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Effects of Sewage Sludge Biochar (Sewchar) Application on Nutrient Uptake and Yield of African Marigold

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The study was conducted in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, Thiruvananthapuram, India to evaluate the effect of sewage sludge (SS), sewage sludge compost (SSC) and sewage sludge biochar (sewchar, SC) on plant growth and productivity. Comparative studies showing the effect of sewage sludge, sewage sludge compost and its biochar on plant growth and productivity are limited. Sewage sludge, sawdust, zeolite

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(50:30:20) and 2.5 kg of flyash were combined and composted for 60 days to prepare sewage sludge compost. Sewchar was prepared through the process of slow pyrolysis at a temperature of 400℃ for 2 hours. A field experiment was conducted to using marigold as a test crop. Experimental results showed that conversion of sewage sludge to sewchar causes the enrichment of nutrients in them. Field experiment revealed that maximum N, P, K content, uptake and yield parameters such as flower diameter (9.35 cm), flower weight (9.21 g) and number of flowers per plant (98) was recorded with sewchar received treatments compared to other treatments. Gradual release of nutrients from sewchar is important in maintaining the soil fertility and boosting the plant growth parameters and productivity.

Keywords: Biochar; marigold; sewage sludge; sewage sludge compost; sewchar.

1. INTRODUCTION

The amount of solid waste from the community produced per person has increased due to rapid urbanisation, industrialisation and economic expansion, placing a strain on the capabilities of the current waste management system. India generates 160038.9 tonnes per day (TPD) of solid waste daily, of which 152749.5 TPD are effectively collected at a rate of 95.4 %. Of this, 50 % is treated, 18 % is dumped in a landfill, and 37 % is not recorded [1]. Kerala generates 3543 TPD of solid waste in total, of which 2550 TPD are treated [2].

Sewage sludge or solid waste, is an unavoidable product of treating municipal waste water. Because of its growing volume and the problems involved with its disposal, sewage sludge is a major problem in many countries since it contains a range of hazardous organic compounds, bacteria and potentially hazardous metals, its safe disposal is a major responsibility [3]. Among the typical sludge management techniques most commonly employed are land application, land filling and incineration. Because of its high operating costs and poor public approval, incineration is not utilised very often.

About 30-60 % of the organic matter, 1.5-4.5 % nitrogen, 1.0-2.2 % phosphorus and minerals such microcline, quartz, calcite and heavy metals are present in sewage sludge [4]. When applied to agricultural land, it increases crop productivity and soil fertility while also improving the physical characteristics of the soil, such as porosity, infiltration rate, aggregate formation and stability and it decreases bulk density, surface runoff and water erosion [5]. Its application in agricultural production is being restricted by the existence heavy metals. Inadequate sludge application can alter the qualities of the soil because of the higher concentrations of pathogens, heavy metals and toxic components. Growing food crops with the sludge requires stabilising the heavy metal and lowering its bioavailability.

Pyrolysis is a major practical approach for the long-term sustainable handling of sewage sludge. Biochar is a solid product of pyrolysis with a high carbon content that is produced by the thermochemical conversion of biomass in an oxygen-free environment [6]. Pyrolysis decreases the amount of sludge gets rid of any viruses or parasites, turns organic materials into bioenergy and immobilises metals in a leftover carbonaceous solid material called sewchar that has been burned and left behind. Sewchar makes the soil more stable and recalcitrant because the pyrogenic carbon compounds present in this carbonaceous product stay in the soil for a longer amount of time. The pyrogenic carbon also affects the quality of the soil's organic matter and can reduce its susceptibility to losses brought on by insufficient management techniques. Sewchar is a stable, high-carbon material that can fix carbon during preparation and storage to keep carbon out of the environment. This improves soil carbon sink and lowers soil emissions of carbon dioxide and methane [7].

Biochar made from sewage sludge can fix heavy metals found in soil. Applying sewchar can also enhance nutrient uptake, boost crop development and lessen the amount of exchangeable heavy metals and their biological consequences. Pyrolysis can dramatically alter the weakly bound forms of metals in sewage sludge to more stable states (in oxidisable and residual forms), lowering the environmental risk connected to the land application of sludge biochars [8]. Energy efficiency and reduced heavy metal pollution at temperatures below 600°C are benefits of using pyrolysis of sewage sludge rather than incineration at high temperatures between 300°C and 1000 °C.

Most of the studies on sewage sludge biochar is based on the agronomic performance, carbon sequestration and green house gas emissions. Only a little research were focussed on the impact of sewage sludge biochar on soil properties, plant growth parameters and nutrient uptake. Eventhough sewage sludge biochar can fix heavy metals and pathogens in sewage sludge, the scope of utilisation of sewage sludge for the production of edible crops are limited. But there is a possibility for utilising this sewchar as a fertiliser for ornamental crop production. Because they are not naturally edible and they can extract heavy metals from contaminated soil floriculture plants can be used for phytoremediation purposes [9]. Marigold (*Tagetes sp*.) is a popular and aesthetically pleasing decorative plant that have a good capacity to absorb heavy metals [10]. Marigold plant have a strong root system that enables them to endure in a conditioned soil environment and can grow quickly [5]. Marigold hence has the potential to clean up contaminated areas. Because of its broad adaptability in a variety of soil types, ease of cultivation, fast growth rate, early maturity, low nutrient requirements, virtuous adaptation to heavy metal stress and inedible nature, the marigold species was chosen as a test plant. With this back ground the study was conducted for the evaluation of of sewchar for ornamental crop production using marigold as test crop.

2. MATERIALS AND METHODS

2.1 Sewage Sludge Compost and Sewchar Preparation

For the preparation of sewage sludge compost and sewchar the raw material sewage sludge was collected from the waste water treatment plant, Muttathara, Thiruvananthapuram, Kerala. For sewage sludge compost preparation sewage sludge was composted for 60 days with sewage sludge, sawdust, zeolite (50: 30: 20) and 2.5 kg flyash. The compost heap was irrigated every weeks to ensure adequate moisture and turned once in a week to ensure enough oxygen for the composting process. This method was adopted from our previous study [11]. Slow pyrolysis was used to produce sewchar from sewage sludge. The feed stock, sewage sludge was oven dried at 45°C. Sewage sludge was placed in the ceramic crucibles and the crucibles were then pyrolysed at 400 ℃ for 2 hours in a muffle furnace. After the completion of pyrolysis, the muffle furnace was let to cool overnight and sewchar was collected.

2.2 Field Experiment

A field experiment was carried out at the instructional farm of the College of Agriculture, Vellayani, by using marigold as a test crop. The experimental field soil belongs to loamy, kaolinite isphyperthermic typic Kandiustult of Vellayani series. The field was laid out in Randomized Block Design with nine treatments. The treatment details are given in Table 1.

Seeds of Inca Orange marigold was sown in portrays that were filled with coirpith, vermiculite and perlite. The seeds were irrigated and covered with fine FYM. Portrays were watered every two days and maintained in insect-proof stands. The seedlings were moved to the main field one month after they were sown and transplanted main field at a spacing of 45 × 45 cm. From T_2 to T_9 recommended fertiliser dosage (N: P: K @225:60:60 kg ha^{-1}) was applied as muriate of potash, urea and single-supper phosphate. The entire dosage of single-supper phosphate, muriate of potash and ½ dose of urea were applied at the time of transplantation with the remaining ½ dose of urea being applied one month later.

Table 1. Treatment details of field experiment

Treatments	Details
T_1	Absolute control (Soil alone)
T_2	Sewchar @ 5t ha^{-1}
T_3	Sewchar @ 10t ha^{-1}
T_4	Sewchar @ 20t ha^{-1}
T_5	Sewchar @ 5t ha^{-1} + 10t FYM
T_6	Sewchar @ 10t ha^{-1} + 5 t FYM
T_7	Sewage sludge compost @ 20 t ha^{-1}
T_8	Sewage sludge @ 20 t ha^{-1}
T_9	KAU POP (20 t ha^{-1} FYM + NPK @ 225:60:60 kg ha^{-1})

For the estimation of N, P, K and uptake by marigold the plant samples were collected after the harvest. The plant samples such as shoot, root and flower were powdered separately for the estimation. The 2mm sieved air-dried sewage sludge, sewage sludge compost and sewchar were kept in an airtight container for chemical analysis. Nitrogen content was estimated using Kjeldahl's method, phosphorus was estimated by Vanadomolydophosphoric acid yellow colour method (di-acid extract), potassium was estimated by using the flame photometer [12]. Uptake was calculated by multiplying the dry matter yield with the corresponding content of N, P and K.

3. RESULTS AND DISCUSSION

3.1 Chemical Characterisation of Sewage Sludge, Sewage Sludge Compost and Sewage Sludge Biochar

Chemical analysis of the sewage sludge, sewage sludge compost and sewchar showed that the nutrient content in the sewage sludge compost is lower than sewage sludge (Table 2). Sewage sludge had a nitrogen content of 1.68 %, which reduced to 1.60 % and 0.92 % when it is converted to sewage sludge compost and sewchar respectively. During sewage sludge composting process, 40 – 80 % of N is lost as NH_3 emissions, this level of nitrogen loss must lower the compost's quality and cause air pollution [13]. When the sewage sludge is pyrolyzed at 400℃ for 2 hours, a massive loss of N as NH_4^+ and NO_3^- occurs. During this process decomposition of nitrate and ammonium salts initially present in the sewage sludge causes the decline in the amount of NH_4-N and NO_3-N [14]. According to [15], nitrogen can be extracted by losing NH_4-N and NO_3-N fractions as well as volatile materials that contain N groups at 200°C. In comparison to SSC and SS, sewchar's overall P and K contents increased. The loss of P and K content in sewage sludge compost may be due to the dilution effect offered by the bulking agent (sawdust) used in this composting process [16]. The enrichment of the P content in sewchar might be attributed to the fact that phosphorous present in the sewage sludge is mostly associated with thermostable phosphate minerals, which is difficult to decompose and crystallised more during the pyrolysis process [17]. The increased K content in sewchar may be described by the fact that, the breakdown of organic matter releases nutrients linked to organic compounds and causes a loss of volatile content, causing the enrichment of nutrient during the pyrolytic conversion of sewage sludge to sewchar [18].

3.2 Floral parameters of Marigold

The weight of the marigold flower varied from 4.05 to 9.21 grams, while the days to flowering ranged from 31.82 to 44.52. When compared to the other treatments, the sewchar @ 5 t ha^{-1} + 10 t FYM applied treatment had the shortest flowering time and the largest flower weight. Marigold flowers have a diameter ranged from 5.01 to 9.35 cm (Table 3). When compared to SS and SSC, the maximum flower diameter was seen in sewchar received treatments. The marigold's flower length did not significantly vary throughout the treatments.

Table 2. Chemical properties of sewage sludge, sewage sludge compost and sewchar

Parameter	Sewage sludge	Sewage sludge compost	Sewchar
Bulk density (Mg m^{-3})	-	0.64	0.41
Water holding capacity (%)	-	50.14	58.75
Water stable aggregates (%)	-	-	-
pH	5.36	7.07	6.20
EC (dS m^{-1})	8.08	5.30	2.25
OC (%)	17.03	13.54	5.28
N (%)	1.68	1.60	0.92
P (%)	7.73	1.24	7.80
K (%)	1.20	0.29	1.60

Table 3. Effect of treatments on floral parameters of marigold

Treatments	Days to flowering	Flower diameter (cm)	Flower weight (g)	No of flowers per plant
T_1	43.49 [a]	5.43 [de]	5.11 [c]	63.80 [e]
T_2	41.68 [a]	5.68 [de]	6.65 [b]	65.56 [de]
T_3	36.04 [bc]	7.54 [c]	7.47 [b]	70.30 [bc]
T_4	33.51 [cd]	8.21 [bc]	7.56 [b]	73.74 [b]
T_5	31.82 [d]	9.35 [a]	9.21 [a]	93.58 [a]
T_6	33.04 [d]	8.70 [ab]	8.83 [a]	97.77 [a]
T_7	37.54 [b]	5.94 [d]	6.97 [b]	68.15 [cd]
T_8	44.52 [a]	5.01 [e]	4.05 [c]	46.17 [f]
T_9	37.20 [b]	7.52 [c]	7.45 [b]	69.13 [cd]
SEm (±)	0.99	0.31	0.41	1.43
CD (0.05)	2.97	0.92	1.22	4.27

The treatment receiving SC @ 10 t ha^{-1} + 5 t FYM showed the maximum number of flowers per plant, which was comparable to the treatment receiving SC @ 5 t ha^{-1} + 10 t FYM. Significantly, T_8 receiving 20 t ha^{-1} SS achieved the lowest value. This is consistent with the results of [19], who found that the floral parameters decreased with an increase in the rate of sewage sludge application. This may be explained by the pH decreasing when a certain amount of sewage sludge was added, despite this, the plant growth and floral parameters were decreased. Driesen [20] claimed that biochar increases plant growth by strengthening the soil's structure, encouraging root development and increasing stomatal density, photosynthetic rate and total plant productivity.

3.3 Content and Uptake of Nitrogen

The various sewage sludge treatments significantly influenced the content (Table 4) and uptake of nitrogen (Fig. 1). The nitrogen content of the root, shoot and flower varied from 1.54 (T_1) to 2.81 % (T_5), 1.25 (T_1) to 1.92 % (T_5) and 1.12 (T_8) to 1.92 % (T_5). Considering the different treatments the treatments receiving sewchar recorded the highest nitrogen content in shoot, root, flower and the uptake by shoot, root and flower. Similar result was quoted by [21] that the application of paddy husk biochar to ginger crop attained the highest N content in root, shoot and rhizome. This higher performance could be attributed to the gradual release of nutrients from biochar. This release corresponds with the crops' nutrient requirements, ensuring a consistent supply of nutrients over a longer period of time, which in turn promotes better plant growth. The application of sewchar along with mineral fertilisers causes the reduction in the leaching of nitrogen and thus retaining N in the soil. The retention of N hinders the hinders the denitrification and volatilisation thus supplying N for a prolonged period [22]. The reason for high N uptake in sewchar treatments could be attributed to the plants producing more dry matter as a result of absorbing a greater amount of nitrogen from the soil. In African marigold, similar findings were reported by [23,24]. Because of the porous nature and presence of negatively charged functional groups in sewchar it can electrostatically retain NH_4^+ in the soil [25]. As per the findings of [26], soil microorganisms are crucial for the production of ammonium compounds during the ammonification process and for reducing nitrogen losses due to gaseous fluxes and leaching. It has been reported that adding biochar to the soil increases its nitrogen content [27]. The quantity of nitrogen that seeps out of the soil can be decreased by adding biochar. According to [28] the application of biochar enhanced the fertiliser nitrogen recovery. Furthermore, biochar may indirectly impact the nitrogen content by enhancing microbial populations.

3.4 Content and Uptake of Phosphorus

The phosphorus content in the root, shoot and flower varied from 0.34 (T_1) to 0.46 % (T_5), 0.30 (T_1) to 0.44 % (T_5) and 0.18 (T_8) and 0.31 % (T_4) respectively. With respect to the uptake, it varied from 1.32 (T_1) to 2.41 kg ha^{-1} (T_5), 3.03 (T_1) to 9.71 kg ha^{-1} (T_5) and 2.05 (T_8) to 15.99 kg ha^{-1} (T_6) in root, shoot and flower respectively (Fig. 2). Biochar applied treatments had the highest uptake of P compared to other as suggested by [29]. The application of biochar and fertilisers leads to extensive root growth, which in turn causes an increase in the phosphorus content and uptake by plants. The relationship between mycorrhizal fungi and plant roots produces P- solubilising organic acids and extracellular phosphatase enzymes, which convert P into a state that is available [30]. The present study's findings demonstrated that applying SC might enhance the soil's P status while lowering leaching. This is consistent with the results of [31], who found that the highest available P content was recorded in both sandy and laterite soils when applying 20 t ha^{-1} biochar. The primary reason why sewchar increases soil P content availability is that it creates a large number of micropores, which serve as a habitat for microorganisms that increases the availability of P [32]. Yang et al. [33] stated that oxygen-containing functional groups on the surface of biochar aid in the adsorption of soluble P and thus, aid in the retention of P in the soil.

Table 4. Content of major nutrients

Treatments	N content (%)			Phosphorous (%)			Potassium (%)		
	Root	Shoot	Flower	Root	Shoot	Flower	Root	Shoot	Flower
T_1	1.54 ^{e}	1.25 ^{f}	1.42 ^{cd}	0.34 ^{d}	0.30 ^{i}	0.19 ^{fg}	1.17 ^{e}	1.17 ^{e}	2.28 ^{e}
T_2	2.22 ^{c}	1.51 ^{e}	1.42 ^{cd}	0.39 ^{bc}	0.33 ^{g}	0.21 ^{ef}	1.53 ^{c}	1.54 ^{d}	2.38 ^{de}
T_3	2.28 ^{c}	1.74 ^{c}	1.76 ^{abc}	0.39 ^{bc}	0.37 ^{d}	0.28 ^{c}	1.54 ^{c}	2.17 ^{c}	2.58 ^{b}
T_4	2.40 ^{b}	1.83 ^{b}	1.78 ^{ab}	0.41^{b}	0.39 ^{c}	0.31 ^{a}	1.57 ^{c}	2.53 ^{b}	2.80 ^{a}
T_5	2.81 ^{a}	1.92 ^{a}	1.92 ^{a}	0.46 ^{a}	0.44 ^{a}	0.29 ^{bc}	2.07 ^{a}	2.86 ^{a}	2.58 ^{b}
T_6	2.72 ^{a}	1.87 ^{ab}	1.84 ^{ab}	0.43 ^{ab}	0.42 ^{b}	0.30 ^{ab}	2.01 ^{a}	2.57 ^{b}	2.64 ^{b}
T_7	2.43 ^{b}	1.62 ^{d}	1.54 ^{bc}	0.43 ^{ab}	0.35 ^{f}	0.22 ^{de}	1.84 ^{b}	1.97 ^{c}	2.46 ^{cd}
T_8	1.97 ^{d}	1.32 ^{f}	1.12 ^{d}	0.38 ^{cd}	0.32 ^{h}	0.18 ^{g}	1.17 ^{e}	1.32 ^{e}	1.68 ^{f}
T_9	2.18 ^{c}	1.68 ^{cd}	1.65 ^{abc}	0.38 ^{cd}	0.36 ^{e}	0.23 ^{d}	1.32 ^{d}	2.07 ^{c}	2.54 ^{bc}
SEm (±)	0.041	0.025	0.117	0.015	0.001	0.007	0.035	0.067	0.04
CD (0.05)	0.121	0.074	0.349	0.045	0.003	0.022	0.104	0.202	0.12

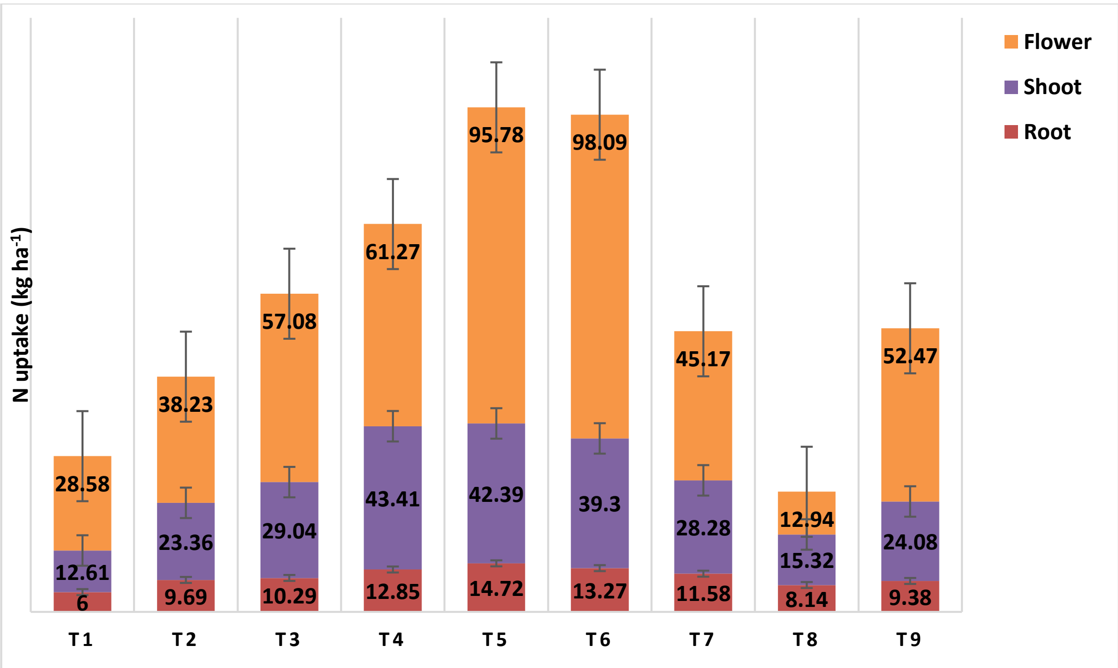

Fig. 1. N uptake by marigold

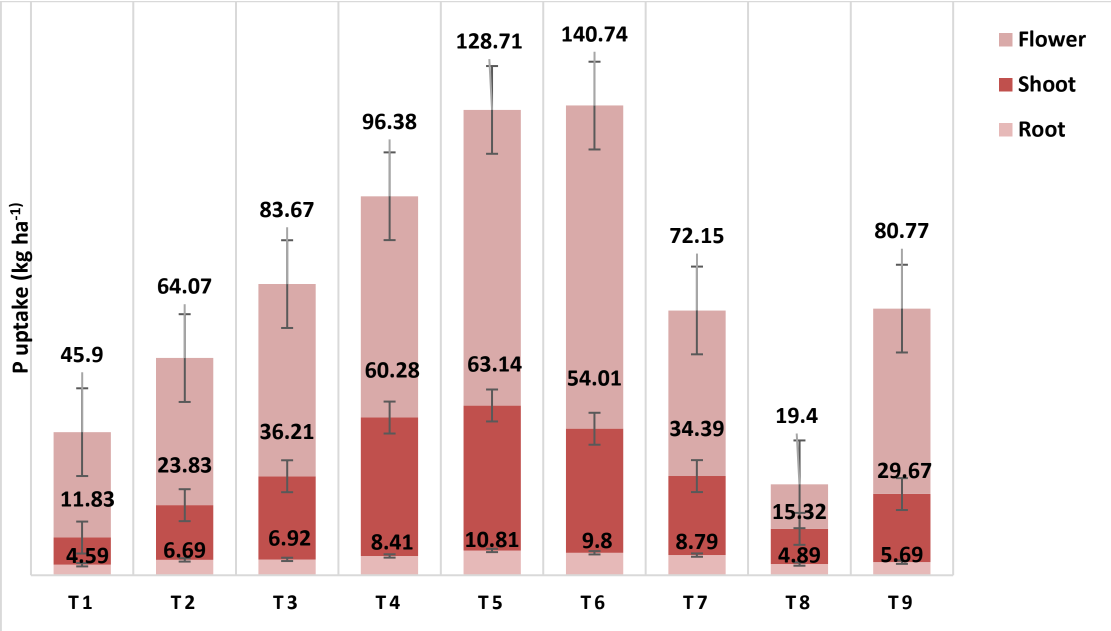

Fig. 2. P uptake by marigold

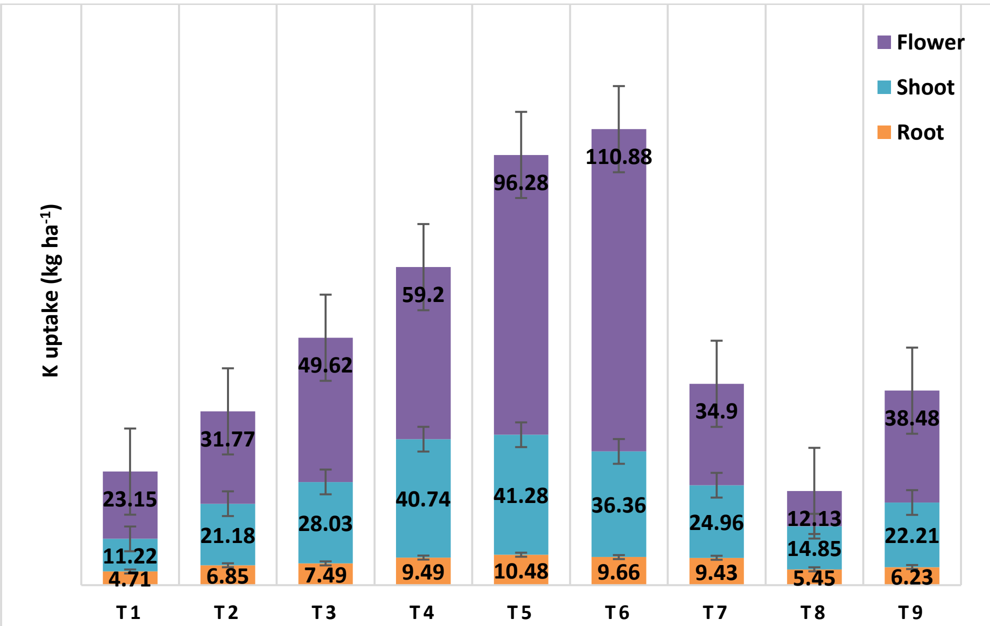

Fig. 3. K uptake by marigold

3.5 Content and Uptake of Potassium

The potassium content in the root, shoot and flower varied from 1.17 to 2.07 %, 1.17 to 2.86 % and 1.68 to 2.80 % respectively. The uptake of potassium ranged between 4.59 to 10.81 kg ha^{-1}, 11.83 to 63.14 kg ha^{-1} and 19.40 to 140.74 kg ha^{-1} in root, shoot and flower respectively (Fig. 3). Treatment receiving sewchar recorded the highest nutrient content and uptake of potassium. The superior results in sewchar received treatments may be due to the result of increased potassium absorption from the soil, which has improved plant development and increased dry matter generation by the plants in comparison to the other treatments. According to [34], the application of biochar increases K uptake because of its capacity to decrease nutrient leaching and increase nutrient availability. The prolonged and consistent presence K in readily available form and the improved root development brought about by the fertilisers and biochar enhanced the plants' uptake of K. The presence of K nutrients in the amendments may be the cause of the soil's increased K content. Biochar reduces K leaching losses and increases soil K availability due to its comparatively high K content and ability to absorb large amounts of K from soil solutions. The use of biochar leads to an improvement in pH and CEC, which is consistent with the higher nutritional levels. A higher degree of oxidation, an increase in the surface area accessible for adsorbing cations, or a combination of these factors can be attributed to the enhanced CEC. This increase in charge density per unit surface area of organic matter can be measured [35].

4. CONCLUSION

The results of the present study showed that application of sewage sludge, sewage sludge compost and its biochar significantly enhanced the growth, productivity and uptake of marigold plant. When compared to sewage sludge, sewage sludge compost and sewchar the better results were given by sewchar. From the experiment it was revealed that application of SC enhanced the floral parameters such as flower diameter, flower weight and number of flowers per plant. Treatment receiving SC @ 5 t ha^{-1}+ 10 t FYM was found to be the highest in nitrogen uptake and those receiving SC @ 10 t ha^{-1} + 5 t FYM registered the highest uptake for P and K. Thus it can be concluded that sewchar application had more benefits to marigold and soil when compared to the application of sewage sludge and sewage sludge compost.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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