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Sewage Sludge and its Impact on Soil Property

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Abstract Recognized as a valuable resource, sewage sludge could be recycled as fertilizer and soil improvement material for land because it consists largely of organic substance and also contains N and P, which are the main nutriental elements of plants and soil fertility. However, sewage sludge consists of not only valuable cpmponents such as nutrients but also heavy metals. This paper reports the physico-chemical properties of sewage sludge (obtained from NMK-STP, Hyderabad) and its impact on soil fertility as a soil health amendment. A total of seven potting media were prepared containing soil, sewage sludge and different ratios of soil + sewage sludge. Results indicated that sewage sludge can be safely used as a rich organic matter for realizing batter soil properties as ecofriendly manners insteda of inorganic fertilizers. Among treatments, T_5 was found to be significantly superior in all observed parameters. The physico-chemical and chemical characteristics of sewage sludge were done which indicated that it was moderately acidic (pH 5.81) in nature. EC was 5.48 dS m^{-1} and total organic carbon was 25.76%. Total N, P and K contents of sewage sludge were 3.29, 1.23 and 2.98%, respectively. The triacid extractable zinc, in sewage sludge, was 27.72 mg kg^{-1}. The diacid extractable heavy metals viz., Cd, Co, Ni, and Pb were accordingly 0.97, 0.37, 1.69 and 6.86 mg kg^{-1}. All the heavy metals were within maximum permissible limits as per the USEPA standards. It was concluded that addition of sewage sludge, in appropriate quantities, to potting media has synergistic effects on soil physico-chemical properties, its organic matter contains and nutrients status.

Keywords Sewage sludge, Soil properties, Organic amendment, Nutrients, SVI.

Introduction

Sewage sludge is a residual mixture of organic and inorganic solids derived from municipal waste water

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treatment. It contains a large amount of major and micro nutrients besides having high organic matter content. Hence, it can improve soil physical, chemical and biological properties [1]. Thus, it can be explored as an alternative organic source to supplement chemical fertilizers in crop production. The major interest to use this sewage sludge for growing crops is to promote the concept of wealth out of waste in order to have green and clean earth. It also makes better earning by investing less as low-cost technology.

Waste management has become a major environmental challenge, and land application of sewage sludge is generally considered the best option for disposal of sewage sludge because it offers the possibility of recycling plant nutrients, provides organic material, improves soil fertility along with physical properties and enhances crop yields [2].

There is a growing concern to decrease the application of chemical fertilizer to soils using soil nutrients more efficiently and by more application of organic matter. Excessive applications of agro-chemicals in crops have adversely affected the soil flora, fauna, and enzymes which help to maintain the natural fertility of the soil. Higher usage of fertilizers and pesticides has also desired more irrigation causing additional stress on water sources [3]. Incorporation of organic amendments such as animal manures, crop residues, compost and sewages sludge, to the soil, improved its properties [4, 5].

The organic fraction in organic amendments can enhance significantly soil aggregate-on, water infiltration, microbial activity, structure, and water-holding capacity particularly in soils of arid and semiarid regions and it can reduce soil compaction and erosion [6, 7]. Chemical properties such as cation exchange capacity, organic carbon, and soil pH may also be improved by organic amendments application [6].

Application of sewage sludge can improve soil fertility and productivity [8, 9]. Sewage sludge production has increased with urbanization throughout the world. In light of this, there is a need to increase sewage sludge safety as a soil amendment. The use of mineral fertilizer by farmers is limited because of scarcity, high costs and basic disadvantages in apparent inability to substantially redress the physical fragility and chemical deterioration of the soil [10].

This necessitates research on the use of organic wastes that are cheap, readily available and environmentally friendly as fertilizers. One of the ways of improving soil fertility is by maintaining its organic matter. This is possible through the use of organic sources of fertilizer. Research has shown that organic based fertilizers are less leached into ground water than the chemical fertilizer.

Sludge is a concentrated suspension of solids, largely composed of organic matter, nutrients and organic solids. In addition to the major plant nutrients, sewage sludge also contains trace elements that are essential for plant growth. As soil has become deficient in certain trace elements such as Zn and Fe due to intensive cultivation, land application of sewage sludge gains importance to circumvent this problem. Seldom, it may contain toxic heavy metals. Hence, physico-chemical and chemical properties of the sewage sludge collected from Noor Mohammed Kunta-sewage treatment plant (NMK-STP) were analyzed along with nutrient status and heavy metals which are presented in Table 1.

In India, more than 100 cities and towns have complete or partial sewerage system in addition to 700 towns with the open drainage system. Sewage available from these cities and towns are estimated to about 800 million gallons day^{-1}. This amounts to an addition of organic manure to an extent of 1,456 t day^{-1} or about 5,30,000 t annum^{-1} with an approximate nutrient content of 33,000 t N, 7,000 t P_2O_5 and 20,000 t K_2O. Because of the higher nutritive value of sewage sludge, there is abundant scope in India for the gainful use of this source as an organic manure to supplement chemical fertilizer in agriculture.

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manuscript writing).

Materials and Methods

Study site

A pot culture experiment was conducted on alfisols (red soil) at green house farm of the Department of Horticulture, College of Agriculture, Rajendranagar, Hyderabad during *kharif* 2013 to study the innovative approach of the effect of sewage sludge on soil properties.

Treatments

The experiment was laid out in completely randomized design (CRD) with three replications and necessary data was collected whenever required. There were seven treatments consisting of T_1 (20% sewage sludge), T_2 (40% sewage sludge), T_3 (60% sewage sludge), T_4 (80% sewage sludge), T_5 (100% sewage sludge), T_6 (RDF - Inorganic N, P and K @ 100, 100 and 100 kg ha^{-1}, respectively) and T_7 (Control).

Experimental protocol

Before starting of an experiment the silent properties of soil and sewage sludge were analyzed using standard methods, which are presented in Table 1.

Soil sampling and analysis

The representative soil (Red soil) sample was analyzed for its physico-chemical properties and nutrient status and the data is given in Table 1. The pH of soil was determined in 1:2.5 soil-water suspension after half an hour equilibration, with a glass electrode pH meter [11]. The electrical conductivity was determined in 1:2 soil-water suspension by using conductivity bridge [11] and expressed in dS m^{-1}. Organic carbon content of the soil was estimated by the wet digestion method [12]. Available nitrogen content of the soil was estimated by alkaline permanganate method [13]. Available phosphorus was extracted from soil by using Olsen's extractant (0.5 N $NaHCO_3$ with pH 8.5). The readings were recorded with a spectrophotometer at 420 nm and were expressed in kg P_2O_5 ha^{-1}. Available potassium was extracted from the soil using neutral normal ammonium acetate in 1:5 ratio and the readings were recorded using flame photometer. The quantity was calculated and expressed as kg K_2O ha^{-1}.

Table 1. Initial properties of soil and sewage sludge.

Parameters	Units	Values: Soil	Values: Sewage sludge
Physio-chemical properties			
Soil reaction	pH	7.79	5.81
EC	dS m^{-1}	0.88	5.48
OC	%	0.72	25.76
Total major nutrients status			
Nitrogen	Kg ha^{-1}	271.64	3.29 (%)
Phosphorus	Kg P_2O_5 ha^{-1}	38.75	1.23 (%)
Potassium	Kg K_2O ha^{-1}	253.81	2.98 (%)
Micro nutrients			
Zinc	mg kg^{-1}	3.61	27.72
Total heavy metals			
Cadmium	mg kg^{-1}	0.23	0.97
Cobalt	mg kg^{-1}	0.13	0.37
Nickel	mg kg^{-1}	0.83	1.69
Lead	mg kg^{-1}	3.85	6.86
SVI	mL g^{-1}	–	482.71

DTPA extractable zinc and heavy metals in soil

Method developed by [14] was used for zic, cadmium, cobalt, nickel and lead analysis. The filtrate was used for estimation of Zi, Cd, Co, Ni and Pb using atomic absorption spectrophotometer (AAS model no. NovAA 300 BU).

Sewage sludge chemical analysis

Sewage sludge used in the pot culture experiment was analyzed for physico-chemical and chemical properties by using standard procedures. The pH was determined in 1:10 sewage sludge (1 mm sieved) and water suspension by using combined glass electrode pH meter [11]. Electrical conductivity was determined in 1:20 sewage sludge and water suspension by using Electrical Conductivity Meter [11] and expressed in dS m^{-1}. Organic carbon content of sewage sludge was estimated by the digestion method [12]. The nitrogen content of the sewage sludge was determined following [15] method.

Digestion of sewage sludge for P, K, and Zn

Finely ground sample (0.5 g) was digested with 20 ml triacid mixture consisting of HNO_3: H_2SO_4: $HClO_4$ in 9:4:1. The digest was kept on the hot plate for about two hours at 160°C until a clear digest was obtained. The intensity of yellow color was determined by using double beam UV Spectrophotometer model UV5704SS at 420 nm [16]. The potassium content in the triacid digest was determined by using Flame photometer model CL 361 [11]. Zinc in the triacid extract was determined by using the Atomic Absorption Spectrophotometer (AAS) model NOVAA300 and expressed as mg kg^{-1} [14].

Digestion of sewage sludge for heavy metals (Cd, Co, Ni, and Pb)

Finely ground sample (1g) was digested with 20 ml diacid mixture consisting of HNO_3: $HClO_4$ in 9:4. The digest was kept on the hot plate for about two hours at 160°C, until a clear digest was obtained. The diacid extract was used for analysis of heavy metals (Cd, Co, Ni and Pb) using the Atomic Absorption Spectophotometer (AAS) model NOVAA300 and expressed as mg kg^{-1} [17].

Sludge volume index (SVI)

The sludge volume index is the volume in milliliters occupied by one gram of a suspension after 30 minutes settling [18]. SVI determined through used standard laboratory test method [19]. The procedure involves measuring the Mixed Liquor Suspended Solids (MLSS) value and also the sludge settling rate.

$$\text{SVI (mL g}^{-1}\text{)} = \frac{\text{SSV (mL L}^{-1}\text{)}}{\text{MISS (mg L}^{-1}\text{)}} \times 100$$

Statistical analysis

The results of pot culture study were subjected to statistical analysis as per the procedures outlined by Snedecor and Cochran [20].

Permissible limit

Permissible limits for selected parameters were mentioned earlier [21, 22].

Results and Discussion

Physico-chemical properties of sewage sludge

The sewage sludge was moderately acidic with pH of 5.81. It was slightly saline with EC value of 5.48 dS m^{-1}. Organic carbon was high (27.76%) and SVI was 482.71 mL g^{-1}. The available total nutrients viz., N, P and K in sewage sludge were 3.29, 1.23 and 2.98%, respectively. The N, P and K content of sewage sludge was more by 6.58, 6.15 and 5.96 times, respectively than Farm Yard Manure and compared with urban compost, available N, P and K was more by 6.58, 2.46 and 2.98 times, respectively. The triacid extractable zinc of sewage sludge was 27.72 mg kg^{-1} which was within the maximum permissible limits as per [21].

Diacid extractable heavy metals (Cd, Ni, Co and Pb)

The diacid extractable contents of heavy metals Cd, Ni, Co and Pb were 0.97, 1.69, 0.37 and 6.86 mg kg^{-1}, respectively. The heavy metal contents were within the maximum permissible limits [21, 22].

Physico-chemical properties of soil

The soil was slightly alkaline with pH of 7.79. Its EC value was 0.88 dS m^{-1}. Organic carbon was high (0.72%). The available total nutrients viz., N, P and K in soil were 271.6, 38.7 and 253.8 kg ha^{-1}, respectively. The triacid extractable zinc of soil was 3.6 mg kg^{-1}.

Diacid extractable heavy metals (Cd, Ni, Co and Pb)

The diacid extractable contents of heavy metals Cd, Ni, Co and Pb were 0.23, 0.83, 0.13 and 3.85 mg kg^{-1}, respectively. The heavy metal contents were within the maximum permissible limits [21, 22].

Effect of sewage sludge on soil properties

The analysis of soil, collected from marigold experiment at initial (before transplanting), mid (45 DAT) and harvesting stages (90 DAT) was carried to assess the effect of sewage sludge on soil properties.

Soil reaction (pH)

The soil pH recorded at initial, mid and harvesting stages are presented. The soil pH differed significantly at all the stages by different treatments of sewage sludge. The pH of soil increased as crop age advanced. Significantly lowest soil pH (5.81) was recorded at initial stage in T_5 followed by T_4 (6.49). In contrast, highest pH of 7.79 was observed in T_7. The soil pH in T_5 was significantly less by 34.08%, 23.41% and 11.70%, respectively as compared with T_7, T_6 and T_4. The soil pH at mid stage ranged from 6.16 in T_5 to 7.90 in T_7. The pH recorded in T_5 was significantly less by 28.25%, 16.88% and 10.23%, respectively as compared with T_7, T_6 and T_4. The pH observed in T_1, T_2 and T_3 were on par with each other. Similar trend in soil pH that observed at initial and mid stage was noticed even at harvesting stage. The lowest soil pH (6.53) was obtained in T_5 and the highest pH of 8.03 was observed in T_7 as compared with other treatments. The pH was 22.97% less in T_5 than T_7. Soil pH was though slightly alkaline initially, changed to neutrality with increase in dose of sewage sludge application and with advancement in crop age. Thus, in T_5 at harvesting stage, the pH was found to be neutral (6.53). The observation of lowest soil pH in T_5 at initial, mid and also at harvesting stages can be attributed to more acidic nature of sewage sludge and the quantity of sewage sludge applied in this treatment was more as compared with rest of the treatments. This finding can be corroborated by the observations made by Lindsay and Norwell [14] that release of humic acid due to biodegradation of organic carbon-rich sewage sludge. Jingjun and Phunch [23] also stated that, pH was lower in surface soil with the application of more sewage sludge than control. Soil pH decreased significantly from 6.36 to 6.01 by the addition of organic manures like cow dung. Reduction in soil pH with application of poultry manure and mustard oil cake was also reported earlier [24]. Similar result was also expressed by Singh and Agrawal [25] who reported that, with increased dose of sewage sludge application, soil pH decreased as compared with control.

Electrical conductivity (EC)

The highest EC (5.48 dS m^{-1}) was observed in T_5 followed by T_4 and T_3. The lowest EC of 0.88 dS m^{-1} was observed in T_7. The soil EC was recorded more by 30.48% in T_5 than T_4. The soil EC recorded at mid stage ranged from 0.76 dS m^{-1} in T_7 to 5.25 dS m^{-1} in T_5. The EC recorded in T_5 was significantly more by 37.08% and 108.33%, respectively as compared with T_4 and T_3, similar that seen at initial stage. The EC obtained in T_3 was significantly more than T_2. At harvesting stage, the highest soil EC (4.89 dS m^{-1}) was recorded in T_5 and was significantly more than T_4 (3.53 dS m^{-1}) followed by T_3 (2.37 dS $m^{-1)}$. The lowest soil EC of 0.75 dS m^{-1} was observed in T_7. The soil EC was more by 38.53% in T_5 than T_4. Similar trend was also observed at initial and mid stage. Soil EC at initial stage was though slightly saline and it was also slightly saline in T_5 at harvesting stage. The higher soil EC recorded at initial, mid and harvesting stages in T_5 may be due to higher salt content and mineralization of sewage sludge. Mallesh [26] also stated that, there was an increase in EC of the soil from 0.38 to 0.53 dS m^{-1} with the application of compost, from 0.38 to 0.45 dS m^{-1}. The application of farm yard manure and poultry manure also resulted similarly [27]. Singh and Agrawal [25] also opined that, there was increase in soil EC with increase in dose of sewage sludge application.

Organic carbon (OC) content

The content of soil organic carbon was increased as crop age advanced. The soil organic carbon (SOC) recorded at initial stage in T_5 was highest (25.76%) followed by T_4 (21.65%). The lowest SOC of 0.72% was observed in T_7. The soil organic carbon was significantly more by 18.98% in T_5 than T_4. The content of soil organic carbon at mid stage ranged from 0.71% in T_7 to 27.86% in T_5. In T_5, it was significantly more to the extent of 20.35%, 51.33% and 121.11%, respectively as compared with T_4, T_3 and T_2, similar to that seen at initial stage. The SOC notice in T_6 and T_7 were on par with each other. The trend observed in soil organic carbon at harvesting stage was similar to initial and mid stages. Significantly highest (32.56%) and lowest soil organic carbon (0.69%) were recorded in T_5 and T_7, respectively. Soil organic carbon at initial stage was medium and was high at harvesting stage in T_5. The highest soil organic carbon recorded at initial, mid and harvesting stages in T_5 was due to higher organic carbon, organic matter and nutritional value of sewage sludge. Similar result was expresed according to application of sewage sludge and urban compost in 1:1 ratio resulted in high organic carbon content. Poornesh et al. [28] also stated that, the application of urban garbage compost increased the organic carbon content in soil. The macronutrients in the sewage sludge serve as a good source of organic matter and plant nutrients [8]. Similar results were also expressed by Begum [29] that the organic carbon increased from 2.4 to 3.3 g kg^{-1} with increase in dose of municipal sewage sludge vermicompost application from 10 to 30 t ha^{-1} at Bangaluru.

Available nitrogen (kg ha^{-1})

The availability of nitrogen increased with increase in dose of sewage sludge and with advancement with crop age. The highest soil nitrogen content (562.4) was observed at initial stage in T_5 followed by T_4 (552.9) and T_3 (482.6), unlike soil organic carbon where, T_5 recorded significantly highest as compared with T_4. The lowest nitrogen (271.6) was observed in T_7 followed by T_1 (265.4). Available soil nitrogen at mid stage ranged from 252.8 in T_7 to 608.4 in T_5. In T_5, it was significantly more by 4.20% than T_4, unlike that noticed at initial stage. The available nitrogen in T_2 was significantly more by 25.71% than T_1. The data recorded on available nitrogen at harvesting stage in T_5 was significantly highest (678.2) and it was more by 9.13% and 25.56%, respectively as compared with T_4 and T_3. Similar trend was also noticed at mid stage. The lowest available nitrogen (248.9) was observed in T_7 followed by T_1 (275.9). Available soil nitrogen content in T_5 at both initial stage and harvesting stage can be categorized as high. Highest available nitrogen in T_5 at initial, mid and harvesting stages was due to more nitrogen content of sewage sludge and its availability with more sewage sludge application. Relatively high per cent of organic carbon in sewage sludge increased the cation exchange capacity, which helped to retain essential plant nutrients within the rooting zone due to additional cation binding sites [30]. Similar trend was also observed by Ullah et al. [24].

Available phosphorus (kg P_2O_5 ha^{-1})

The highest phosphorus content (59.5) at initial stage recorded in T_5 was differed significantly as compared with rest of the treatments. This trend was also observed in soil organic carbon. The availability of P ranged from 38.7 in T_7 to 59.5 in T_5. The increase in available phosphorus was more by 11.21% in T_5 than T_4. Highest available phosphorus (64.2) at mid stage was recorded in T_5 and it was significantly more than that in T_4 (59.9) followed by T_3 (52.6), similar that observed at initial stage. The lowest available phosphorus (36.3) was observed in T_7. The available phosphorus was more by 7.18% in T_5 than T_4. The trend observed in available phosphorus at harvesting stage was similar to initial and mid stages. Significantly highest (52.7) and lowest available phosphorus (31.9) were obtained in treatments of T_5 and T_7, respectively. Soil phosphorus content at initial and harvesting stage was high in T_5. More available phosphorus in T_5 at initial, mid and harvesting stages as compared with rest of the treatments can be attributed to higher phosphorus availability from sewage sludge similar to nitrogen. This finding can be supported by the observation made by Singh and Agrawal [25] that, the soil P content increased with increase in dose of sewage sludge. Soon [30] also stated that, relatively high per cent of organic carbon in sewage sludge increased the cataion exchange capacity, which subsequently helped to retain essential plant nutrients within the rooting zone.

Available potassium (kg K_2O ha^{-1})

Highest available soil potassium (618.3) at initial stage was recorded in T_5 followed by T_4 (570.1) and T_3 (497.4), similar to trend of available nitrogen. The available potassium was more by 8.45% in T_5 than T_4. The lowest available potassium (253.8) was recorded in T_7. The data recorded on soil available potassium at mid stage ranged from 243.6 in T_7 to 643.2 in T_5. The available potassium recorded in T_5 was significantly more by 9.00%, 25.77% and 90.35%, respectively as compared with T_4, T_3 and T_2, unlike to the trend observed at initial stage among the T_5, T_4 and T_3. Similar trend in soil available potassium that observed at initial and mid was also noticed even at harvesting stage. The lowest soil available potassium (238.1) was obtained in T_7 and the highest available potassium of 662.6 was observed in T_5 as compared with other treatments. The available potassium was 9.39% more in T_5 than T_4. Similar result was also expressed by Saruhan et al. [31] that, the availability of K in soil increased (528.6, 688.4 and 789.1 mg kg^{-1}, respectively) with the increase in sewage sludge application rates (@ 3, 6 and 9 t ha^{-1}, respectively). The explanation given in case of more organic carbon, nitrogen and phosphorus also holds good here in terms of more availability of potassium in T_5 than T_7.

DTPA extractable zinc (mg kg^{-1})

Significant differences were observed at initial stage due to the different rates of sewage sludge application. The highest DTPA extractable zinc (27.72) was observed in T_5 followed by T_4 and T_3. The lowest DTPA extractable zinc of 3.61 was observed in T_7. The soil DTPA extractable zinc was more by 21.37% in T_5 than T_4. This trend was similar that seen in case of nitrogen and potassium availability at initial stage. Significantly highest DTPA extractable zinc (30.44) at mid stage was recorded in T_5 followed by T_4 (23.22), unlike that at initial stage among T_5 and T_4. The lowest DTPA extractable zinc (3.49) was observed in T_7. The zinc content was significantly more by 31.09% in T_5 than T_4. DTPA extractable zinc of soil at harvesting stage ranged from 3.56 in T_7 to 31.60 in T_5. In T_5 it was significantly more by 26.00% than T_4, similar to that noticed at mid stage. The lowest DTPA extractable zinc (3.56) was recorded in T_7 followed by T_1 (8.65) and T_2 (11.79). Studies on sewage sludge [32] showed that, metal concentration released to the supernatant liquid increased as pH decreased below the threshold value, which was 5.8 for Zn in loaded sludge. The results expressed by Singh and [8]; [25] and [29] corroborates this finding of the present study that in T_5, pH was significantly lowest as compared with rest of treatments resulting in release of Zn to soil.

DTPA extractable lead (mg kg^{-1})

The highest DTPA extractable Pb (6.863) was observed in T_5 followed by T_4 (6.623) and T_3 (6.567). The lowest DTPA extractable Pb of 3.854 mg kg^{-1} was observed in T_7. The Pb recorded was more by 78.07% in T_5 than T_7. This trend was similar that observed in case of potassium and zinc availability at initial stage. The DTPA extractable Pb recorded at mid stage ranged from 3.852 in T_7 to 10.443 in T_5. The Pb recorded in T_5 was significantly more by 15.38% than T_4. Extractable Pb in T_3 (8.259) was also significantly more than T_2 (7.290). The trend of DTPA extractable Pb in soil at harvesting stage renged from 3.972 in T_7 to 14.941 in T_5. The highest DTPA extractable lead (14.941) was recorded in T_5 followed by T_4 and T_3. The DTPA extractable Pb was significantly more by 8.76% in T_5 than T_4. This trend was similar that at mid stage. The magnitude of increase in DTPA Pb content in T_5 compared to T_4 was much lower at mid stage (15.38%) and lowest (8.76%) at harvesting stage than at initial stage (78.07%). The DTPA extractable Pb content was within the maximum permissible limits as per WHO standards, 1996. More availability of DTPA extractable Pb in T_5 as compared with rest of the treatments can be attributed to low pH in this treatment. The present experimental results follow the observations made by Singh and Agrawal [25] that with increase in dose of sewage sludge application, soil Pb content increased Begum [29] also reported higher availability of heavy metals and zinc with municipal sewage sludge vermicompost.

DTPA extractable nickel (mg kg^{-1})

The DTPA extractable nickel increased in soil with advancement in crop age. DTPA extractable Ni at initial stage ranged from lowest value of 0.830 in T_7 to highest value of 1.693 in T_5. In T_5, it was significantly more by 36.86% and 69.13%, respectively as compared with T_4 and T_3. This trend was similar to that observed in case of K, Zn and Pb availability at initial stage. The Ni content in T_1 0.841 and in T_2 (0.912). T_6

(0.886) and T_7 (0.830) were on par with each other in Ni content. The DTPA extractable Ni in soil recorded at mid stage ranged from 0.826 in T_7 to 1.860 in T_5. The DTPA extractable Ni was more by 36.97% and 83.79%, respectively as compared with T_4 and T_3, which was similar to that recorded at initial stage. The highest DTPA extractable Ni content (2.233) recorded at harvesting stage was observed in T_5 followed by T_4. The lowest DTPA extractable Ni (0.813) was observed in T_7. The Ni content was more by 55.39% in T_5 than T_4, similar to that seen at initial and mid stage. The data recorded on Ni content was within the maximum permissible limits as per [32]. Higher DTPA extractable nickel (Ni) in T_5 was found due to more concentration in sewage sludge and Ni availability from sewage sludge due to low pH. Studies on sewage sludges done and showed that, metal concentration released into the supernatant liquid increased as pH decreased.

DTPA extractable cobalt (mg kg^{-1})

Significantly highest DTPA extracatable cobalt (0.373) was recorded at initial stage in T_5 followed by T_4 (0.341) and T_3 (0.262). Similar trend was also observed in case of K, Zn, Pb and Ni content at initial stage. Significantly lowest DTPA extractable cobalt (0.136) was observed in T_7 followed by T_1 (0.185). The DTPA extractable cobalt at mid stage ranged from 0.140 in T_7 to 0.459 in T_5. The cobalt content was significantly more by 31.90% in T_4 than T_4, similar to that recorded at initial stage. The cobalt content recorded in T_1 and T_6 was on par with each other. The highest DTPA extractable cobalt content (0.680) in soil at harvesting stage was observed in T_5 followed by T_4 (0.414). The lowest cobalt content (0.145) was observed in T_7 followed by T_1 (0.198). This trend was unlike to the trend that noticed al initial and mid stage among T_7 and T_1. Generally sewage sludge consists of organic compounds, macronutrients and a wide range of micronutrients, non-essential trace metals, organic micro pollutants and microorganisms. The present result was also similar to the observation made by Singh and Agrawal [10]. Similar result was also expressed by Saruhan et al. [27] that, the concentration of cobalt in soil increased with increase in sewage sludge application rates.

DTPA extractable cadmium (mg kg^{-1})

The DTPA extractable cadmium increased in soil as the crop age advanced. Significantly highest DTPA extractable Cd (0.975) in soil was recorded at initial stage in T_5 followed by T_4 (0.619) and T_3 (0.556) similar to other heavy metal viz., Ni, Co. The lowest DTPA extractable cadmium (0.234) was found in T_7 followed by T_1 (0.492). Extractable cadmium content at mid stage ranged from 0.237 in T_7 to 1.145 in T_5. In T_5, it was significantly more by 15.19% than T_4, similar to that seen at initial stage. The DTPA extractable cadmium (0.568) in T_2 was on par with T_1 (0.568). Extractable Cd content in soil at harvesting stage was significantly highest (1.363) in T_5 followed by T_4 (1.199) and T_3 (0.680). The Cd content was more by 13.68% in T_5 than T_4. Cadmium content at all stages of observation was within the maximum permissible limits as per [32].

Potting mixture temperature (°C)

The temperature values were recorded at both the 45 and 60 DAT. Potting mixture temperature at 45 DAT ranged from 32.7°C in T_7 to 35.7°C in T_5. In T_1 (33.0°C), T_2 (33.2°C), T_3 (33.5°C), T_6 (32.9°C) and T_7 (32.7°C), the temperature were on par with each other. The temperature was significantly more by 9.17% in T_5 than T_7. The highest temperature (35.8°C) of potting mixture measured at 60 DAT in T_5 followed by T_4 (33.2°C), similar to that noticed at 45 DAT. The lowest temperature of 31.7°C was observed in T_7 followed by T_1 (32.3°C). The higher temperatures of potting mixture recorded at 45 and 60 DAT in T_5 may be due to more decomposition and higher root concentration in higher dose of sewage sludge treatment as compared with lower dose of sewage sludge. Soil temperature was the major factor influencing the rate of sewage sludge decomposition. He demonstrated a relationship between the amounts of CO_2 evolved and degree temperature at Polytechnic Institute of Virginia. The rate of decomposition increased when the amount of sewage sludge increased. The rate of sludge decomposition in soil was influenced by temperature, type and amount of sludge and time of application. The mineralization rate of sewage sludge in soil increased approximately 1.9 times when the temperature was increased from 8 to 22°C.

Conclusion

The NPK content of sewage sludge used in the present experiment was high along with organic carbon content. The content of heavy metals Pb, Ni, Co and Cd was within maximum permissible limits. The major nutrients (NPK), organic carbon, micronutrient (Zn) and heavy metals (Pb, Ni, Co and Cd) content in soil were found to be highest in the treatment of 100% sewage sludge (T_5) at all stages of observation. However, the heavy metals (Pb, Ni, Co and Cd) were within maximum permissible limits as per USEPA standards. Thus, sewage sludge generated from NMK-STP located near College of Agriculture was found to be a good organic source of fertilizer in eco-friendly way. However, the trial needs further study to confirm the results before extensive and intensive use of sewage sludge in the field.

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