randomized complete block design with three replications comprised of nine treatment combinations of SS, AWC and inorganic fertilizers. In the present study, the conjoint use of SS with chemical fertilizer recorded maximum build-up of soil microbial biomass carbon (MCB), *urease* and *dehydrogenase* activity with treatment T_1. There were significant correlations between soil MCB and from *urease* and *dehydrogenase* activity ($r^2 = 0.95$ and 0.97; $P < 0.05$), respectively. The micronutrient and heavy metal concentrations in kale exposed to SS and AWC were significantly higher than those in the untreated plants, with the highest concentration found in sole application of SS (T_7). However, heavy metal concentrations were within the acceptable limits and did not overcome the maximum phytotoxic levels. The study's finding leads to conclusion that SS along with chemical fertilizers (T_1) can improve the enzymatic activity in soil, quality parameters and nutrient content in plants thereby enhancing the yield.

Keywords Sewage sludge · Agricultural use · *Urease* · *Dehydrogenase* · Heavy metals

Introduction

Sewage sludge (bio-solids) generation in Kashmir is increasing at a faster rate and waste water treatment facilities with enhanced efficiencies are being developed. Similarly, macrophytes are being harvested manually and mechanically, providing a source for compost production (Nazir et al. 2021). These bio-solids and harvested aquatic weeds could easily be used for the restoration of soil fertility or for the production of quality vegetables, as they have good nutrient value (availability of NPK). The presence of heaps of sewage sludge (SS) and aquatic weed compost (AWC) on the

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banks of Dal Lake is a challenging task for Lake Management authorities for their proper disposal (Lone et al. 2013; Najar and Khan 2013). However, these organic wastes have a potential scope in agricultural practices by increasing the soil nutrient content; hence will increase the soil fertility. Thereby provides a solution to environmental nuisance and pollution (Goldan et al. 2022).

Conventional farm systems have been characterized by a high input of chemical fertilizers which leads to qualitative deterioration of soil and agricultural produce (Gitonga et al. 2021). However, growing environmental and ecological concerns, as well as understanding of the negative effects of inorganic fertilizers on crop yield, has generated more interest in using organic wastes for agricultural production (Zaffar et al. 2020). Further, broad application of agrochemicals interferes with the regular enzymatic activity of proliferating soil microorganisms and upsets the delicate equilibrium of the soil and ecological balance over the long term (Sawicka et al. 2020). There is need to shift to integrated, sustainable farming methods that utilize local, organic resources as fertilizers (Chukwuka and Omotayo 2009; Selim 2020).

Aquatic weed compost and sewage sludge are inevitable by-product of water bodies and wastewater treatment plants, respectively. These organic amendments generally contain beneficial compounds of potential environmental value such as nitrogen, phosphorus, and other plant nutrients like Mn, Cu, Mo and Zn depending on the specific nature of the sludge material (Arlo et al. 2021). The composting and use of these by-products has a positive impact on soil biological, chemical and physical qualities, and is being increasingly recognised as an environmentally appropriate disposal option (Dar et al. 2019).

Solid waste compost could be used as a soil conditioner without any phytotoxic effects on agricultural crops and abnormal increase in the level of Cu and Zn (Rasool et al. 2022). It has been suggested that enzyme activity, which are thought to be sensitive to heavy metals (Pb and Cd), could serve as possible markers for gauging the level of pollution in contaminated soil. (Lee et al. 2007, 2020). Micronutrients like Fe, Cu, Mn and Zn functions as precursors of many enzyme systems in plants. All of these are supplied by sewage sludge in adequate amount at proper time (Morkunas et al. 2018). Enzymatic activity is inhibited or rendered inactive when certain heavy metals interact with the sulphydral groups of enzymes. (Oves et al. 2016). However, organic matter and soil solutions contain organic matter-heavy metal fractions that are easily assimilated by plants. This would prevent the heavy metal from interacting directly with the active sites of enzyme, thus affecting the enzyme activity (Bartkowiak et al. 2020; Deforest et al. 2012).

Therefore, keeping in view the disposal challenges of sewage sludge and aquatic weed the present study was conducted to investigate the comparative effect of different combinations of sewage sludge and aquatic weed compost on soil enzymatic activity, nutrient and heavy metal status of kale (*Brassica oleracea* L.).

Materials and methods

Experiment design and agronomic practices

The present investigation was conducted at the Experimental Farm located in Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar campus for two consecutive years (*Rabi* 2016 and *Rabi* 2017). The experiment comprised of nine treatment combinations of sewage sludge, aquatic weed compost and inorganic fertilizers with triplicates in Randomized Complete Block Design (Table 1). The G.M. Dari variety (*Brassica oleracea* L. var. acephala) commonly known as kale was grown in the experimental field (Picture 1). The variety was selected keeping in view its growing capacity and market value. The field was levelled with uniform topography and suitable drainage mechanism. Vigorous and healthy seedlings of uniform size of kale were selected and transplanted in well prepared and fertilized plots at spacing of 30 × 15 cm. Climatically the experimental site is in mid to high altitude temperate zone characterized by hot summers and very cold winters. The mean weekly meteorological data collected from Meteorological observatory, Division of Agronomy SKUAST. The data revealed that average maximum and minimum temperatures during cropping seasons were 16.71, 2.70 °C (2016) and 15.94, 2.08 °C (2017), respectively. Total annual precipitation (rainfall) amounted to 383.70 and 428.10 mm during 2016 and 2017, respectively (Fig. 1).

Application of organic manures and inorganic fertilizers

Sewage sludge and aquatic weed compost were air dried and then mixed with soil in different proportion (w/w %) as

Table 1 Details of treatments with their symbols

Treatment	Treatment details
T_1	20% Sewage sludge + 80% RDF
T_2	40% Sewage sludge + 60% RDF
T_3	20% Aquatic weed compost + 80% RDF
T_4	40% Aquatic weed compost + 60% RDF
T_5	20% Aquatic weed compost + 20% Sewage sludge + 60% RDF
T_6	100% Aquatic weed compost
T_7	100% Sewage sludge
T_8	100% RDF
T_9	Absolute control (without fertilizers)

Picture 1 Picture 1 *Brassica oleracea* L. var. acephala growing in the field

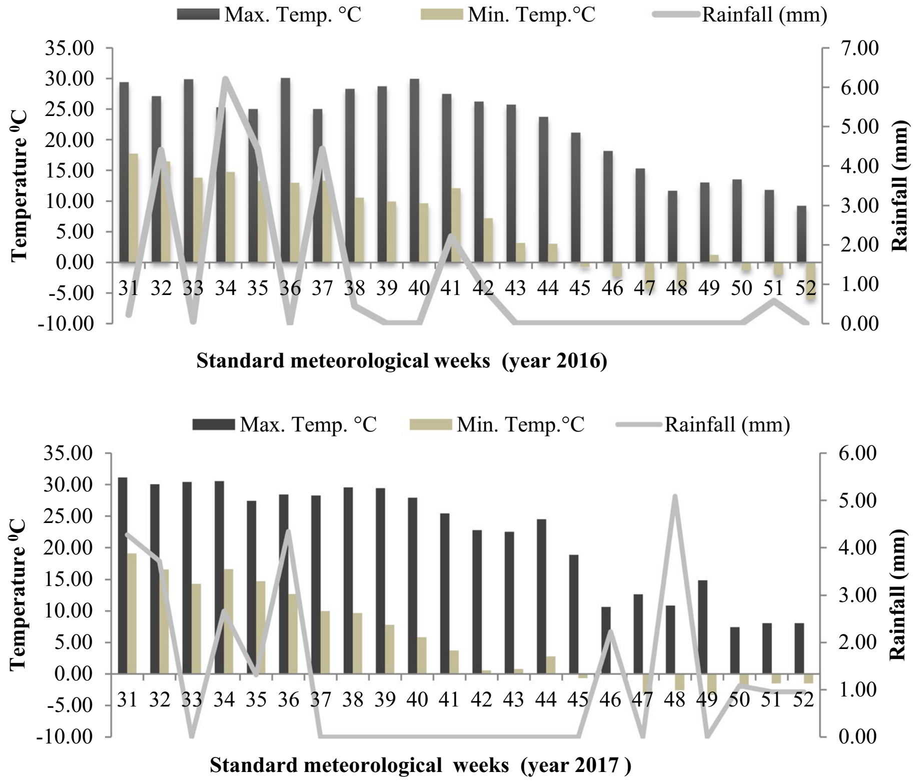
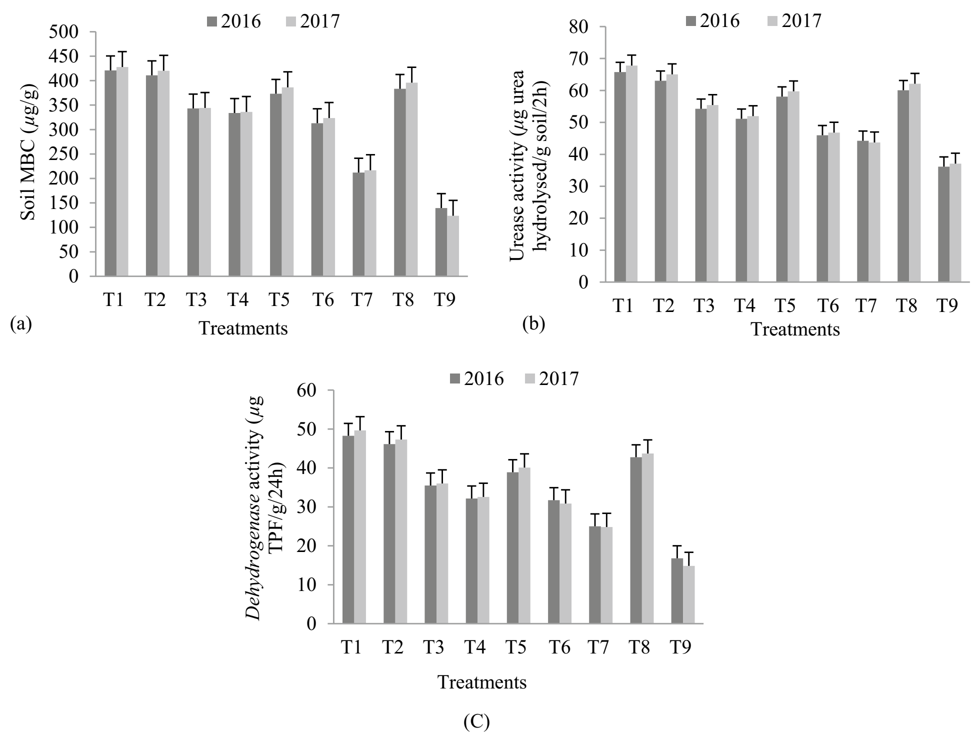


Fig. 1 Mean weekly meteorological parameters during growth period



specified in different treatments fifteen days before transplantation. The application of recommended doses of fertilizers (RDF: 90 kg N, 60 kg P_2O_5 and 60 kg K_2O ha^{-1}) for kale were given as basal application at the time of sowing.

Analytical details

Dried sewage sludge, aquatic weed compost and composite soil (collected from each plot at the depth of 1–15 cm before and after the crop harvest) samples were analysed for pH (Jackson 1973), soil texture (Piper 1966) and organic carbon (Walkley and Black 1934). Micro nutrients (Cu, Zn, Fe and Mn) and heavy metals (Cd and Pb) were analyzed by atomic absorption spectrophotometer (Jackson 1973) using di-acid digestion mixture (HNO_3:$HClO_4$, 4:1).

Ascorbic acid was determined using 2, 6 dichlorophenol indophenol dye. Dye factor was calculated by titrating 5 ml standard ascorbic acid plus 5 ml (3%) metaphosphoric acid against 2, 6 dichlorophenol till pink colour appeared and volume used was noted (Rangana 1986).

$$\text{Dye factor} = \frac{0.5}{\text{Titre value}}$$

Ascorbic acid was estimated by taking 10 ml of sample, volume made upto 100 ml with 3% metaphosphoric acid and filtered. The aliquot of 10 ml was taken in a titration flask and titrated against 2, 6 di-chlorophenol indophenol till pink colour appeared (which persists for 15 s). Ascorbic acid was calculated using the following formula,

$$\text{Ascorbic acid}\left(\text{mg } 100\,\text{g}^{-1}\right) = \frac{\text{Titre value} \times \text{Dye factor} \times \text{Volume made up}}{\text{ml of filtrate taken for estimation} \times \text{Weight of sample taken for estimation}} \times 100$$

Total nitrogen content of the samples was estimated by modified Kjeldahl's method (Jackson 1973). The sample was digested with sulphuric-salicylic acid. Organic and nitrate nitrogen is converted to ammonium sulphate and the ammonia gas is distilled into boric acid and titrated with standard sulphuric acid.

The total nitrogen was calculated by the following formula:

$$\text{N}(\%) = \frac{0.00007 \times \text{titration value} \times 100 \times 100}{\text{Aliquot taken(ml)} \times \text{wt. of sample(g)}}$$

Total phosphorus content was estimated by vanado-molybdate-phosphoric method after digestion in diacid mixture (HNO_3:$HClO_4$ in the ratio of 9:4). During digestion phosphorus is converted to orthophosphates. These orthophosphates reacts with molybdate and vanadate and give yellow coloured unreduced vanado-molybdo-phosphoric complex in acid solution (Jackson 1973). The absorbance of solution was read after 30 min at 420 nm on spectrophotometer on blue filter.

The absorbance was then plotted against concentration and the total phosphorus was calculated from the following formula:

$$\text{Phosphorus}(\%) = \frac{C}{\text{Wt. of sample}} \times \frac{100}{\text{Aliquot taken}} \times \frac{\text{Volume of digest}}{10000}$$

where C = Concentration obtained from standard curve (ppm).

Total potassium content in selected plant was estimated with the help of Flame photometer (Toth et al. 1948). The samples were digested in di-acid (HNO_3:$HClO_4$; 2:1). A series of standard solution of potassium (0.0, 5.0, 10.0 mg kg^{-1}) were prepared. The flame photometer was calibrated with solution of highest concentration (i.e. 10.0 mg kg^{-1}). Readings of other standards were then taken and curve was plotted. The samples were then read in flame photometer at 548 nm wavelength using potassium filter. The potassium content was calculated from the following formula:

$$\text{Potassium}(\%) = \frac{R \times U \times 50}{0.5 \times 10000}$$

where weight of plant sample = 0.5 g, total volume of plant digest = 50 ml, reading on flame photometer = R and potassium (ppm) as read from standard curve = U.

For estimation of soil *urease* activity 5 g of fresh soil sample was amended with 5 ml of urea solution and later incubated at 37 °C for 5 h. 50 ml of 2 M KCL-PMA solution and 30 ml of the colouring reagent were added. Total volume of sample was made 50 ml by adding water and later absorbance of red colour extract was determined by spectrophotometer at 527 nm. The amount of *urease* was computed from a calibration curve drawn under identical conditions (Bremner and Douglas 1971).

Soil *dehydrogenase* activity was determined by Tetrazolium salt method given by Klein et al. (1971). In this method 1 g of air dried soil was put in an air tight screw capped test tube. 0.2 ml of triphenyl tetrazolium chloride and 0.5 ml of glucose solution were added in the test tube. The tubes were sealed and incubated for 24 h at 28 °C in the dark and product triphenyl formazan (red colour) compound formed from the reduction of triphenyl tetrazolium chloride was extracted using methanol. Total volume of sample was made 10 ml by adding methanol. The triphenyl formazan concentration was determined by the spectrophotometric method at 485 nm.

The soil microbial biomass carbon (MCB) was determined by chloroform fumigation extraction method (Voroney et al. 1993). In the fumigation-extraction method, a direct measurement of carbon and other nutrients contained therein microbial biomass was carried out. Overnight fumigation with chloroform was carried out to kill all the organisms in soil samples. The microbial biomass constituents released by chloroform fumigation treatments can be extracted directly through chemical extract. MCB was measured in 10 ml of aliquots of K_2SO_4 extracts after oxidation with mixture of 2 ml of 0.2 N $K_2Cr_2O_7$, 10 ml of H_2SO_4 and 5 ml of ortho-phosphoric acid at 100 °C for 30 min. and back titrated with ferrous ammonium sulphate.

$$\text{Soil MCB}(\mu g/\text{gsoil}) = \frac{EC_f - EC_{uf}}{K_{ec}}$$

where EC_f is extractable carbon in the fumigated and non-fumigated (EC_{uf}) soil sample and $K_{ec} = 0.35$ represents the efficiency of extraction of organic carbon.

Plant micronutrients and heavy metals

The plant samples were digested in a di-acid mixture consisting of HNO_3 and $HClO_4$ to the known amount of plant material (1 g) 5 ml of conc. HNO_3 was added and kept overnight. Next day 12 ml of di-acid mixture (HNO_3:$HClO_4$, 3:1) was added and digested on hot plate. The digestion process begins with the evolution of reddish brown fumes (NO_2 gas) and the plant samples slowly start to dissolve and digested in a di-acid mixture. After few hours the plant samples dissolved completely in the digestion mixture and the solution was then evaporated until only 2 ml was left in the flask (Jackson 1973). The remaining digested material was diluted to 25 ml with distilled water and was then analyzed for the presence of heavy metals zinc, copper, manganese, iron, lead and cadmium by using atomic absorption spectrophotometer.

Statistical analysis

Data recorded during the experiment was subjected to statistical analysis using SPSS Version 18. The experimental results were subjected to ANOVA. The mean ± SE (standard error) were subjected to $P < 0.05$; Tukey's test at $\alpha = 0.05$.

Results and discussion

Nutrient characterization of of organic manures and non-amended soil

Table 2 shows the nutrient characterizations of SS, AWC and non-amended soil before crop transplantation. The SS and AWC used in this study were both acidic in nature and rich in SS and AWC. The concentrations of micronutrients and heavy metals in both SS and AWC were in the following order: Fe > Mn > Zn > Cu > Pb > Cd, whereas non-amended soil has the opposite trend: Fe > Mn > Cu > Zn > Pb, with cadmium concentration below detection level (BDL). Raw sewage sludge composition varies considerably and is primarily determined by the applied process technology, as well as the quantity and origin of raw wastewater. There is a high content of organic matter (up to 70%) in dehydrated sewage sludge, and its suitability for agricultural use is primarily determined by this content (Buta et al. 2021; Cheng et al. 2014; WWAP 2017), increasing soil fertility and promoting the development of plants and soil microbes (Samara et al. 2017; Tyrrell et al. 2019). The literature suggests that, in addition to the above advantages, sewage sludge also contains hazardous or potentially toxic heavy metals that impede its use in agriculture, as well as phyto-toxicity, soil pollution, and increase levels of toxic elements in food (Hussian et al. 2019; Iglesias et al. 2018).

During the study, we found micronutrients and heavy metal concentrations in sewage sludge used as organic amendments were very low, and far below the permissible

Table 2 Nutrient status of soil and organic manures before crop transplantation (means ± SD)

Particulars	Soil	Sewage sludge	Aquatic weed compost	Permissible limits*
Texture	Silty clay loam			
pH	7.22 ± 0.02	6.95 ± 0.03	6.79 ± 0.01	5.5–8.5
OC (%)	0.49 ± 0.23	4.89 ± 0.88	2.05 ± 0.45	NA***
Zn (ppm)	0.74 ± 0.03	15.87 ± 1.32	9.67 ± 0.98	1000
Cu (ppm)	1.04 ± 0.05	4.98 ± 0.77	2.03 ± 0.25	300
Fe (ppm)	21.89 ± 0.77	59.57 ± 1.30	47.34 ± 1.11	NA***
Mn (ppm)	5.33 ± 0.39	29.46 ± 0.69	19.45 ± 0.21	NA***
Cd (ppm)	BDL**	1.03 ± 0.05	0.57 ± 0.02	5.0
Pb (ppm)	0.69 ± 0.03	6.9 ± 0.59	3.4 ± 0.53	100

*CPCB (2005), **BDL below detection level, ***NA not available

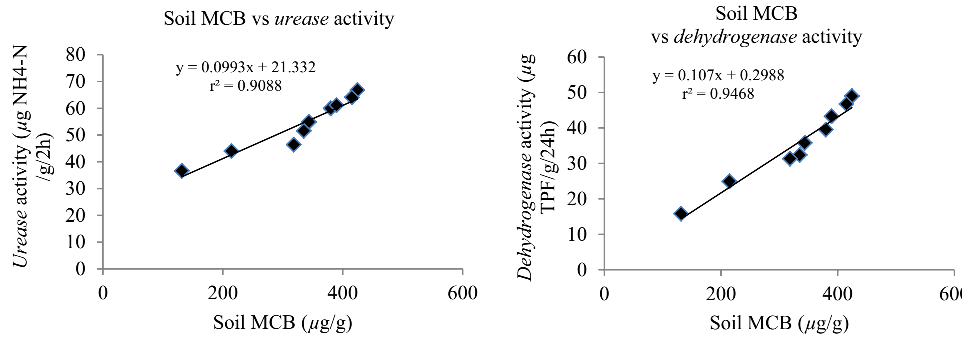


Fig. 2 **a–c** Soil MCB and enzyme activity under different amendment rates of SS, AWC and inorganic fertilizers during year 2016 and 2017 ($n=9$). Error bars represent the standard error of the mean with $P<0.05$; Tukey's test at $\alpha=0.05$)

levels. The non-amended soil was silty clay loam in texture and pH was neutral. Soil organic carbon and other nutrient concentrations were less in non-amended soils (Table 2). The results are in confirmatory with the finding of Qurashi (2012) who reported that nutrient concentration of initial soil before crop transplantation was very low and below the permissible limit. The experimental results as mentioned above indicated that soil before crop transplantation needs additional fertilizers for proper growth and development of crop.

Soil enzymatic activity and microbial biomass carbon

A critical perusal of the data presented in Fig. 2a regarding the soil MCB, it is evident that using SS combined with chemical fertilizer, resulted in the maximum buildup of soil MCB (μg/g) with treatment T_1 (421.06 ± 2.25 and 427.82 ± 1.24) followed by T_2 as compared to T_8. Increased microbial biomass carbon content recorded in the conjoint use of SS with chemical fertilizers could be attributed to the supply of additional mineralizable substratum and readily hydrolysable carbon for microbial growth and activity (Kunda et al. 2016; Dhaliwal et al. 2022). Soil microbial population behavior depends on the quality and quantity of residues added. Fernando et al. (2005) demonstrated that the highest rates of sewage sludge application resulted in a 220% increase in atmospheric CO_2 fluxes when compared to the controls.

We observed significant differences in *urease* and *dehydrogenase* activity in soil when SS, AWC, and inorganic fertilizers were applied. Moreover, all the combinations were statistically at par with each other treatments maximum *urease* (μg urea hydrolysed/g soil/2 h) and *dehydrogenase* (μg TPF/g/24 h) activity were recorded in T_1 (65.76 ± 0.25 and 67.80 ± 0.15) and (48.26 ± 1.15 and 49.66 ± 0.28) followed by treatment T_2 as compared to RDF (T_8), respectively (Fig. 2b, c). While as, treatment T_9 recorded lowest *urease* and *dehydrogenase* activities during 2016 and 2017. The increase in enzymatic activities may be attributed to the reason that addition of balanced application of organic and chemical fertilizers causes an increase in substrate thereby increases the diversity and activity of microorganisms accompanied by better *urease* and *dehydrogenase* activity (Lazcano et al. 2013).

The relation between soil MCB and urease activity yielded the linear regression equation: $y=0.0993x+21.332$ ($r^2=0.9088$; $P<0.05$), where $x=$ soil MCB and $y=$ *urease* activity. The linear regression equation between soil MCB and *dehydrogenase* activity was: $y=0.107x+0.2988$ $r^2=0.9468$; $P<0.05$), $x=$ soil MCB and $y=$ *dehydrogenase* activity Fig. 3. The *urease* and *dehydrogenase* activity values followed the same trend as the values obtained for soil MCB. There were significant correlations between soil MCB and from *urease* and *dehydrogenase* activity ($r^2=0.95$ and 0.97; $P<0.05$), respectively. As per previous findings, the enzyme activity was greater in forest soils compared to cultivated soils, and the availability of fresh soil organic matter (SOM) enhanced the microbial activity in forest soil and increased enzyme activity (De Medeiros et al. 2015; Meena and Rao 2021; Vinhal-Freitas et al. 2017).

Quality analysis of kale

Ascorbic acid is a major antioxidant agent in plants. It is involved in many enzymatic activities like hydroxylation of proline to hydroxyproline, cyclic oxidation reduction reactions and protects the plants against the harmful side-effects of heavy metals (Agar et al. 2020). The pooled data presented in Fig. 4a indicated that sole application of SS and AWC has a significant effect on ascorbic acid content. Among all treatments, maximum ascorbic acid content was recorded in treatment T_7 (122.47 ± 1.38) as compared to sole application of RDF (T_8; 106.18 ± 0.68). Lowest ascorbic acid content was recorded when no fertilizer amendments were carried out (T_9; 71.15 ± 0.27). This may be due to the fact that ascorbic acid, a natural antioxidant, may have scavenged the effect of free radicals generated by heavy metals (Alarmi et al. 2018). Furthermore, hydrophilic antioxidants, such as ascorbic acid (AsA), play an important role in scavenging reactive oxygen species (Sofy et al. 2020). According to our findings, Pb-stressed kale leaves contained

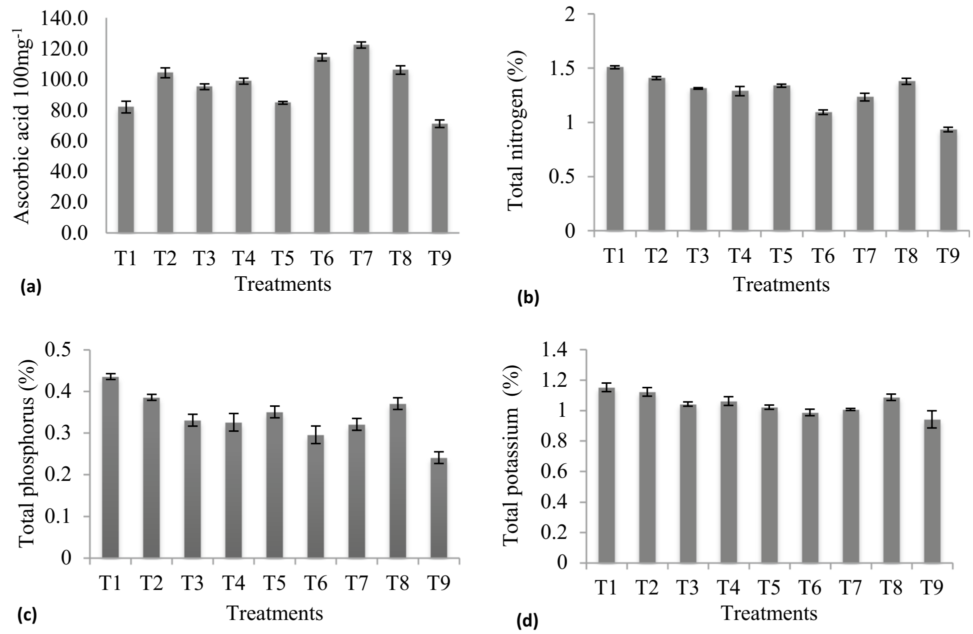


Fig. 3 Variation of *urease* and *dehydrogenase* activity with soil MCB among different amendment rates of SS, AWC and inorganic fertilizers

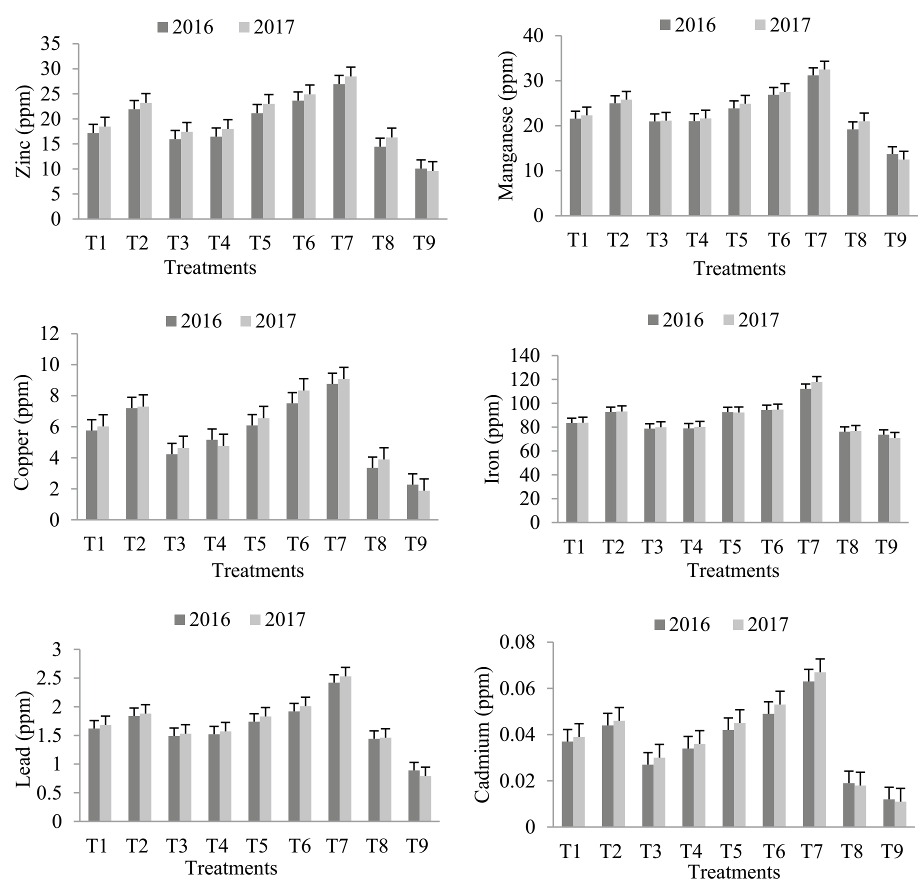


Fig. 4 a–d Soil enzyme activity and microbial biomass carbon under different amendment rates of SS, AWC and inorganic fertilizers ($n = 9$). Error bars represent the standard error of the mean with $P < 0.05$; Tukey's test at $\alpha = 0.05$)

significantly higher levels of ascorbic acid (AsA) than non-Pb-stressed leaves. Our results are in conformity with the finding of Akladious and Mohamed (2018).

The pooled data presented in Fig. 4b, c, d reveal significant variation with respect to total nitrogen (N), phosphorus (P) and potassium (K) content in kale crop. In treatment T_1, the highest concentrations of NPK were found (1.51 ± 0.01, 0.43 ± 0.01 and 1.15 ± 0.001) followed by treatment T_2 compared to T_8, respectively. The elevated levels of total NPK due to conjunctive use of organic manure with chemical fertilizers can be attributed to good carbon/nitrogen and carbon/phosphorus ratios, organic matter buildup, and leaching losses. Improved soil fertility might increase the ability of soil to absorb more nutrients.

Moreover, synergistic and stimulatory effects of organic amendments may result in a better root formation and enhanced photosynthetic activity of plants (Kariithi 2018; Sebnie et al. 2018). Wierzbowska et al. (2016) observed that elevated nitrogen and phosphorus levels encourage potassium uptake, and that mineralization and solubilization possibly facilitated their uptake. It could be related to the supply of nitrogen, phosphorus, and potassium, since the chemical fertilizers present a continuous supply of nutrients in the early stages of the crop and the slow and incessant release of nutrients from organic sources in the later stages of the crop. Our finding was also supported by Verma et al. (2021) who stated that application of sewage sludge along with recommended doses of NPK significantly enhanced the uptake of nitrogen, phosphorus, and potassium in wheat (*Triticum aestivum* L.) as compared to sewage sludge alone.

Micro-nutrients and heavy metals in kale

The data presented in Fig. 5 revealed that application of higher levels of SS and AWC recorded significantly elevated levels of Zn, Mn, Cu, Fe, Pb and Cd in kale. While comparing nine treatments significantly maximum Zn, Mn, Cu, Fe, Pb and Cd (ppm) concentrations were reported in 100% SS (26.94 ± 0.46 and 28.49 ± 0.16), (31.21 ± 0.48 and 32.50 ± 0.20), (8.75 ± 0.29 and 9.07 ± 0.06), (112.07 ± 0.50 and 117.78 ± 0.74), (2.42 ± 0.05 and 2.53 ± 0.03) and (0.063 ± 0.002, and 0.067 ± 0.006) as compared to unamended soil, respectively, during two successive years. The concentration of these metals in kale treated with different rates of SS and AWC were ranked in the following order: Fe > Mn > Zn > Cu > Pb > Cd. This was perhaps due to the fact that these metals in soil are present in different forms such as solid phases, free ions, and soluble organic mineral complexes. Hence, SS and AWC addition to soils could affect the availability of these metals as initial concentration of these metals was found high in both organic fertilizers (Belhaj et al. 2016; Rastetter and Gerhardt 2017). Our results are also in conformity with the finding of Eid et al. (2018) who stated that elevated levels of SS modified the chemical properties of soil, thus increased the bioavailability of heavy

Fig. 5 Showing the changes in the plant micro-nutrients and heavy metals with different amendment rates of SS, AWC and inorganic fertilizers ($n = 9$). Error bars represent the standard error of the mean with $P < 0.05$; Tukey's test at $\alpha = 0.05$)

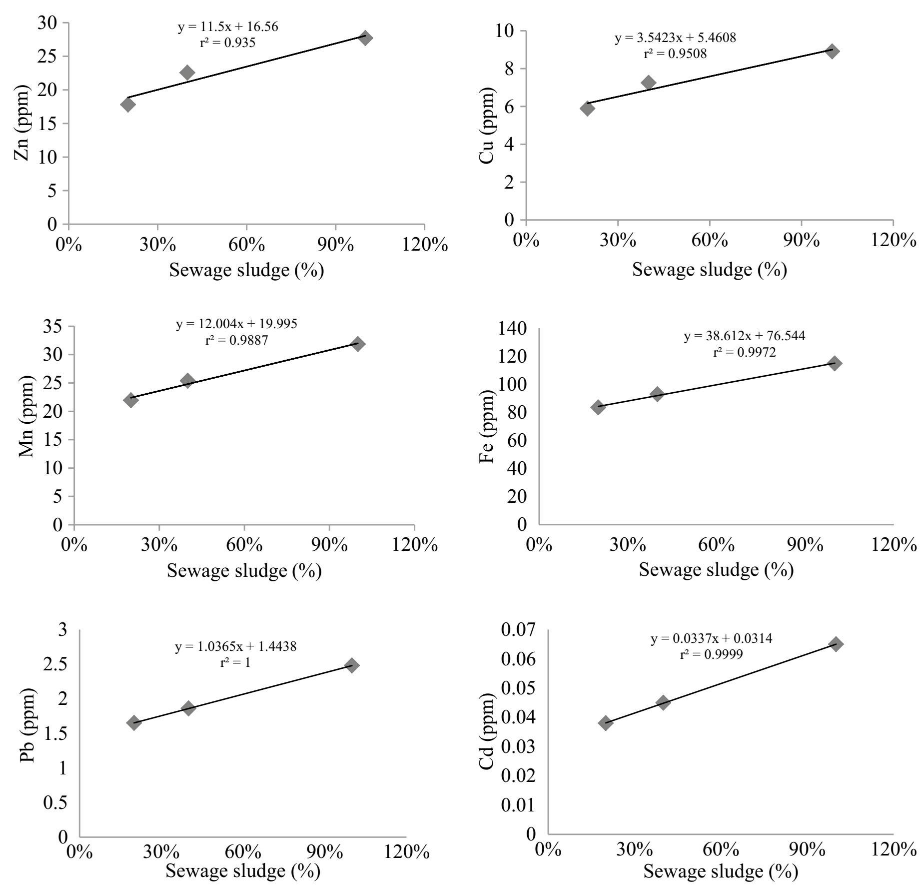


Fig. 6 Simple linear correlations and fitted lines between 20, 40 and 100% of sewage sludge dosage and concentrations of heavy metal fractions in *Brassica oleracea* (Kale) (i.e., $P < 0.05$)

metals in soil and subsequently a significant increase in most heavy metal in different tissues of wheat was observed.

Generally, in this study, the distribution of heavy metals in plant bound to the mobile fractions increased gradually over successive rates of sewage sludge (Fig. 5). Correlation coefficients (r) shown in Fig. 6 indicate high positive correlation between the metals and sewage sludge dosage, i.e., by increasing the proportion of sewage sludge from 20 to 40 to 100% with respect to RDF an increase in accumulation of metals were reported. Eid et al. (2017) reported that the application of sewage sludge to soil at a rate of 40 g kg^{-1} or less may be beneficial for spinach, soil health and avoid the risk to human health. At elevated sewage sludge rates (e.g., 50 g kg^{-1}) higher accumulation of heavy metals in crop is a serious concern for human health. Chopra et al. (2017) also reported that elevated levels of heavy metals, i.e., Cd (0.35 and 0.32 mg kg^{-1}), Cu (1.28 and 1.26 mg kg^{-1}), Fe (2.25 and 2.20 mg kg^{-1}), Mn (0.78 and 0.74 mg kg^{-1}) and Zn (2.14 and 2.05 mg kg^{-1}) in tomato (*Lycopersicon esculentum* L.) were recorded in sole application of sewage sludge (T_6). In the current study, concentrations of most of the heavy metal were below or within the permissible limits and did not exceed the maximum levels of phytotoxic at any of the SS amendment rates

Table 3 Permissible limits of heavy metals in sewage sludge, soil and plant

Parameters	Sewage sludge (mg kg^{-1} dry basis)	Soil (mg kg^{-1} dry basis)		Plant (mg kg^{-1} dry basis)	
	CPCB (2005)	Awashthi (2000)	USEPA (2010)	Awashthi (2000)	WHO/FAO (2007)
pH	5.5–8.5	–	–	–	–
Zinc	1000	300–600	200	50.0	60
Manganese	NA*	NA*	80	NA*	500
Iron	NA*	NA*	NA*	NA*	450
Copper	300	135–270	50	30.0	40
Cadmium	5.0	3–6	3	1.5	0.2
Chromium	50.0	NA*	NA*	NA*	5.0
Lead	100	250–500	300	2.5	5.0
Nickel	15.0	75–150	NA*	1.5	NA*

NA not available

(Table 3). Kabata-Pendias (2011) reported the concentrations of all of the monitored heavy metals in *C. olitorius* shoots (except Fe) did not reach the critical levels.

Conclusion

It is concluded that, among nine treatments under study T_1 (20% SS + 80% RDF) and T_2 (40% SS + 60% RDF) proved superior over rest of the treatments with respect to improvement in quality attributes, macro-nutrient uptake by plant and enzymatic activity of soil. The integrated use of inorganic fertilizers with SS at all levels was found to be better than integrated use of inorganic fertilizers with AWC in enhancing the yield and nutrient availability. Sole application of SS and AWC as fertilizers may have hazardous impact on soil/plant in terms of bioaccumulation of heavy metals as lead content in plant exceeds the critical toxicity level. In order to avoid their accumulation in the food chain, it is, however, recommended that agricultural products be routinely tested and processed for heavy metal levels. Utility of SS and AWC as organic manure will reduce the hazardous environmental impact caused due to their disposal.

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Declarations

Conflict of interest All the authors declared no conflict of interest.

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