Original Research Article

Content Uptake and Yield of African Marigold as Influenced by the Application of Sewage Sludge Biochar (Sewchar)

ABSTRACT

Aim: The study was conducted to evaluate the effect of sewage sludge (SS), sewage sludge compost (SSC) and sewage sludge biochar (sewchar, SC) on soil chemical properties and plant growth and productivity.

Study design: The preparation of sewage sludge compost and sewchar were done in completely randomized block design. The field experiment was laid out in randomised block design.

Place and duration of study: Department of Soil science and agricultural chemistry, College of agriculture, Vellayani, Thiruvananthapuram, India.

Methodology: Sewage sludge which is the residue from waste water treatment process is a rich source of available plant nutrients and minerals. Comparative studies showing the effect of sewage sludge, sewage sludge compost and its biochar on soil properties, plant growth and productivity are limited. Sewage sludge compost was prepared by using sewage sludge, sawdust and zeolite in the ratio 50: 30: 20 and for the adjustment of pH 2.5 kg flyash was used. Sewchar was prepared through the process of slow pyrolysis at a temperature of 400℃ for 2 hours using the muffle furnace. The influence of sewage sludge, sewage sludge compost and sewchar on soil and plant properties were studied by using marigold as a test crop.

Results: Experimental results showed that conversion of sewage sludge to sewchar causes the enrichment of nutrients in them. Application of SS, SSC and SC improved the soil electro chemical properties such as pH, EC and CEC and nutrient content such as OC, N, P and K. Field experiment revealed that the application of the amendments significantly influenced the vegetative as well as yield parameters of marigold, but application of sewchar along with FYM was found to be the superior from other treatments. Slow and steady release of nutrients from sewchar is important in maintaining the soil fertility and boosting the plant growth parameters and productivity.

Keywords: Sewage sludge, Marigold, Biochar, Sewage sludge compost, Sewchar

1. INTRODUCTION

The amount of garbage 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 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. Kerala generates 3543 TPD of solid waste in total, of which 2550 TPD are treated [1].

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. 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. 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. 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 [2]. 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.

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. 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 phyto remediation purposes [3]. Marigold (*Tagetes sp.*) is a popular and aesthetically pleasing decorative plant that have a good capacity to absorb heavy metals [4]. 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 METHOD

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 combined with sewage sludge, sawdust, zeolite in 50: 30: 20 ratio and 2.5 kg flyash was added. Heap method of composting was used and the composting process lasted for 60 days. The heap were irrigated every two 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 [6].

Slow pyrolysis was used to produce sewchar from sewage sludge. Following a 2 mm filtration, 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. The resulting sewchars were ground up and put through a 2 mm filter. For the chemical and physical analysis of sewchar, they were sieved and kept in an airtight container.

The air-dried sewage sludge, sewage sludge compost and sewchar were crushed separately and passed through 2mm sieve. Using an aqueous extract of dried materials in distilled water (1:5 w/v), the pH and electrical conductivity were measured using a CyberScan PC510 pH meter and a Systronics MK509 conductivity meter, respectively. Using the vario EL cube elemental analyser, the weight loss upon ignition of the dried materials was used to determine the total organic carbon. The total nitrogen content was estimated using Kjeldahl's method, phosphorus was estimated by Vanadomolydophosphoric acid yellow colour method (di-acid extract) and potassium was estimated by using the flame photometer [7].

2.2 Experimental set up

A field experiment was carried out at the instructional farm of the College of Agriculture, Vellayani, to assess the impact of sewage sludge, sewage sludge compost and sewchar on agricultural productivity using marigold as test crop. The experimental field soil belongs to loamy, kaolinite isphyperthermic typic Kandiustult of Vellayani series. The experimental field was laid out in randomized block design with the application of nine treatments. The treatments consist of different rate of application of sewchar, sewage sludge compost, sewage sludge and sewchar in combination with FYM. Treatment details are: 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}). Seeds of Inca Orange marigold were sown in pots that were filled with corpith, vermiculite and perlite. The seeds were irrigated and covered with fine FYM after being sown in pots. 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. The 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.

For the estimation N, P, K content 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. 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 [7]. Uptake was calculated by multiplying the dry matter yield with the corresponding content of N, P and K. Biometric observations such as plant height, number of primary and secondary branches were recorded one month after transplanting. Yield parameters such as dry matter yield of root, shoot and flower were analysed separately and recorded during the harvest of crop.

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 the nutrient content in the sewage sludge compost is lower than sewage sludge (Table 1). Sewage sludge had a higher total nitrogen content than sewage sludge and lower pH, P and K values. A lower electrical conductivity was observed in sewchar (2.25 dS m^{-1}) compared to the sewage sludge (8.08 dS m^{-1}). The lower total nitrogen content of sewchar (0.92%) compared to SSC (1.60%) and SS (1.68%) could be the nitrogen's volatilisation during pyrolysis. According to [8], 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.

Table 1. Chemical properties of SS, SC and soil

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

a. Vegetative parameters

3.2.1 Plant height

Data on plant height of marigold is shown in table 2. The application of several treatments, including sewchar, sewage sludge compost, sewage sludge and FYM had a substantial impact on plant height. Plant height ranged from 122.7 cm (T_1) to 138 cm (T_5). T_5 (SC @ 5 t ha^{-1} + 10 t FYM) had the highest value (138 cm) and T_8 had the lowest value, measuring 117.33 cm (SS @ 20 t ha^{-1}).

3.2.2 Number of primary branches

The number of primary branches of the marigold was significantly influenced by the treatments (Table 2). In comparison to other treatments, sewchar received treatment registered the greatest number of primary branches and the value ranged between 11.97 (T_8) and 23.05 (T_5). Treatment, T_5 receiving sewchar @ 5 t ha^{-1} + 10 t FYM showed the largest number of primary branches of 23.05, which was determined to be comparable to T_6 (20.97) and T_4 (19.95). T_8 had the lowest number primary branches (11.97), which was on par with T_1 (15.00).

3.2.3 Number of secondary branches

The number of secondary branches in marigold was strongly influenced by sewchar, sewage sludge, composted sewage sludge and FYM treatments (Table 2). The number of secondary branches ranged between 25.98 and 47.12. Treatment T_5 receiving sewchar @ 5 t ha^{-1} + 10 t FYM produced the largest number of secondary branches of 47.12, which was found to be on par with T_6 (44.95) receiving SC @ 10 t ha^{-1} + 5 t FYM. The lowest number of secondary branches was found with T_8 (25.98), received SS @ 20 t ha^{-1}.

The treatment getting SC @ 10 t ha^{-1} + 5 t FYM was found to be on par, with the highest value being recorded by application of SC @ 5 t ha^{-1} + 10 t FYM. With SS @ 20 t ha^{-1} treatment, the lowest value was observed. Similar findings were also reported by [9] who found that applying sewage sludge alone to marigold crops reduced plant height, the number of primary and secondary branches. The highest value for plant height, the number of primary and secondary branches was found in the sewchar application. This is consistent with research by [10], who found that using biochar boosted the growth of the ginger crop. The improvement of soil physical qualities, microbial activity and soil organic matter as a result of applying organic manures may account for the rise in biometric observations observed with the addition of sewchar along with FYM. Additionally, they generate organic acids that have the direct effect of influencing plant growth by inhibiting enzymes, particularly IAA oxidase and increasing the effect of auxin-IAA [11]. Plant height and the number of branches per plant in the treatment may have increased as a result of the application of sewchar in conjunction with FYM, which may have had a direct positive effect on plant growth and stimulation of auxillary buds. Biochar can increase soil aeration and microbial activity, reduce nutrient leaching and improve water and nutrient retention its usage may promote better plant development [12].

Table 2. Effect of treatments on vegetative parameters of marigold

Treatments	Plant height (cm)	No. of primary branches	No. of secondary branches
T_1 (Control)	122.7 ^{de}	15.00 ^{de}	26.97 ^{e}
T_2 (SC @ 5 t ha^{-1})	124.3 ^{cde}	17.05 ^{cd}	27.95 ^{e}
T_3 (SC @ 10 t ha^{-1})	130.0 ^{bc}	18.97 ^{bc}	42.07 ^{bc}
T_4 (SC @ 20 t ha^{-1})	132.7 ^{ab}	19.95 ^{abc}	42.90 ^{bc}
T_5 (SC @ 5 t ha^{-1}+ 10 t FYM)	138.0 ^{a}	23.05 ^{a}	47.12 ^{a}

T_6 (SC @ 10 t ha^{-1}+ 5 t FYM)	133.0 ^{ab}	20.97 ^{ab}	44.95 ^{ab}
T_7 (SSC @ 20 t ha^{-1})	127.0 ^{bcd}	18.00 ^{bcd}	37.93 ^{d}
T_8 (SS @ 20 t ha^{-1})	117.3 ^{e}	11.97 ^{e}	25.98 ^{e}
T_9 (KAU POP- 20 t ha^{-1} FYM)	129.0 ^{bcd}	18.93 ^{bc}	41.03 ^{cd}
SEm (±)	2.414	1.149	1.208
CD (0.05)	7.238	3.446	3.622

SC- sewchar, SSC- sewage sludge compost, SS- sewage sludge.

NPK was applied as per POP from T_2 to T_9.

3.3 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.

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 [9], 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. [13] 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.

Table 3. Effect of treatments on floral parameters of marigold

Treatments	Days to flowering	Flower diameter (cm)	Flower length (cm)	Flower weight (g)	No of flowers per plant
T_1 (Control)	43.49 ^{a}	5.43 ^{de}	12.24	5.11 ^{c}	63.80 ^{e}
T_2 (SC @ 5 t ha^{-1})	41.68 ^{a}	5.68 ^{de}	13.60	6.65 ^{b}	65.56 ^{de}
T_3 (SC @ 10 t ha^{-1})	36.04 ^{bc}	7.54 ^{c}	13.76	7.47 ^{b}	70.30 ^{bc}
T_4 (SC @ 20 t ha^{-1})	33.51 ^{cd}	8.21 ^{bc}	13.34	7.56 ^{b}	73.74 ^{b}
T_5 (SC @ 5 t ha^{-1} + 10 t FYM)	31.82 ^{d}	9.35 ^{a}	13.96	9.21 ^{a}	93.58 ^{a}
T_6 (SC @ 10 t ha^{-1} + 5 t FYM)	33.04 ^{d}	8.70 ^{ab}	14.07	8.83 ^{a}	97.77 ^{a}
T_7 (SSC @ 20 t ha^{-1})	37.54 ^{b}	5.94 ^{d}	14.16	6.97 ^{b}	68.15 ^{cd}
T_8 (SS @ 20 t ha^{-1})	44.52 ^{a}	5.01 ^{e}	13.80	4.05 ^{c}	46.17 ^{f}
T_9 (KAU POP- 20 t ha^{-1} FYM)	37.20 ^{b}	7.52 ^{c}	15.02	7.45 ^{b}	69.13 ^{cd}
SEm (±)	0.99	0.307	-	0.405	1.425
CD (0.05)	2.969	0.919	NS	1.215	4.273

SC- sewchar, SSC- sewage sludge compost, SS- sewage sludge.

3.4 Yield parameters of marigold

Dry matter yield of root varied from 3.9 (T_1) to 5.4 kg ha^{-1} (T_4). Treatment T_4 (SC @ 20 t ha^{-1}) had the maximum dry matter yield of 5.4 kg ha^{-1}, whereas T_1 (control) had the lowest yield of 3.9 kg ha^{-1}. The dry matter production of the shoot varied significantly between treatments, ranging from 10.1 kg ha^{-1} (T_1) to 23.8 kg ha^{-1} (T_4). Treatment T_4 received the maximum yield of 23.8 kg ha^{-1} from SC @ 20 t ha^{-1}; however, this yield was comparable to T_5 (22.1 kg ha^{-1}) receiving SC @ 5 t ha^{-1} + 10 t FYM, T_6 (21 kg ha^{-1}) receiving SC @ 10 t ha^{-1} + 5 t FYM and T_7 (17.5 kg ha^{-1}) receiving SSC @ 20 t ha^{-1} and T_1 (control) had the lowest value of 10.1 kg ha^{-1}. The flower's dry matter production ranged from 11.55 (T_8) to 53.31 kg ha^{-1} (T_6). Treatment T_6 had the greatest value of 53.31 kg ha^{-1}, which was comparable to T_5

(49.89 kg ha^{-1}) receiving SC @ 5 t ha^{-1} + 10 t FYM and the lowest dry matter yield of flower was observed in T_8 (11.55 kg ha^{-1}). The marigold's total dry matter production ranged from 27.25 (T_8) to 79.21 kg ha^{-1} (T_6). 53.31 kg ha^{-1} was the highest value recorded in T_6 receiving SC @ 10 t ha^{-1} + 5 t FYM, which was comparable to T_5 (49.89 kg ha^{-1}) receiving SC @ 5 t ha^{-1} + 10 t FYM and the lowest value of 27.25 kg ha^{-1} in T_8 (SS @ 20 t ha^{-1}).

It is evident from the data that the use of sewchar enhanced the shoot, root and flower dry matter yield. According to [14] using biochar made from chicken litter significantly increased the production of radish crops. According to [15], applying cow manure biochar increased maize crop output when compared to the control. This might be the result of improved soil physico-chemical properties, increased uptake of nitrogen, and increased maize yield. In general, sewchar application enhanced marigold yield parameters. According to [16], biochar produced by pyrolysis at lower temperatures has improved the nutritional efficacy of soil. Biochar encourages plant growth by strengthening the soil's structure, encouraging root development, and increasing stomatal density, photosynthetic rate, and overall plant productivity [13]. Because of its highly developed pore structure and high nutritional content, biochar effectively retains soil nutrients. As a result, this encourages agricultural development and increases crops' availability of nutrients [17].

Table 4. Effect of treatment on yield parameters of marigold

Treatments	Dry matter yield (kg ha^{-1})			Total dry matter yield (kg ha^{-1})
	Root	Shoot	Flower	
T_1 (control)	3.9	10.1 ^{d}	20.13 ^{cd}	34.13 ^{e}
T_2 (SC @ 5 t ha^{-1})	4.4	15.5 ^{bcd}	26.92 ^{cd}	46.82 ^{d}
T_3 (SC @ 10 t ha^{-1})	4.5	16.7 ^{bcd}	32.43 ^{c}	53.63 ^{c}
T_4 (SC @ 20 t ha^{-1})	5.4	23.8 ^{a}	34.42 ^{bc}	63.62 ^{b}
T_5 (SC @ 5 t ha^{-1}+ 10 t FYM)	5.2	22.1 ^{ab}	49.89 ^{ab}	77.19 ^{a}
T_6 (SC @ 10 t ha^{-1}+ 5 t FYM)	4.9	21.0 ^{ab}	53.31 ^{a}	79.21 ^{a}
T_7 (SSC @ 20 t ha^{-1})	4.8	17.5 ^{abc}	29.33 ^{c}	51.63 ^{c}
T_8 (SS @ 20 t ha^{-1})	4.1	11.6 ^{cd}	11.55 ^{d}	27.25 ^{f}
T_9 (KAU POP- 20 t ha^{-1} FYM)	4.3	14.3 ^{cd}	31.80 ^{c}	50.40 ^{cd}
SEm (±)	-	2.218	5.347	1.217
CD (0.05)	-	6.649	16.032	3.649

SC- sewchar, SSC- sewage sludge compost, SS- sewage sludge.

3.5 Content and uptake of nitrogen

The various sewage sludge treatments significantly influenced the content (Table 5) and uptake of nitrogen (Fig.1). The nitrogen content of the root varied from 1.54 (T_1) and 2.81 % (T_5). The treatment T_5 receiving SC @ 5 t ha^{-1} + 10 t FYM recorded the highest (2.81 %) N content. Significantly lowest value of 1.54 % was observed in T_1 (control). Total nitrogen content in the shoot varied between 1.25 (T_1) and 1.92 % (T_5). Treatment T_5 receiving SC @ 5 t ha^{-1} + 10 t FYM recorded the highest value of 1.92 %, followed by T_6 (1.87 %), receiving SC @ 10 t ha^{-1} + 5 t FYM and the lowest value (1.25 %) for shoot nitrogen was recorded with T_1 (soil alone). The nitrogen in flower varied between 1.12 (T_8) and 1.92 % (T_5). The highest mean value (1.92 %) was observed with T_5 receiving SC @ 5 t ha^{-1} + 10 t FYM, which was on par with T_6 (1.84 %) receiving SC @ 10 t ha^{-1} + 5 t FYM, T_4 (1.78 %) receiving SC @ 20 t ha^{-1}, T_3 (1.76 %) receiving SC @ 10 t ha^{-1} and T_9 (1.65 %) receiving 20t ha^{-1} FYM. Treatment T_8 receiving SS @ 20 t ha^{-1} recorded the lowest value (1.12 %).

Regarding the root nitrogen uptake, it varied between 6.0 (T_1) and 14.72 kg ha^{-1} (T_5). The highest value of 14.72 kg ha^{-1} was observed in T_5 (SC @ 5 t ha^{-1} + 10 t FYM), which was found to be on par with T_6 (13.27 kg ha^{-1}) receiving SC @ 10 t ha^{-1} + 5 t FYM and T_4 (12.85 kg ha^{-1}) receiving SC @ 20 t ha^{-1}) and the lowest value of 6.0 kg ha^{-1} was observed in T_1 (control). The uptake of nitrogen by the shoot varied from 12.61 (T_1) and 43.41 kg ha^{-1} (T_4). The highest value of 43.41 kg ha^{-1} was observed in T_4 receiving SC @ 20 t ha^{-1} and found to be on par with T_5 (42.39 kg ha^{-1}) receiving SC @ 5 t ha^{-1} + 10 t FYM and T_6 (39.30 kg ha^{-1}) receiving SC @ 10 t ha^{-1} + 5 t FYM and the least nitrogen uptake was observed in T_1 (12.61 kg ha^{-1}). With respect to uptake of nitrogen by flower it varied from 12.94 (T_8) to 98.09 kg ha^{-1} (T_6). The highest value of 98.09 kg ha^{-1} was registered with T_6 receiving SC @ 10 t ha^{-1} + 5 t FYM), which was on par with T_5 (95.78 kg ha^{-1}) receiving SC @ 5 t ha^{-1} + 10 t FYM) and the least value of 12.94 kg ha^{-1} was observed in T_8 (SS @ 20 t ha^{-1}).

The total uptake of nitrogen was significantly influenced by different treatments and the values ranged between 36.40 (T_8) and 152.89 kg ha^{-1} (T_5). Significantly highest value of 152.89 kg ha^{-1} was observed in T_5 (SC @ 5 t ha^{-1} + 10 t FYM), which was on par with T_6 (150.66 kg ha^{-1}). The total uptake of nitrogen followed the order T_5 (152.89 kg ha^{-1}) > T_6 (150.66 kg ha^{-1}) > T_4 (117.53 kg ha^{-1}) > T_3 (96.41 kg ha^{-1}) > T_9 (85.93 kg ha^{-1}) > T_7 (85.03 kg ha^{-1}) > T_2 (71.28 kg ha^{-1}) > T_1 (47.19 kg ha^{-1}) > T_8 (85.93 kg ha^{-1}).

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 results was quoted by [10] 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 slow and constant release of nutrients from biochar. This release corresponds with the crops' nutrient requirements, guaranteeing a consistent supply of nutrients over a longer period of time, which in turn promotes better plant growth.

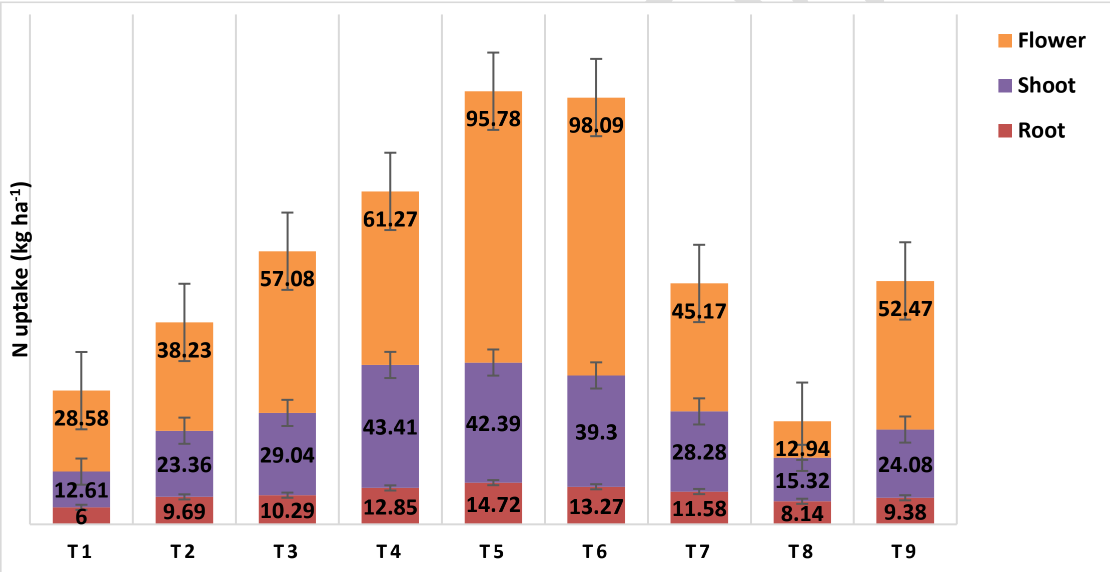

Fig. 1 Effect of treatments on N uptake by marigold

3.6 Content and uptake of phosphorus

It is clear from the data that the application of different treatments such as sewchar, sewage sludge compost, sewage sludge and FYM had a significant influence on the content and uptake of P in shoot, root and flower (Table 5). The phosphorus content in the root varied from 0.34 (T_1) and 0.46 % (T_5). Treatment T_5 receiving SC @ 5 t ha^{-1} + 10 t FYM recorded the highest value of 0.46 %, which was on par with 0.43 % in T_6 receiving SC @ 10 t ha^{-1} + 5 t FYM (0.43 %) and T_7 receiving SSC @ 20 t ha^{-1} (0.43 %) and significantly lowest value of 0.34 % was observed in T_1 (control). The total phosphorus in shoot varied between 0.30 (T_1) to 0.44 % (T_5). The highest value of 0.44 % was observed in T_5 (SC @ 5 t ha^{-1} + 10 t FYM) followed by T_6 (0.42 %) receiving SC @ 10 t ha^{-1} + 5 t FYM, T_4 (0.39 %) receiving SC @ 20t ha^{-1} and the lowest value of 0.30 % was recorded with T_1 (control). Phosphorus content in the flower ranged between 0.18 (T_8) and 0.31 % (T_4). Among the treatments, T_4 (SC @ 20 t ha^{-1}) recorded the highest value (0.31 %), which was on par with T_6 (0.30 %) which received SC @ 10 t ha^{-1} + 5 t FYM and T_1 (0.19 %). T_8 (SS @ 20 t ha^{-1}) recorded the lowest value (0.18 %), which was found to be on par with T_1 (0.19 %).

With respect to the uptake, phosphorous uptake of root varied between 1.32 (T_1) and 2.41 kg ha^{-1} (T_5). The highest value of 2.41 kg ha^{-1} was observed in T_5 receiving SC @ 5 t ha^{-1} + 10 t FYM, which was on par with T_4 (2.20 kg ha^{-1}) receiving SC @ 20 t ha^{-1}, T_6 (2.10 kg ha^{-1}) receiving SC @ 10 t ha^{-1} + 5 t FYM and T_7 (2.05 kg ha^{-1}) receiving SSC @ 20 t ha^{-1}. The least value of 1.32 kg ha^{-1} was observed in T_1 (control). Phosphorus uptake in the shoot it ranged between 3.03 (T_1) and 9.71 kg ha^{-1} (T_5) and the treatments significantly influenced the P uptake of shoot. Among the treatments, T_5 (SC @ 5 t ha^{-1} + 10 t FYM) recorded the highest value (9.71 kg ha^{-1}), which was on par with T_4 (9.29 kg ha^{-1}) which received SC @ 20 t ha^{-1} and T_6 (8.83 kg ha^{-1}) which received SC @ 10 t ha^{-1} + 5t FYM. Treatment T_1 (control) recorded the lowest value (3.03 kg ha^{-1}). The P uptake of flower ranged between 2.05 (T_8) to 15.99 kg ha^{-1} (T_6). The highest value of 15.99 kg ha^{-1} was noticed in T_6 receiving SC @ 10 t ha^{-1} + 5 t FYM, which was on par with T_5 (14.47 kg ha^{-1}) receiving SC @ 5 t ha^{-1} + 10 t FYM. The least uptake of 2.05 kg ha^{-1} was noticed in T_8 receiving SS @ 20 t ha^{-1}. The total uptake of phosphorous varied between 7.33 (T_8) and 26.9 kg ha^{-1} (T_6). The highest value of 26.92 kg ha^{-1} was observed in T_6 (SC @ 10 t ha^{-1} + 5 t FYM) which was on par with T_5 (26.59 kg ha^{-1}) receiving SC @ 5 t ha^{-1} + 10 t FYM and the least value of 7.33 kg ha^{-1} was observed in T_8 (SS @ 20 t ha^{-1}).

Biochar applied treatments had the highest uptake of P compared to other as suggested by [18]. 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-solubilizing organic acids and extracellular phosphatase enzymes, which convert organic P into a state that is accessible [19].

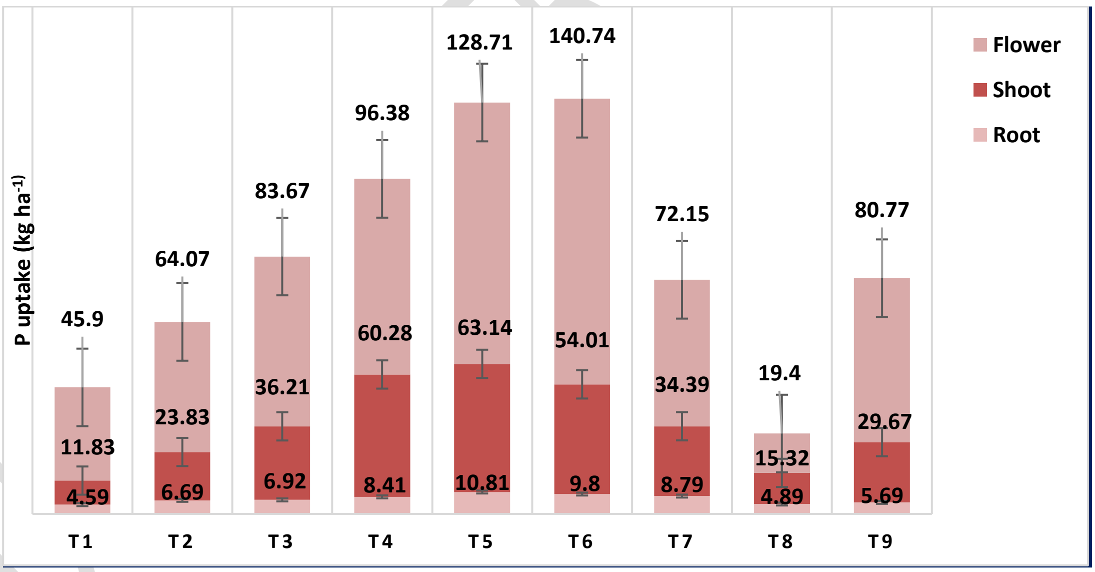

Fig.2 Effect of treatments on P uptake by marigold

3.7 Content and uptake of potassium

It is clear from the data that the application of different treatments such as sewchar, sewage sludge compost, sewage sludge and FYM had significant influence on potassium content in root, shoot, flower (Table 5) and its uptake (Fig.3). Regarding the potassium content in the root it varied from 1.17 and 2.07 %. Treatment T_5 receiving SC @ 5 t ha^{-1} + 10 t FYM recorded the highest value of 2.07 %, which was on par with treatment T_6 receiving SC @ 10 t ha^{-1} + 5 t FYM (2.01 %). Lowest value of 1.17 % was attained by the control (T_1) and T_7 receiving SSC @ 20 t ha^{-1}. Regarding the potassium content in the shoot, it varied between 1.17 (T_1) and 2.86 % (T_5). The treatment T_5 which received SC @ 5 t ha^{-1} + 10 t FYM recorded significantly higher potassium content in shoot (2.86 %) and the least value of 1.17 % was recorded with T_1 (soil alone). Significant variation was observed with respect to total potassium content in flower and the values ranged from 1.68 (T_8) to 2.80 % (T_4). The highest value was recorded with T_4 which received SC @ 20 t ha^{-1} (2.80 %) and the least value was observed in T_8 (1.68 %) receiving sewage sludge @ 20 t ha^{-1}.

The root uptake of potassium the value ranged between 4.59 (T_1) and 10.81 kg ha^{-1} (T_5). The highest value of 10.81 kg ha^{-1} was recorded in T_5 (SC @ 5 t ha^{-1} + 10 t FYM), was found to be on par with T_6 (9.80 kg ha^{-1}) receiving SC @ 10 t ha^{-1} + 5 t FYM and T_7 (8.79 kg ha^{-1}) receiving SSC @ 20 t ha^{-1} and the treatment T_1 (control) recorded the least value of 4.59 kg ha^{-1}. The potassium uptake of the shoot varied between 11.83 (T_1) and 63.14 kg ha^{-1} (T_5). The highest value of 63.14 kg ha^{-1} was observed in T_5 (SC @ 5 t ha^{-1} + 10 t FYM), followed by T_4 (60.28 kg ha^{-1}) receiving SC @ 20 t ha^{-1} but were on par and the least value of 11.83 kg ha^{-1} was observed in T_1 (soil alone). The uptake of potassium by flower ranged between 19.40 (T_8) and 140.74 (T_6). The highest potassium uptake of 140.74 kg ha^{-1} was noticed in T_6 receiving SC @ 10 t ha^{-1} + 5 t FYM and the lowest value of 19.4 kg ha^{-1} in T_8 (SS @ 20 t ha^{-1}. The total K uptake ranged between 39.61 (T_8) and 204.55 kg ha^{-1} (T_6). The highest value was observed in T_6 (SC @ 10 t ha^{-1}) which was found to be on par with T_5 (202.66 kg ha^{-1}) receiving SC @ 5 t ha^{-1} + 10 t FYM). The least value of uptake was observed in T_8 (SS @ 20 t ha^{-1}). According to [21], the application of biochar increases K uptake because of its capacity to decrease nutrient leaching and increase nutrient availability. K's prolonged and consistent presence in readily accessible form and the improved root development brought about by the fertilisers and biochar enhanced the plants' uptake of K.

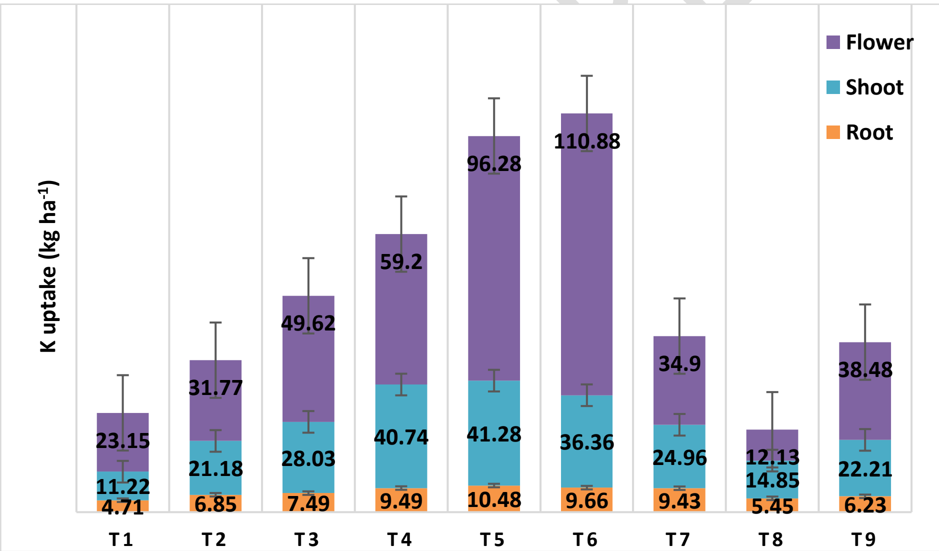

Fig.3 Effect of treatments on K uptake by marigold

Table 5. 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

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}).

3.8 Electrochemical properties of post harvest soil

3.8.1 pH

Table 6 showed that the application of different treatments showed an increase in the soil pH when compared to the pH of initial soil (5.35). The treatment T_4 (SC @ 20 t ha^{-1}) recorded the highest pH (6.42), which was on par with T_6 (6.36) receiving SC @ 10 t ha^{-1} + 5 t FYM, T_7 (6.29) receiving SSC @ 20 t ha^{-1} and T_3 (6.21) receiving SC @ 10 t ha^{-1}. Significantly lower pH of 5.44 was recorded with T_1 (control). Similar results was obtained by [that application of biochar @ 10 kg $plant^{-1}$ + 75 % (NPK + secondary and micronutrients as per STBR) increased the pH from 4.73 to 5.17.

One significant characteristic of biochar that makes it useful as a soil amendment in agriculture is its pH range. The higher pH of biochar, which varies depending on production temperature and raw material type may be the cause of an increase in soil pH following the application of biochar [21]. The presence of negatively charged phenolic groups, such as carboxyl and hydroxyl which link H^+ ions to soil solution and lower the concentration of H^+ ions in the soil is another cause raising pH levels in soils, which was applied with biochar. According to [19], biochar's metal carbonates, hydroxides, and oxides can elevate the pH of soil. When added to soil, biochar can reduce the amounts of Al^{3+} and H^+ ions by exchanging with these ions in water, which can increase base saturation and modify the pH of the soil [17].

3.8.2 Electrical conductivity

The electrical conductivity of the soil ranged between 0.21 (T_1) and 0.48 dSm^{-1} (T_4) (Table 6). The electrical conductivity of initial soil was 0.22 dSm^{-1}. An increase in the electrical conductivity of the soil was noticed in all treatments, except T_1 (control). The treatment T_4 (SC @ 20 t ha^{-1}) recorded the highest value of 0.48 dSm^{-1} which was on par with T_6 (0.44 dSm^{-1}) receiving SC @ 10 t ha^{-1} + 5 t FYM, T_7 (0.41 dSm^{-1}) receiving SSC @ 20 t ha^{-1} and T_3 (0.40 dSm^{-1}) receiving SC @ 10 t ha^{-1}. The least value was recorded with T_1 (0.21 dSm^{-1}). From the data it was clear that treatments receiving sewchar had the highest electrical conductivity compared to the other treatments. This result was consistent with the findings of [22] who found that adding 100 t ha^{-1} of biochar increased soil electrical conductivity by a factor of 15. Because it reacts with water to produce soluble organic and mineral components, the application of biochar and organic amendments might increase the electrical conductivity of soil [17]. The increased electrical conductivity may be the result of the biochar's ions being released into the soil solution over an extended period of time. According to [20], the pyrolysis process's ash generation could be the reason for the biochar application's increase in electrical conductivity. The high pH features of the soil are a significant contributing factor to the rise in electrical conductivity.

3.8.3 Cation exchange capacity

Cation exchange capacity of soil ranged between 4.13 (T_1) to 6.18 cmol(+) kg^{-1} (T_4). Treatment receiving sewchar @ 20 t ha^{-1} (T_4) recorded the highest value of 6.18 cmol(+)kg^{-1} which was on par with T_6 (6.01 cmol(+) kg^{-1}) receiving SC @ 10 t ha^{-1} + 5 t FYM, T_7 (5.93 cmol(+) kg^{-1}) receiving SSC @ 20 t ha^{-1} and the lowest value of 4.13 cmol(+) kg^{-1} was observed in T_1 (control). An increase in the cation exchange capacity of the soil was noticed compared to initial (5.84 cmol(+) kg^{-1}) in all the treatments except treatments T_1 (soil alone), T_2 (SC @ 5 t ha^{-1}) and T_9 (20 t ha^{-1} FYM). When compared to the original soil, there was a noticeable improvement in the soil's capacity for cation exchange. This is consistent with the results of [21] who found that adding biochar raised the soil's CEC. This could be because the surface of the biochar contains acidic aromatic carbon, which enables the formation of many functional groups like -COOH and -OH, which enhance soil cation adsorption and in turn, CEC [22].

Table 6. Effect of treatments on electro-chemical properties of soil

Treatments	pH	EC (dSm^{-1})	CEC c mol(+)kg^{-1}
T_1 (Soil alone)	5.44 ^{d}	0.21 ^{e}	4.13 ^{c}
T_2 (SC @ 5 t ha^{-1})	5.64 ^{d}	0.34 ^{cd}	5.80 ^{b}
T_3 (SC @ 10 t ha^{-1})	6.21 ^{ab}	0.40 ^{abc}	5.91 ^{b}
T_4 (SC @ 20 t ha^{-1})	6.42 ^{a}	0.48 ^{a}	6.18 ^{a}
T_5 (SC @ 5 t ha^{-1}+ 10 t FYM)	6.19 ^{b}	0.35 ^{bcd}	5.88 ^{b}
T_6 (SC @ 10 t ha^{-1}+ 5 t FYM)	6.36 ^{ab}	0.44 ^{ab}	6.01 ^{ab}
T_7 (SSC @ 20 t ha^{-1})	6.29 ^{ab}	0.41 ^{abc}	5.93 ^{ab}
T_8 (SS @ 20 t ha^{-1})	5.89 ^{c}	0.29 ^{de}	5.85 ^{b}
T_9 (KAU POP- 20 t ha^{-1} FYM)	5.60 ^{d}	0.32 ^{cd}	4.26 ^{c}
SEm (±)	0.072	0.031	0.090
CD (0.05)	0.216	0.094	0.270

SC- sewchar, SSC- sewage sludge compost, SS- sewage sludge.

3.9 Chemical properties of soil

3.9.1 Organic carbon

The organic carbon content in the post harvest soil was significantly influenced by various treatments and in the soil, it ranged between 1.01 (T_1) and 1.67 % (T_5) (Table 7). The organic carbon content of the initial soil was 1.09 % and an increase in organic carbon content was observed in post harvest soil due to the application of different treatments of SS, SSC, SC and FYM except T_1 (control). It followed the order T_5 (SC @ 5 t ha^{-1} + 10 t FYM) > T_6 (SC @ 10 t ha^{-1} + 5 t FYM) > T_4 (SC @ 20 t ha^{-1}) > T_9 (20 t FYM) > T_3 (SC @ 10 t ha^{-1}) > T_7 (SSC @ 20 t ha^{-1}) > T_2 (SC @ 5 t ha^{-1}) and T_8 (SS @ 20 t ha^{-1}) with the highest value noticed in T_5 (1.67 %), which was on par with T_6 (1.53 %) and the lowest value in T_1 (1.01 %). When compared to other treatments, the application of SC @ 5 t ha^{-1} + 10 t FYM resulted in the soil having the highest organic carbon content. Similar findings were made by [23], who discovered that applying 10 t ha^{-1} biochar raised the organic carbon content to 0.5 %. Applying biochar can increase the amount of organic carbon in soil due to its high carbon content and recalcitrant nature [24]. According to [25] increased the soil's organic carbon content by 30 to 40 %. The application of sewchar raises soil organic carbon by the interaction of carbon from biochar, microbial activity, rhizosphere breakdown and root exudates [26].

3.9.2 Nitrogen

The available nitrogen concentration of the soil was shown to be significantly impacted by the treatments (Table 7). The mean available nitrogen concentration of post harvest soil ranged from 238.67 (T_1) to 281.33 kg ha^{-1} (T_4). The available nitrogen content of the post-harvest soil was higher than that of the initial soil (245.78 kg ha^{-1}) with the exception of treatment T_1 (control). In comparison to the other treatments, the available nitrogen content of the sewchar treatment was found to be greater. The maximum value (263.37 kg ha^{-1}) was obtained by applying SC @ 5 t ha^{-1} + 10 t FYM (T_5). This value was comparable to that of T_3 receiving SC @ 10 t ha^{-1} (263 kg ha^{-1}) and T_4 receiving SC @ 20 t ha^{-1} (281.33 kg ha^{-1}), T_9 is receiving FYM (250.33 kg ha^{-1}), T_6 is receiving SC @ 10 t ha^{-1} + 5 t FYM (244.77 kg ha^{-1}). T_1 (control), the lowest value of 238.67 kg ha^{-1} was noted. In comparison to the other treatments, the available nitrogen content of the sewchar treatment was found to be greater. Applying sewage sludge biochar raised the total nitrogen, organic carbon, available P and K by more than 1.5, 1.9, 4.5, 5.6, and 0.4 times, respectively [27]. As per the findings of [28], 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 [29]. The quantity of nitrogen that seeps out of the soil can be decreased by adding biochar. According to [30] the application of biochar enhanced the fertiliser nitrogen recovery. Furthermore, biochar may indirectly impact the nitrogen content by enhancing microbial populations.

3.9.3 Phosphorus

The results of the statistical analysis showed that the treatments applied had a substantial impact on the post-harvest soil's available phosphorus concentration (Table 7). In post-harvest soil, the available phosphorus concentration ranged from 58.17 (T_1) to 89.81 kg ha^{-1} (T_5). With the exception of T_1 (control), all treatments showed an increase in available P content relative to the initial available P status of 65.02 kg ha^{-1}. T_6 receiving SC @ 10 t ha^{-1} + 5 t FYM (83.79 kg ha^{-1}), T_3 receiving SC @ 10 t ha^{-1} (78.01 kg ha^{-1}), and T_4 receiving SC @ 20 t ha^{-1} (79.98 kg ha^{-1}) were all on par with T_5 (SC @ 5 t ha^{-1} + 10 t FYM) in terms of best value among the treatments. The present study's findings demonstrated that applying SC might keep the soil's P status while lowering leaching. This is consistent with the results of Kavya 2023, 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 increase P availability [31]. [32] 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.

3.9.4 Potassium

Table 7 presents the data indicating a considerable variation in the available K content of the post-harvest soil across the treatments. The range of values was 161.65 kg ha^{-1} (T_5) to 119.58 kg ha^{-1} (T_1). All treatments, with the exception of T_1, showed an increase in the post-harvest soil's available K content above the initial K status (134.46 kg ha^{-1}). T_5 receiving SC at 5 t ha^{-1} + 10 t FYM recorded the highest value (161.65 kg ha^{-1}), which was comparable to T_6 receiving SC at 10 t ha^{-1} + 5 t FYM (158.71 kg ha^{-1}) and T_4 receiving SC at 20 t ha^{-1} (154.62 kg ha^{-1}). T_1 (control) registered the lowest value of 119.58 kg ha^{-1}.

In comparison to SC @ 10 t ha^{-1} + 5 t FYM and SC @ 20 t ha^{-1}, the highest value was recorded by the sewchar treatment receiving SC @ 5 t ha^{-1} + 10 t FYM. The K status of the soil was improved by applying sewchar. Additionally, [21] noted that the addition of biochar treatments at the 6 months after planting stage of banana enhanced the soil's K availability. 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.

Table 7. Effect of treatments on available major nutrients of soil

Treatments	OC (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
T_1 (Soil alone)	1.01 ^{d}	238.67 ^{d}	58.17 ^{e}	119.58 ^{e}
T_2 (SC @ 5 t ha^{-1})	1.07 ^{cd}	254.53 ^{cd}	69.00 ^{cde}	139.68 ^{cd}
T_3 (SC @ 10 t ha^{-1})	1.22 ^{cd}	263.00 ^{abc}	78.01 ^{abc}	147.64 ^{bc}
T_4 (SC @ 20 t ha^{-1})	1.29 ^{bc}	281.33 ^{abc}	79.98 ^{abc}	154.62 ^{ab}
T_5 (SC @ 5 t ha^{-1}+ 10 t FYM)	1.67 ^{a}	263.37 ^{a}	89.81 ^{a}	161.65 ^{a}
T_6 (SC @ 10 t ha^{-1}+ 5 t FYM)	1.53 ^{ab}	244.77 ^{ab}	83.79 ^{ab}	158.71 ^{a}
T_7 (SSC @ 20 t ha^{-1})	1.21 ^{cd}	276.33 ^{bcd}	74.43 ^{bcd}	140.05 ^{cd}
T_8 (SS @ 20 t ha^{-1})	1.06 ^{cd}	263.33 ^{cd}	65.18 ^{de}	134.63 ^{d}
T_9 (KAU POP - 20 t ha^{-1} FYM)	1.25 ^{bcd}	250.33 ^{abc}	76.91 ^{bcd}	145.50 ^{bc}
SEm (±)	0.092	6.559	4.284	3.324
CD (0.05)	0.277	19.663	12.844	9.964

SC- sewchar, SSC- sewage sludge compost, SS- sewage sludge.

4. Conclusion

The results of the present study showed that application of sewage sludge, sewage sludge compost and its biochar significantly improved the soil chemical properties, 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 @ 5 t ha^{-1} along with 10 t FYM was found to be superior in vegetative parameters such as plant height, number of primary and secondary branches compared to the other treatments. Likewise the floral parametres such as flower diameter, flower weight and number of flowers per plant, yield parameters such as dry matter yield of shoot, root and flower were enhanced by the application of sewage sludge biochar. 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.

References

1. CPCB [Central Pollution Control Board] 2016. *Annual Report* 2015–16. [on-line] Available: http://cpcb.nic.in/annual-report.php [16 Nov 2020].
2. Hwang IH, Ouchi Y, Matsuto, T. Characteristics of leachate from pyrolysis residue of sewage sludge. Chemosphere. 2007. *68*(10):1913-19.
3. Mahmood-Ul-Hassan M, Yousra M, Saman L, Ahmad R. Floriculture: alternate non-edible plants for phyto-remediation of heavy metal contaminated soils. Int J Phytoremediation. 2020;22(7): 725–28.
4. Tabrizi L, Mohammadi S, Delshad M, Moteshare ZB. Effect of arbuscular mycorrhizal fungi on yield and phytoremediation performance of pot marigold (*Calendula officinalis L*.) under heavy metals stress. Int J Phytoremediation. 2015;17(12):1244–52.
5. Coelho LC, Bastos ARR, Pinho PJ, Souza GA, Carvalho JG, Coelho VAT, Oliveira LCA, Domingues RR, Faquin V. Marigold (*Tagetes erecta*) the potential value in the phytoremediation of chromium. Pedosphere. 2017;27(3):559–568.
6. Rehana MR, Joseph, B, Gladis, R. Heavy metal stabilization in sewage sludge composting process. Cur J Appl Sci and Technol. 2020;39(19):38-48.
7. Jackson ML. Soil Chemical Analysis. New Delhi, Prentice Hall of India Pvt. Ltd. New Delhi. 1967;498.
8. Hossain MK, Strezov VK, Yin C, Nelson PF. Agronomic properties of waste water sludge biochar and bioavailability of metals in production of tomato (*Lycopersicon esculentum*) Chemosphere.2010;78:1167–71.
9. Asokan, A. Evaluation of sewage sludge as a growth medium for ornamentals. M.Sc.(Ag) thesis, Kerala Agricultural University. Thrissur. 2017:110p.
10. Jabin N. Biochar for carbon sequestration, soil health and crop crop productivity. PhD thesis, Kerala Agricultural University. 2022:309p.
11. Leopold LB. Reversal of erosion cycle and climatic change. Quatery Research. 1974; 6:557-62.
12. Kavya SR. Nutrient release pattern and performance of biochar blended N and K fertilizers in laterite and sandy soils.2023:350p.
13. Driesen E, Van den Ende W, De Proft M. Saeys W. Influence of environmental factors light, CO2, temperature, and relative humidity on stomatal opening and development: A review. Agronomy. 2020;10(12):1975-84.
14. Chan, KY, Van Zwieten L, Meszaros I, Downie A. Joseph, S. Using poultry litter biochars as soil amendments. 2008. Soil Research;46(5):437-44.
15. Uzoma KC, Inoue M, Andry H, Fujimaki H, Zahoor A, Nishihara E. Effect of cow manure biochar on maize productivity under sandy soil condition. Soil use and management. 2011;27(2):205-12.
16. Purakayastha TJ, Bera T, Bhaduri D, Sarkar B, Mandal S, Wade P et al. A review on biochar modulated soil condition improvements and nutrient dynamics concerning crop yields: pathways to climate change mitigation and global food security. Chemosphere.2019;*227*:345-65.
17. Tanazawa Y, Tomotsune M, Suzuki T, Koizumi H. Yoshitake S. Photosynthetic response of young oaks to biochar amendment in field conditions over 3 years. Journal of Forest Research. 2021.*26*(2):116-26.
18. Dainy MS. Investigations on the efficacy of biochar from tender coconut husk for enhanced crop production. Ph.D. thesis, Kerala Agricultural University, Thrissur, 2015:245p.

19. Antonkiewicz J, Kuc A, Witkowicz R, Tabak M. Effect of municipal sewage sludge on soil chemical properties and chemical composition of spring wheat. *Ecological Chemistry and Engineering.* 2019;*26*(3):583-595.
20. Widowatil W, Asnah A. Biochar can enhance potassium fertilization efficiency and economic feasibility of maize cultivation. 2014;J. Agric.Sci.6(2):24-36.
21. Nagula S. Technology refinement for biochar production and evaluation of its effect on soil health and crop productivity. Ph.D. thesis, Kerala Agricultural University. Thrissur, 2017:243p.
22. Mendes J, Fernandes, JD, Chaves LHG, Guerra HOC, Tito GA, de Brito Chaves I. Chemical and physical changes of soil amended with biochar. Water Air, Soil Pollut. 2021;232(8):338.
23. Zwieten L, Kimber S, Morris S, Chan KY, Downie A, Rust J, Joseph S, Cowie A. Effects of biochar from slow pyrolysis of paper mill waste on agronomic performance and soil fertility. *Plant Soil*. 2010;327(1):235-46.
24. Adeniyi AG, Ogunniyi S, Iwuozor KO and Emenike EC. Thermochemical conversion of African balsam leaves-cow dung hybrid wastes into biochar. *Biofuels Bioproducts and Biorefining*. 2023;*17*(3):510-22.
25. Gross CD, Edward W, Cameron N, Carlyle S, Chang X.. Biochar and its manure-based feedstock have divergent effects on soil organic carbon and greenhouse gas emissions in croplands. Sci. Total Environ. 2022; 806:151337.
26. Qianqian M, Haider FU, Farooq M, Adeel M, Shakoor N, Jun W. et al. Selenium treated Foliage and biochar treated soil for improved lettuce (*Lactuca sativa L.*) growth in Cd-polluted soil. J. Clean. Prod. 2022;335:130267.
27. Yue Y, Cui L, Lin Q, Li G, Zhao X. Efficiency of sewage sludge biochar in improving urban soil properties and promoting grass growth. Chemosphere. 2017.173;2017:551–56.
28. Novak JM, Busscher WJ, Laird DL, Ahmedna M, Watts DW, Niandou MA. Impact of biochar amendment on fertility of a southeastern coastal plain soil. *Soil science*.2009:*174*(2):105-12.
29. Zhao X, Yan X, Wang S, Xing G, Zhou Y. Effects of the addition of rice-straw-based biochar on leaching and retention of fertilizer N in highly fertilized cropland soils. *Soil science and plant nutrition*; 2013;*59*(5):771-82.
30. Kanthle AK, Lenka NK, Lenka S, Tedia K. Biochar impact on nitrate leaching as influenced by native soil organic carbon in an Inceptisol of central India. *Soil and Tillage Research*. 2016;*157*:65-72.
31. Fischer D, Glaser B. Management of organic waste. Halle (Germany): Institute of Agricultural and Nutritional Sciences.2012.
32. Yang D, Liu Y, Liu S, Li Z, Tan X, Huang X, Zeng G, Zhou L, Zheng, B. Biochar to improve soil fertility. A review. *Agron. Sustain. Dev.* 2016*;*36 (2): 36-54.