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by Seema Mehmood

Compost and chemical fertilizer triggered pedospheric compartment's varied response and phyto-morphological alterations in *Helianthus annuus*

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Declarations

Conflicts of interest/Competing interests

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Consent to participate

All authors consent to participate in the manuscript publication

Consent for publication

All authors approved the manuscript to be published

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TT, SI, SN and SM drafted the experimental design and TT and SI performed the experiments. SN and SM wrote the manuscript. ARZG and DIF analyzed the data and edited the language of the manuscript to the present form.

ABSTRACT

Chemical fertilization of soils has been adopted as a productivity-boosting mode for many years but it is marked by excessive synthetic chemical utilization and significant persistence in the ecological matrices. Current research has for the first adopted a cost-effective, eco-friendly, and sustainable mode of soil fertilization and consequent growth augmentation of Helianthus annuus by utilization of kitchen waste and garden waste-based processed compost. Comparative analysis of the prepared compost with chemical fertilizer expressed a profound responsiveness of the soils towards compost in pot experiments conducted at Rawalpindi, Pakistan for assessment of soil quality after modification with compost. Soil amendments were varied including compost amended soil (CAS), di-ammonium phosphate amended soil (DAS), urea amended soil(UAS), and control soil (CS). Organic matter of CAS i.e. 4.67% and 4.91% and micro and macro nutrients excelled in other amendments signifying the potential of CAS to be adopted as a future green manure as an effective substitute to chemical fertilizers. Heavy metals i.e. Ni, Zn, Pb, and Cu concentration determination of soil treatments expressed a slightly higher trend but within permissible limits. *Helianthus annuus* grown in treated soils expressed outstanding phyto-morphological aspects in CAS and UAS. Composting as an organic fertilizer provides a cost-effective, ecologically friendly, and sustainable way to improve soil fertility. As a result, high-quality, reasonably priced compost will be produced, offering a practical and efficient waste disposal alternative.

Key Words: soil compartment; Helianthus annuus L.; green compost; organic matter; macro-elements; heavy metals

1. Introduction

Environmental pollution has been a global problem for many years. The most highlighted environmental problems are soil erosion, soil pollution, organic matter content reduction of soil, surface water and underground water resources pollution, etc. A decline in soil organic matter content has been observed at about 45% of the cultivation area of Europe. Southern Europe and other European areas such as France, Germany, and the UK are among the foremost victims of soil interrelated problems (Doan et al., 2015). Manna et al. (2005) reported the causes of soil organic matter depletion and loss of nitrogen, phosphorus, and sulfur in sub-humid zones of Australia. The ground cause of such declination is the unmanageable use of agricultural land by extensive cropping and nonstop cultivation. Sustainable land use practices can restore soil fertility and maintain the soils organic content such as the application of organic fertilizer over synthetic fertilizers and use of organic manure and reduction of tillage etc. In an urban environment, the improper disposal of abundant food waste is becoming a problematic issue. As well natural land and water resources are getting depleted due to enormous food production (Li et al., 2013; Pandey et al., 2016). In the US about 40% of food production goes to waste and this waste utilizes 50% of land and 80% of freshwater resource (Pandey et al., 2016). The use of organic waste for composting can be a better solution for avoiding waste in streams and landfill sites in urban areas (Beesley et al., 2014). EPA approved the composting process as an ideal waste management solution because of its potential to diminish the potent GHG emissions such as methane gas from landfills by switching the place of re-useable organic materials(Hasling, 2012).

Composting is an aerobic and anaerobic biological process of reducing the mass and volume of raw waste. It is an accelerated process of organic matter decomposition by indigenous microorganisms and its conversion into finally stabilized, humified, and sanitized products also known as compost (Fornes et al., 2012). Compost is an organic matter that can be produced by microbial bio-oxidation of putrescible food waste to make a safe, biologically stable, humified, hygiene and nutrient-rich end-products. It can also be produced via wastes of the agro-food industry(Beesley et al., 2014). Based on the natural decomposition process, composting can be classified into two types. In aerobic composting, microorganisms decomposes the organic matter into stable end product such as ammonia, carbon dioxide, heat, humus, and water. In anaerobic composting, anaerobic microorganisms decompose the organic matter into phytotoxic compounds (sludge-like material). It is considered to be less efficient for agriculture production than aerobic composting (Panda et al., 2003). Composting can be done in numerous ways with various raw materials. For example home or backward composting, bin composting or indoor composting, onsite or offsite composting, vermicomposting, aerated windrow composting, aerated static pile composting, in-vessel composting of food scraps or vegetable waste, yard waste, municipal soil waste, sewage sludge, livestock waste, paper and pulp and sludge etc. (Fornes et al., 2012; Joshi et al., 2013).

Different types of composting methods have been used by different states of the world. In Japan, the sewage sludge composting process has been practiced. In Singapore, food waste of 1,081,700 tons and sewage sludge of 50,100 tons has been disposed of annually. In last few years composting of piggery waste put into practice in China(Guo et al., 2012).In India, the aerobic bioreactor for vermicomposting biotechnology has been used to manage 320 million tons of annual production of agro-waste (Jadia and Fulekar, 2008). Composting also considered being the most ecological and economically feasible way to manage and mitigate the environmental issues in Pakistan (Ahmed et al., 2007; Batool and Chuadhry, 2009).In Lahore open composting of urban bio-waste has been practiced and the value of processed compost has expanded because of its widespread applications. In some parts of Pakistan potato waste or peels and lignocellulose waste are used as composting raw material. This research will provide a cost-effective, environmental friendly, and sustainable way to enhance soil fertility by using compost as an organic fertilizer. The study's main aim is to provide an efficient manageable waste-discarding method by producing economical and high-quality compost.

2. Material and methods

Table 1

2.2. Raw material collection for composting

Two main sources of raw material used to prepare a compost pile are garden and kitchen waste. Greens, which are nitrogen-rich materials such as plant clippings, grass clippings, weeds, and kitchen scraps, comprise one substrate for the compost pile. Browns, which are carbonaceous materials such as dried grass, dried fall leaves in the garden, straw, shredded newspaper, and cardboard pieces, are the other substrate. Bulking agents (BAs) included peanuts shells, newspapers, and cardboards were also mixed for providing air ventilation and inter-particle spaces. The quantities of raw substrates are given in Table 1. Soils were treated with different amendments to analyze their impacts, separately (Table 1).

Figure 1

2.3.Compost preparation

An ordinary plastic bucket (height: 38.1cm, diameter: 30.48cm) with holes was selected as a compost bin. Alternative layers of greens (3-4 inches) browns (1-2 inches) and soil (thin layer) were arranged in the compost bin. These layers were arranged alternatively until the bucket was quarter full as shown in Figure 1. The compost bin was placed in green greenhouse where aeration and sunlight were available. When the compost pile dried, there was a need to maintain the desired moisture. To do so, water was lightly sprinkled over the dried pile. Turning the compost two times a week was also necessary to create an environment favorable to the decomposition of organic matter facilitated by the activities of indigenous micro-organisms, as well as for adequate air ventilation.

2.4.Greenhouse pot experiment

The greenhouse experiment was conducted from 26 February until 25 May 2018 at Fatima Jinnah Women University, The Mall, Rawalpindi, Pakistan. The soil used for the experiment was the normal soil taken from Rawalpindi. *Helianthus annuus* seeds and chemical fertilizers were obtained from a local nursery near Fatima Jinnah Women University. Seeds were germinated in plastic pots having a diameter and length of about 29.21cm and 26.67cm respectively. About eight kg of soil was filled in each pot, and 12 seeds were sown in each plastic pot. Before the germination of seeds different types of amendment were done as mentioned in Table 1. The plants were allowed for growth in greenhouse conditions for 89 days. After every 15 days the plant height, number of flowers, and number of leaves were recorded. For each batch of experiment, three replicates were used. A total of 12 plastic pots were used for the experiment.

2.5.Physiochemical analysis of compost

For analysis, about 500g of the compost was dried using the open air grounding. Then a sieve of <1mm was used to sieve through. The compost sample (1:10 compost-water solution) was tested for pH by using the HANNA pH meter, while EC and TDS of compost sample (1:5 compost-water solution) were determined by using Crison MM 40$^+$. The moisture content, organic matter content, and C: N were analyzed. Walkley-Black method was used to analyze the percentage of total organic carbon content. The total nitrogen was determined by the Kjeldahl nitrogen method. To find out the total Ca, P, K, and Mg content in a dry compost sample, aqua-regia treatment was employed. Furthermore, to measure the heavy metal concentration of the sample, nitric-perchloric acid digestion method was utilized. Finally, for the analysis of the heavy metals, Atomic absorption spectrophotometer (AA-7000) was utilized.

Soil characterization

To assess the physico-chemical characteristics of the soil, 200 g of air-dried, ground, and 2 mm sieved soil samples were collected (Akhtar and Iram, 2016). Several parameters such as texture, EC ,moisture content, TDS, nitrogen, organic matter, phosphorus, pH, and potassium concentrations were determined using techniques outlined by Estefan et al. (2013). Calcium, Magnesium, and Heavy metals in soil samples were determined by the di-acid digestion method(Iram et al., 2013).

2.6.Morphological analysis of Helianthus annuus plants

For the assessment of morphological parameters of *Helianthus annuus* plants harvesting was done after three months of germination. Plants' physical characteristics such as length of shoot and root, the width of the shoot, and dry and fresh weights of leaves were determined(Zahid, 2015; Akhtar and Iram, 2016).

2.7.Data statistical analysis

Microsoft Excel software was used to analyze the data of soil, kitchen waste compost, and plant parameters. The mean and standard deviation of triplicate measurements were calculated using the software.

3. Results and discussions

3.1. Comparative analysis for modified and unmodified soils

3.1.1. Physical and chemical profile

Table 2, Figure 2

The cost-effective and pollution-free composting process turn out a high-value organic fertilizer that enhance plant life, growth, and productivity and also provides stability to soil structure by supplying nutrients. In the present research the finished compost (about 4300g) expressed a commendable fertilization of soil in comparison to the synthetic fertilizer-modified soil.The average values of all parameters of mature compost along with different permissible limits are given in Table 2.Figure 2 exhibits the variation in the physicochemical characteristics when treated with different amendments. In the current research the soil texture was clay loam and textural values were 35% clay, 27% sand, 25% silt and 13% gravel. In CAS, the highest percentage of moisture content was registered among all the other soil samples amended with chemical fertilizer and the control sample. The increased water content in the compost-amended soil samples could be attributed to the high amount of compost present in the soil. Previous research has determined that an ideal moisture level for compost is between 40% and 60%, as stated by Diallo et al. (2017). The moisture content for the compost used in this study was recorded to be 50%. The high moisture content values found in soils treated with compost and chemical fertilizer were attributed to reduced soil compressibility and increased aggregate stability. Contrastingly, the lower moisture content of other fertilizer-treated soils as well as control samples was explained by the decreased water availability and reduced water holding capacity (Edwards et al., 2000; Cooperband et al., 2002).

As per the present study, the pH of mature compost was 7.9. Comparatively to the unaltered control condition, the pH of the soil dropped when chemical fertilizers and compost were used. The pH was further reduced post-harvesting, due to the utilization of organic material. This was attributed to the production of organic acids resulting from mineralization and nitrification processes. During the growth period, NH_{4+} was taken up by the plants and released H^+ ions in return, contributing to a decrease in soil pH (Han et al., 2016). The values for electrical conductivity (EC) and total dissolved solids (TDS) increased in all amended soil samples, except for the control. This was a common phenomenon observed due to the formation of organic acids during decomposition of organic material. It is important to note that the critical limit of EC should not exceed 4.0 dSm^{-1}as per literature. In treated soil pots, TDS was also seen to be significantly higher due to an increase in salt concentrations.

When compost was added to the soil, it showed a higher content of organic matter than in other treatments with chemical fertilizer or no amendments. Previous studies have noticed that mature compost typically has an organic matter fraction ranging between 25%-56%, while municipal solid waste compost, comprised primarily of kitchen refuse, can contain up to 40% organic material (Herrera et al., 2008). The addition of both organic material and chemical fertilizer caused a rise in soil microbial activity, due to the provision of a nutrient-rich source. This increase in soil fertility was reflected as an improvement in overall organic matter content. The microbial life in the soil was further promoted by this amendment.

Figure 3

3.2.Soils' nutritional profile-macronutrients

In a previous study, there was an increased concentration of macro nutrients (nitrogen, potassium, and phosphorus) in compost amended soils compared to other soils treated with fertilizer and control soils (Figure 3). According to the literature, the range of approximate values of nitrogen, phosphorus and potassium found in organic amendments (compost) were 8-18 g/kg, 0.5-4.25 g/kg and 3.37-12.63 g/kg, respectively (Celik et al., 2004; Pathak et al., 2012). In this study, nitrogen concentration in all cases was higher due to the application of organic materials and chemical fertilizers leading to conversion from organic to inorganic forms as well as an increase in the number of indigenously soil microbes present. Therefore it caused increase in available nitrogen content. For P and K, the concentration was higher in all amended soils except for control soil samples. The amended soils had a higher quantity of phosphorus due to compost, DAP and urea fertilizer added. Only a small quantity of macro nutrients utilized by the plants remaining were left in soil that's why their concentration also remained higher after harvesting (Han et al., 2016).

3.3.Soils' nutritional profile-micronutrients

For this test, the average calcium and magnesium concentrations in samples amended with compost, fertilizer and the control were found to be notably high. The values for both micronutrients ranged from 6.97 to 2.23 g/kg for calcium and 2.54 to 1.37 g/kg for magnesium, respectively. Compost was established as a nutrient-rich resource, with 10.92 g/kg of calcium and 4.33 g/kg of magnesium detected in the prepared material. Studies conducted by previous investigators have also indicated the presence of higher levels of these micronutrients in organic amendments and compost (Pandey et al., 2016; Diallo et al., 2017).

Table 3, Figure 4

3.4.Heavy metal characterization

Heavy metal analysis of soils have been depicted in Table 3 and Figure 4. The heavy metals concentration of in all soil samples (Compost, DAP, Urea amended and control soil) are under the maximum permissible limits of European Union (EU)(Bhatti et al., 2016). In case of cadmium, the maximum average concentration was observed in control sample. About 0.2to10mg/kg cadmium concentration was noticed in municipal solid waste and homemade compost. It was also reported that the organic amendment decreased the concentration of cadmium and some amendments also increased the cadmium concentrations of soil. This difference was due to the various types of raw substrates used to make compost (Herrera et al., 2008; Bozym, 2017).In this study,0.96mg/kg cadmium concentration in mature compost was observed and this value was under the allowable Canadian, European Limits and German standards for final compost(Brinton, 2000; Ahmed et al., 2007). The nickel maximum concentration was found in compost amended soil samples as compare to others. About 12.8 to 44mg/kg nickel concentration was observed in different literatures (Herrera et al., 2008; Achiba et al., 2009; Bozym, 2017).

In this study, nickel concentration decreased from initial to post-harvest stage due to the formation of metal complexes in soil. The reason was discussed in previous studies some heavy metals form chelates with organic constituents of soil organic matter. Basically soil has strong affinity towards metals and provides cation-exchange sites to metals therefore metal complexes are formed in soil medium. As a good source of zinc, compost was found to contain varying concentrations in different studies. As per previous research, leaves compost, kitchen waste compost, and municipal solid waste compost concentrations of zinc ranged from 15 mg/kg to 126mg/kg (Pathak et al., 2012). Additionally, it was determined that pH affected 1 the minimum concentration of zinc in control sample as compared to compost amended soil samples. As such, researchers have highlighted that soil pH is an important factor in controlling zinc availability 36 (Angelova et al., 2013).

The average lead concentration was seen higher in compost amended soil. As stated by 12 Achiba et al. (2009) the application of compost in any type of soil increased the some 29 heavy metals concentration such as increase in lead, nickel and cadmium concentration was observed. The maximum chromium concentration was observed in compost amended soil sample. In current research 6.69mg/kg of chromium concentration in mature compost was noticed. Numerous researchers observed the various concentration of chromium in mature compost. About 7.8 to 25mg/kg cadmium concentration was noticed in different compost (Bozym, 2017). There was an increase in 24 the concentration of Cu observed in compost amended soil samples, as compared to other samples. This could be attributed to 25 the application of organic amendments which have been shown to increase both nutrient quantity and heavy metal concentrations in soil (Achiba et al., 2009).

Table 4, Figure 5, 6

3.5.Phyto-morphological alterations

The height of plant, number of leaves and number of flowers were observed after every 15 days to check the growth rate differences among compost amended, fertilizer amended and control soil sample (Table 4, Figure 5, 6).All experiment results showed that the fertility status of compost amended soil was better than control sample. Maximum height of plant was recorded in compost amended soil samples which was about 139.52 cm (Table 4). On the hand urea treatment pots were also showed a better yield. Similarly other results (stem width, root length and flower count) were also remained higher in compost treated soils and chemical fertilizer treated soil as compare to control soil samples. The maximum plant height was seen in plots amended with bio-fertilizers due to their ability to produce growth regulating substances as well as an improved microclimate. As per other studies, a higher fertility rate was noticed in compost amended plots when compared to the control pots (Cooperband et al., 2002).

Amendment of bio compost were increased the yield of many vegetables like chilies, potatoes and red amaranth. The highest nutrient concentration and organic matter content of compost make it an ideal medium for the growth of numerous plant species. Therefore, composting biodegradable waste is a cost-effective and environmentally friendly way to recycle it.

4. Conclusion

The best and most practical approach to handle any kind of organic waste is to compost it, and the finished product has excellent physiochemical qualities. Comparing soils modified with compost to those amended with chemical fertilizers produced favorable outcomes. In essence, it was able to supply all nutrients (micro and macro) necessary for efficient plant growth, and the concentration of heavy metals was likewise within desired bounds. The morphological characteristics of the plant changed noticeably with the addition of compost, chemical fertilizer, and control soil. Because it may greatly reduce the volume of recyclable garbage and transform it into a cost-effective, environmentally beneficial, hygienic, and toxic-free product, this practice can be seen as an advantageous recycling tool.

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Figures Captions

Figure 1 Diagrammatic representation of step wise preparation of compost for soil modification

Figure 2 Variations in the physicochemical parameters i.e. texture, moisture, pH, EC, TDS and OM of the soils treated with different modifiers when they were tested before sowing and at early plantation stage

Figure 3 Concentration estimation in soils amended with different modifiers for Nitrogen, Phosphorus, Potassium calcium and magnesium in g/kg

Figure 4 Modified soil samples estimation of different heavy metals

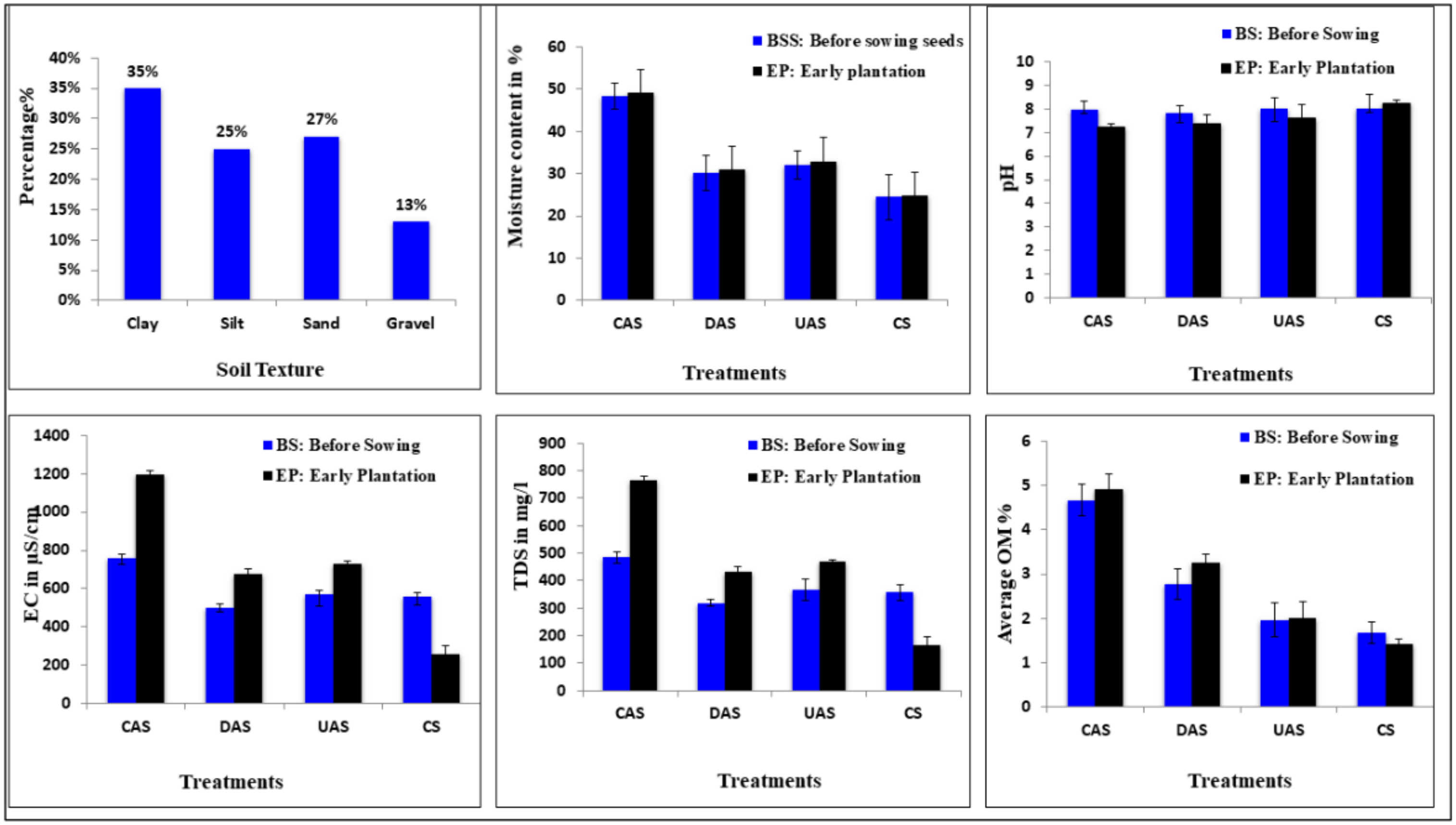
Figure 5 Comparative influence of different soil treatments on the phyto-morphological aspects of sunflower

Figure 6 Growth of *Helianthus annuus* after every 15 days in soils amended with the prepared compost


Step by step compost preparation
Mature compost after
53 days

8
Figure 1

1


Percentage%
40%
35%
30%
25%
20%
15%
10%
5%
0%
35%
25%
27%
13%
Clay
Silt
Sand
Gravel
Soil Texture
Moisture content in %
BSS: Before sowing seeds
EP: Early plantation
60
50
40
30
20
10
0
CAS
DAS
UAS
CS
Treatments
pH
BS: Before Sowing
EP: Early Plantation
10
9
8
7
6
5
4
3
2
1
0
CAS
DAS
UAS
CS
Treatments
EC in µS/cm
BS: Before Sowing
EP: Early Plantation
1400
1200
1000
800
600
400
200
0
CAS
DAS
UAS
CS
Treatments
TDS in mg/l
BS: Before Sowing
EP: Early Plantation
900
800
700
600
500
400
300
200
100
0
CAS
DAS
UAS
CS
Treatments
Average OM %
BS: Before Sowing
EP: Early Plantation
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5
4
3
2
1
0
CAS
DAS
UAS
CS
Treatments

Figure 2

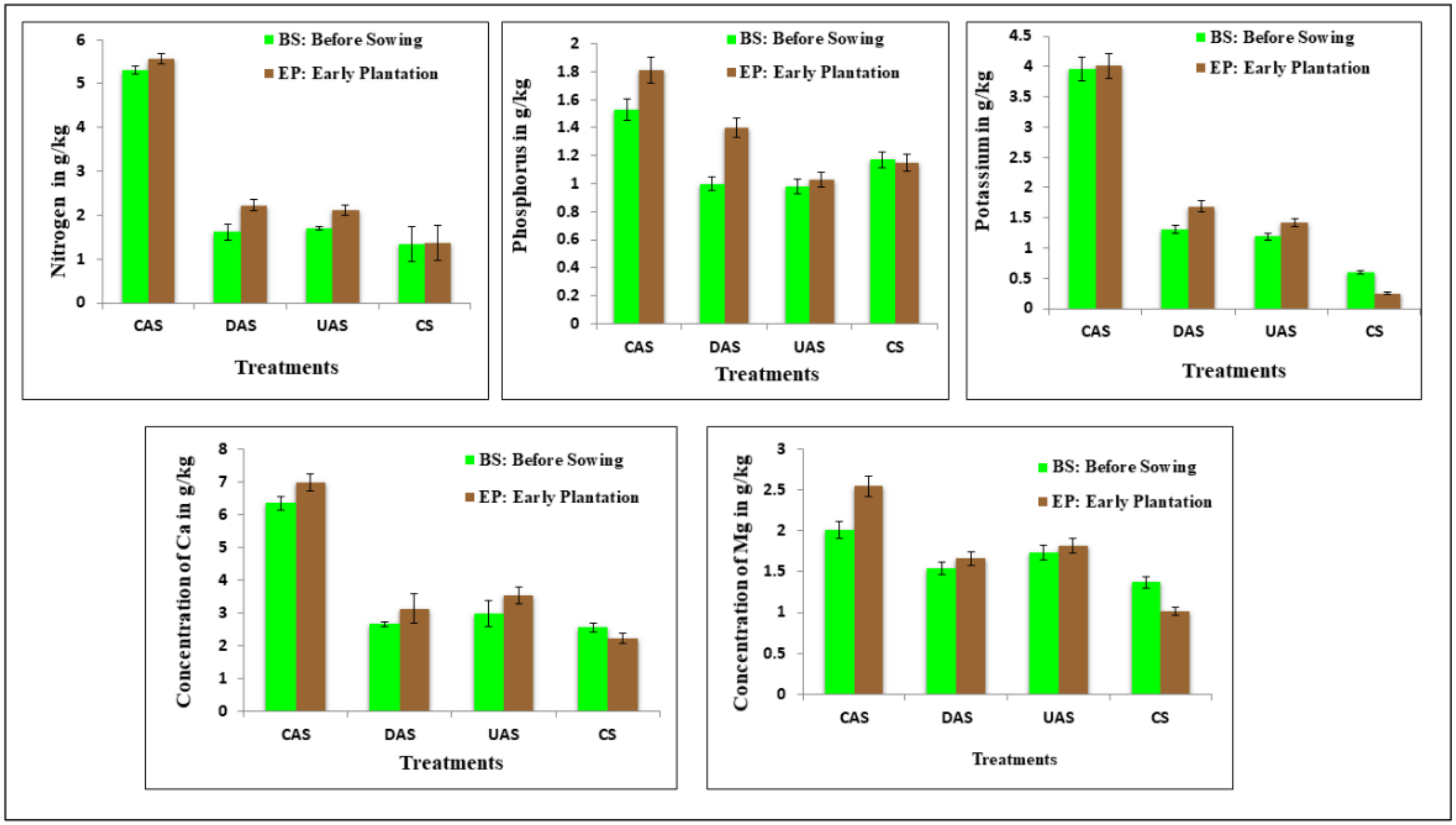
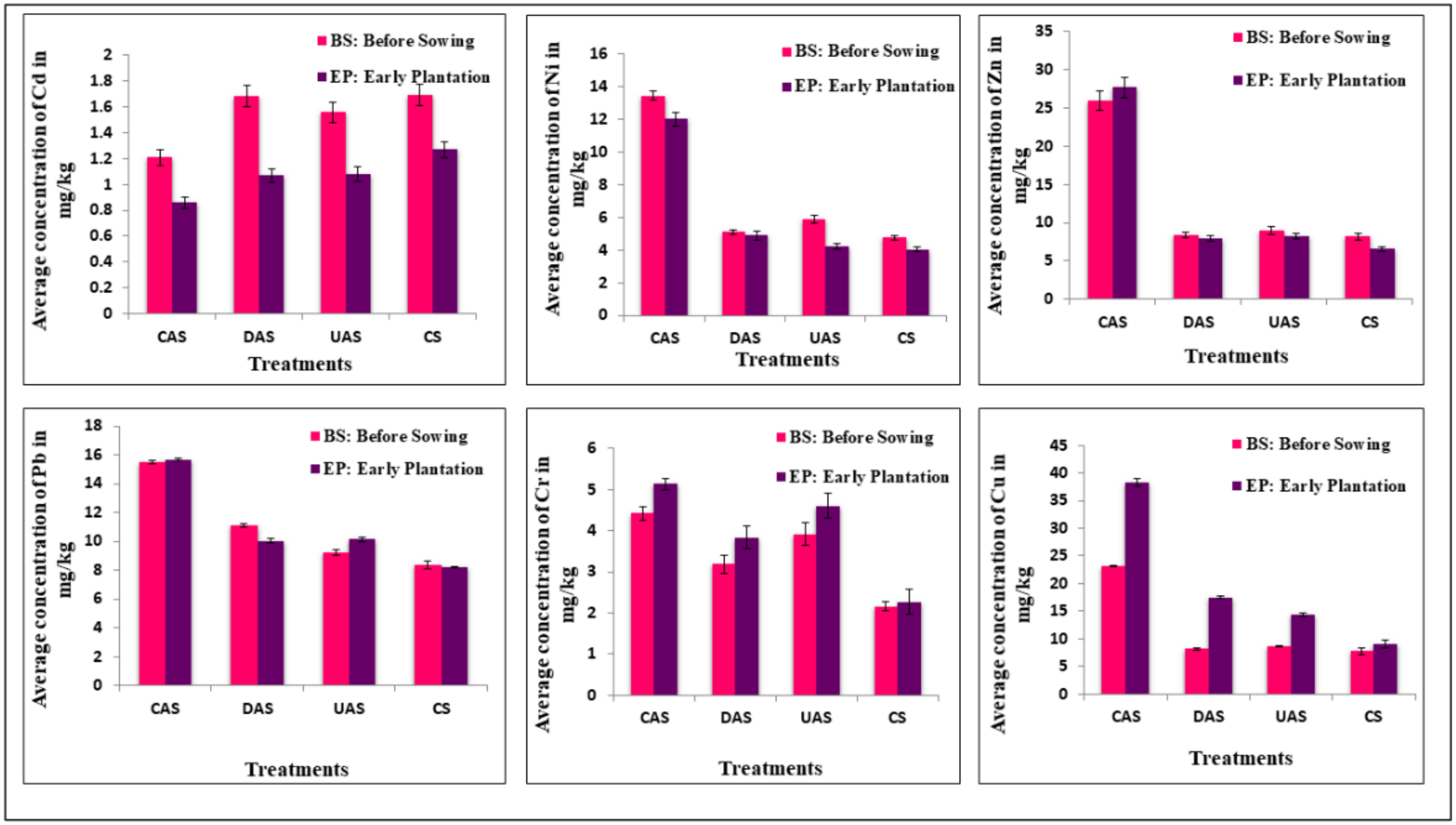

Nitrogen in g/kg
BS: Before Sowing
EP: Early Plantation
CAS
DAS
UAS
CS
Treatments
Phosphorus in g/kg
BS: Before Sowing
EP: Early Plantation
Treatments
Potassium in g/kg
BS: Before Sowing
EP: Early Plantation
Treatments
Concentration of Ca in g/kg
BS: Before Sowing
EP: Early Plantation
Treatments
Concentration of Mg in g/kg
BS: Before Sowing
EP: Early Plantation
Treatments

Figure 3



Average concentration of Cd in mg/kg
BS: Before Sowing
EP: Early Plantation
CAS
DAS
UAS
CS
Treatments
Average concentration of Ni in mg/kg
Average concentration of Zn in mg/kg
Average concentration of Pb in mg/kg
Average concentration of Cr in mg/kg
Average concentration of Cu in mg/kg

Figure 4

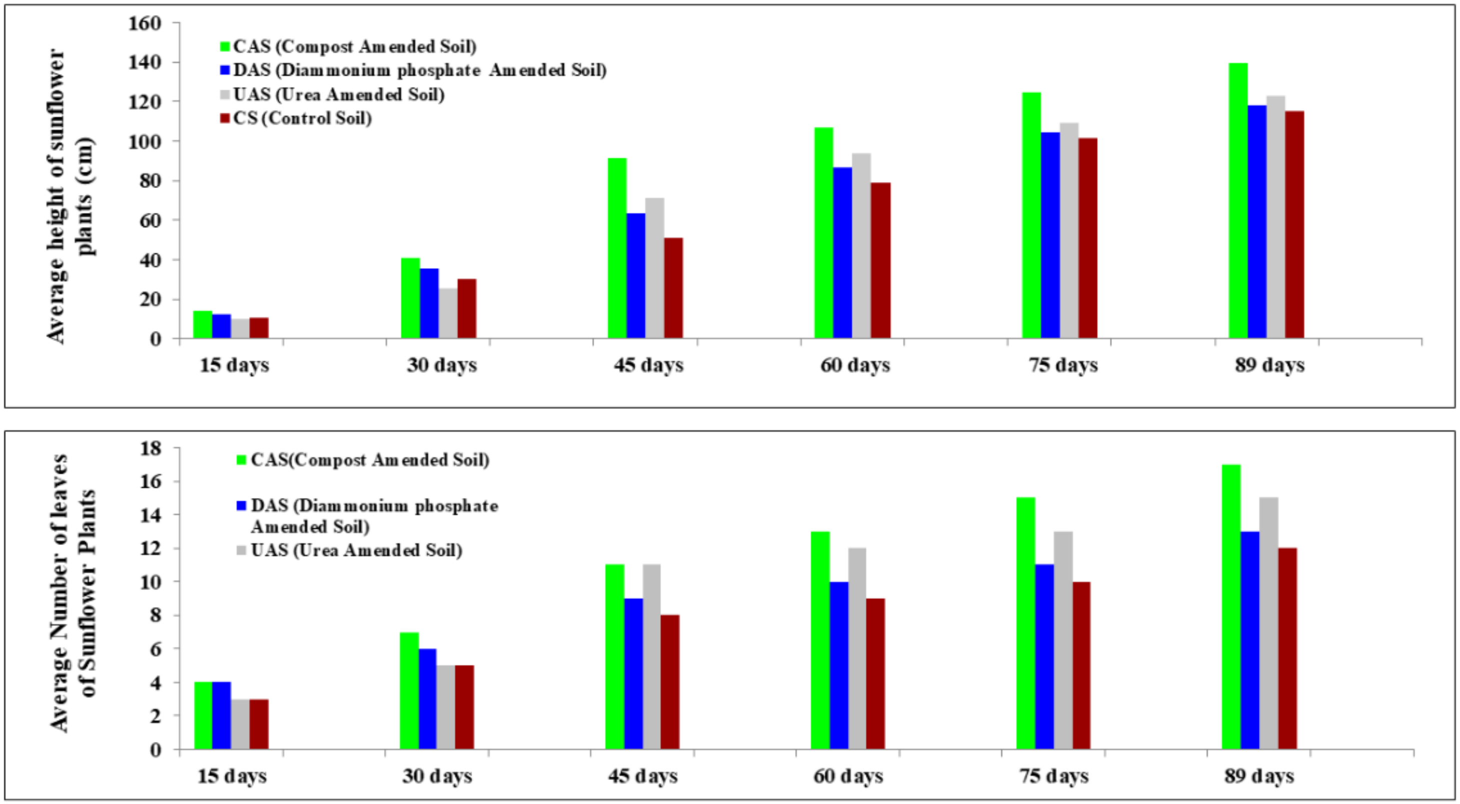

Average height of sunflower plants (cm)
160
140
120
100
80
60
40
20
0
CAS (Compost Amended Soil)
DAS (Diammonium phosphate Amended Soil)
UAS (Urea Amended Soil)
CS (Control Soil)
15 days
30 days
45 days
60 days
75 days
89 days
Average Number of leaves of Sunflower Plants
18
16
14
12
10
8
6
4
2
0
CAS(Compost Amended Soil)
DAS (Diammonium phosphate Amended Soil)
UAS (Urea Amended Soil)
15 days
30 days
45 days
60 days
75 days
89 days

Figure 5

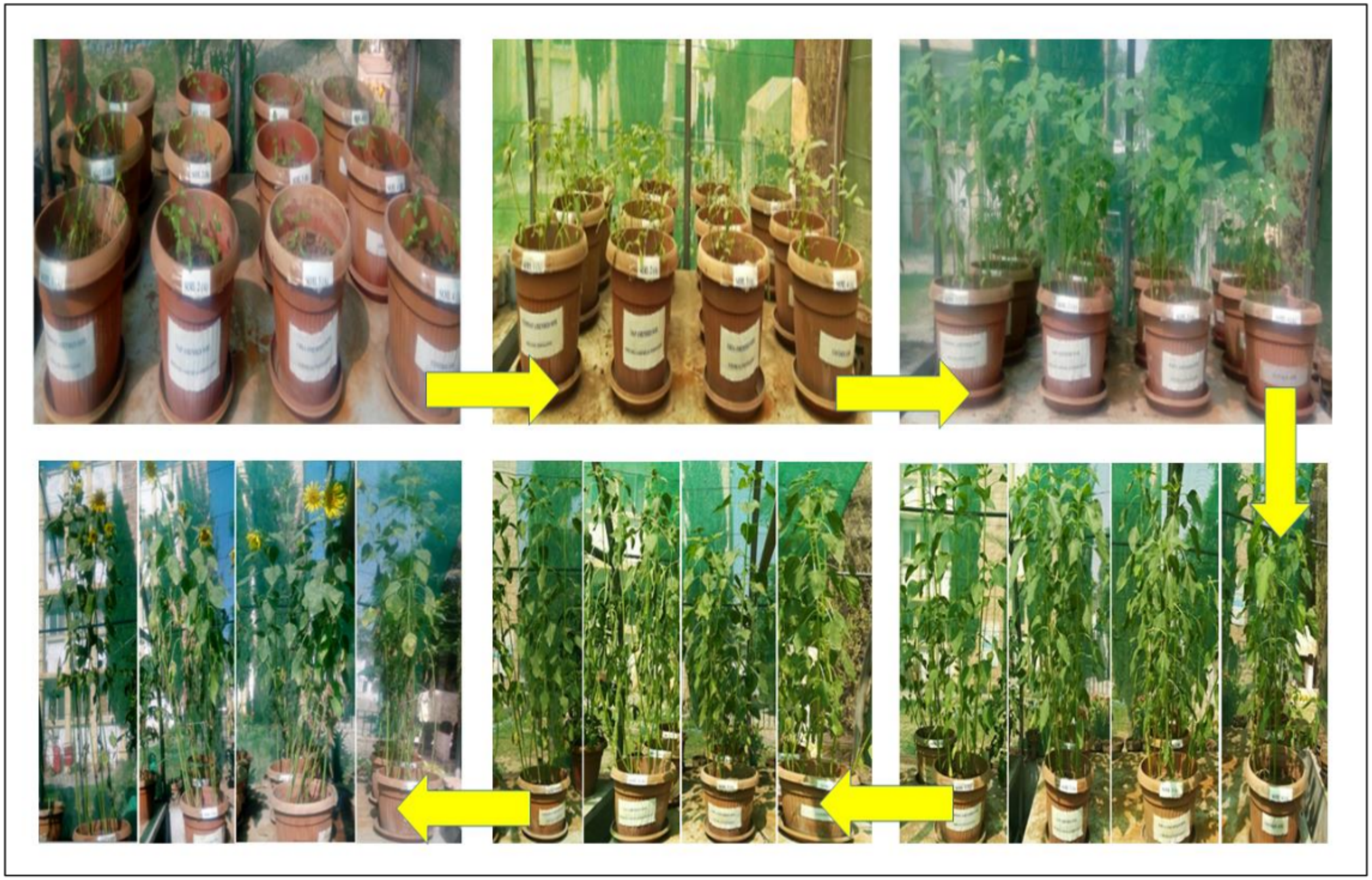


Figure 6

33

3

Table 1 Quantification of the raw materials used for the preparation of compost preparation aimed at soil amendment and the treatments of the selected soils with different substances

Constituents of prepared compost		
	Raw material	Quantity (g)
Greens	Vegetable peels	1450
	Used tea	200
	Grass clippings	100
	Egg shells	250
Browns	Dry leaves	270
	Shredded newspaper	30
	Cardboard pieces	100
Soil added		600
Total weight of raw material		3000
Soil treatments		
Soil-1	Compost amended soil (CAS)	3800 g of the prepared compost in each replicate
Soil-2	Diammonium phosphate amended soil (DAS)	10 g of $(NH_4)_2HPO_4$ fertilizer in each replicate
Soil-3	Urea Amended Soil (UAS)	2.5 g urea in each replicate
Soil-4	Control Soil (CS)	No modifiers applied

Table 2 Comparison of nutrient content of prepared compost with FAO standards and International agricultural soil standards

Parameters	**Compost**	**FAO standards for finished compost**	**International agricultural soil standards**
pH	7.9	5-8	4-8.5
EC (ds/m)	1.388	NGVS	4
TDS (mg/l)	888	NGVS	2564
MC(%)	50	45-60	NGVS
OM (%)	30	>20	>0.86
N (%)	1.2	1-2	NGVS
TOC (%)	24	20-35	NGVS
C/N ratio	20	15-35	NGVS
P (g/kg)	2.5	1-10	>7
K (g/kg)	9.8	3-10	>80
Ca (g/kg)	10.92	NGVS	7-500
Mg (g/kg)	4.33	NGVS	0.02-10

(NGVS= No guide line value set, OM= Organic matter, TOC = Total organic carbon, MC = moisture content)

Table 3 Comparison of heavy metal concentration of the prepared compost with different allowable limits of compost and soils

Heavy metals (mg/kg)	Prepared compost	Allowable Canadian limits for final compost[a]	Allowable European limits for finished compost[b]	German standards for mature compost[c]	European Union Maximum permissible limits for soil[d]

Cd	0.96	3	3	3	3
Ni	24.67	NGVS	110	50	NGVS
Zn	43.64	500	300	500	300
Cr	6.69	210	NGVS	150	150
Pb	25.50	150	300	150	300
Cu	36.56	100	200	150	100

(NGVS: No guide line value set, a: Ahmed et al., 2007, b: Lakhdaret al., 2009, c:Brinton, 2000, d: Bhattiet al., 2016).

Table 4 Comparative enhancement in the morphological parameters of *Helianthus annuus* grown in prepared compost amended soils and other soils

Phytomorphological parameters				
S. No.	Treatments	Plant height (cm)	Stem width (cm)	Root length (cm)
1.	Pot 1 (CAS)	139.52	3.87	11.00
2.	Pot 2 (DAS)	118.19	3.18	10.42
3.	Pot 3 (UAS)	122.92	3.40	10.58
4.	Pot 4 (CS)	115.11	3.13	9.73
Fresh, dry weight and floral pattern of *Helianthus annuus*				
S. No.	Treatments	Weight of fresh leaves (g)	Weight of dry leaves (g)	No of flowers
1.	Pot 1 (CAS)	9.64	2.49	4
2.	Pot 2 (DAS)	9.13	2.24	3
3.	Pot 3(UAS)	11.60	2.71	3
4.	Pot 4(CS)	8.53	2.17	2

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