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Journal of Applied Science, Innovation & Technology (JASIT)

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Research article

Municipal solid waste characterization and vermitech-based management of garbage in Lucknow city: Effects of vermicompost on rhizomatous aromatic crops grown in sodic degraded soil

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ARTICLE INFOR

Article history:
Received: 28 November 2024
Revised: 12 December 2024
Accepted: 14 December 2024
Published online: 28 December 2024

Keywords:
Solid waste;
Garbage;
Vermicompost;
Sodic soil;
Nutrient imbalance

ABSTRACT

Municipal solid waste (MSW) generation and development of sodic degraded soil are two major environmental issues in India. The aims of present study to characterization of solid waste generated from Lucknow city which causes a serious issue with the management of garbage. The garbage was contained 46% of total MSW (1400MT/day) which decomposed openly and generates greenhouse gases responsible for global warming while salt affected soils are also worldwide problem. Sodic soils became unfertile or low crop productivity due to disturb soil morphology, very low organic carbon and nutrient imbalance which may be reclaimed by increasing organic carbon contents. In present study, garbage was managed through the vermi-technology and studied the effect of vermicompost on rhizomatous crops grown in sodic degraded soil. Sweet Flag (Acorus calamus) a rhizomatous crop was grown in sodic soils (pH 10.12)with different level of vermicompost i.e., T_1act as control (100% soil), T_2contains 75% soil and 25% vermicomposting (VC), T_3contain 50% each soil and VC, T_4contain 25% soil and 75% VC while T_5contains 100% VC in a Completely Randomized Design (CRD).The results indicated that increasing the doses of vermicompost up to T_4 considerably enhanced plant height, biomass yield and rhizome yield whereas at T_5 this parameter were declined. When the dosage of vermicompost was increased, there was also a considerable increase in the anti-oxidative enzymes such as catalase and peroxidase vice versa photosynthetic pigments like chlorophyll (Chl.'a', Chl.'b' and Total chl.) and carotenoid contents were increased. The total carbohydrates and sugar contents were also increased. The soil pH and exchangeable sodium percentage (ESP) were decreased while organic C contentwas increased which is an indicator of sodic soil reclamations.

1. Introduction

The MSW management is one of the India's most underdeveloped sectors. The urban population of India is increasing exponentially and making it difficult for civic organizations to provide the basic services likeroads, electricity, water, education and public sanitation including MSW management while in rural areas, crop residue management, nutrient depletion, conversion of fertile land from waste land due to the adoption of modern agricultural practices like use uncontrolled chemical fertilizers and pesticides, soil salinity as well asalkalinity are issues that must be managed. The nation is dealing with a significant waste management burden as a result of rising urbanization. Approximately 7,935 towns and cities are home to over 377 million urban residents, and the total creation of MSW might be as high asup to 68.8 million ton per year (TPY) or 188,500 ton per day (TPD). About 70% of garbage is collected, 30% of it is handled or processed, and the other 70% is disposed of in landfills. With millions of tons of legacy garbage posing a hazard to the environment through continual emissions of greenhouse gases (GHG's) vice versa contamination of leachates in ground and surface water. One of the fundamental services given by local authorities in the nation to maintain the cleanliness of urban areas is solid waste management.

The solid waste management became major issues in Indian cities due to growing of urban population and economic expansion without anefficient management system. The primary issue with MSW management is lack of finance and trained human resource for collection, transportation, processing, and final disposal. So, present study deals with characterization of solid waste generated from Lucknow city.According to the 2011 Census, there were approximately 4.5 million people living in Lucknow city (0.6 million counting the floating population) in which 1.79 lakh of them reside in slums, generating 1200–1300 MT of MSW every day. Gupta et al. (2013) stated that the Lucknow Municipal Corporation collects 70–75% of the city's total MSW with an efficiency of 60%–70%.

Vermitechnology is referred to as technology which converts garbage into vermicompost through earthworm (Kale et al., 1982). Through the combined efforts of aerobic microorganisms and earthworms, vermitech stabilizes organic waste. Vermicompost is a stabilized humus-like product made from complex and energy-rich organic materials using an eco-biotechnological technique. Singh et al. (2019) worked on mango-ginger (*Curcuma amada*) plant at graded levels of vermicompost with sodic soils. The salinity and alkalinity of soil is a common issue in arid and semiarid part of the world (Yadav, 1993). According to Dudaland Purnell (1986) said that salt affected soils cover 932 MHa which is 7% of world land surface area of which 316 M Ha are thought to be in developing nations(Massoud, 1974). According to estimates from time to time, the salt-affected area in India ranged from 6.1 to 23.3 mHa (Bhargava, 1989). Sodic degraded land negatively effects on the growth, dry matter production, and grain yield due to nutrient deficiency, organic matter and disturb morphological charter of soil (Manchanda et al., 1985; Choudhary et al., 1996, Singh and Singh, 1997)

The effects of salinity stress on plant development processes include seed germination, seedling growth, vigorous vegetative growth, flowering and fruit setting (Sairam and Tyagi, 2004). The main effects of salt on plants are hyperosmol and ionic imbalance. This imbalance or disturbance of homeostasis has a stress effect on the entire plant as well as on individual cells. Growth arrest and molecular damage result from drastic shifts in the ionic equilibrium. Finally, this causes tissue loss and ultimately plant mortality in highly salinized environments (Zhu et al., 1997; Xiong and Zhu, 2002). Because salt stress produces reactive oxygen species (ROS) (Smirnoff, 1993). it affects the integrity of cellular membranes, enzyme activity, and the functioning of the plant photosynthesis machinery (Serrano et al., 1999).

Thus, application of vermicompost and biodynamic compost may enhance the organic matter and remove nutrient deficiency in crops as well as increase micro biota in sodic soil.The aromatic crops have economic significance on the domestic and global market for the creation of novel and exotic flavors and fragrances, India has a significant potential for the cultivation of numerous aromatic crops.But with the growing demand for more food, fiber, fodder, and other agricultural products, it is difficult to use the fertile land for aromatic crop cultivation. The development of agro-technology by using vermicompost on sodic degraded soil may be a viable alternative to using uncultivable wastelands, such as salt-affected soil like alkali, sodic, and saline wastelands, to grow these crops.

The current study illustrates the problems and obstacles that solid waste management is now facing, as well as their effects on environmental sustainability. The present endeavor was aimed to develop agro techniques to use the sodic wasteland for cultivation rhizomatous crops and provide a solution to manage garbage of MSW and agricultural wastes into vermicompost that reclaimed sodic land through increasing the organic matter content and curing the nutrient imbalance in sodic degraded land.

2. Materials and methods

2.1 Site study and methods adopted for characterization

Lucknow city is situated at 123 meter above of sea level and occupied an area of 402 square kmwhich located between latitude 26°55' North and longitude 80°59' east. The city is divided into eight zones as per the master plan 2021.Lucknow is a semi-arid subtropical monsoon climate which receives average 872 mm rain fall and average temperature 39.1^{o}C in the month of May and the mean minimum temperature was 7.6^{o}C in moth of January.

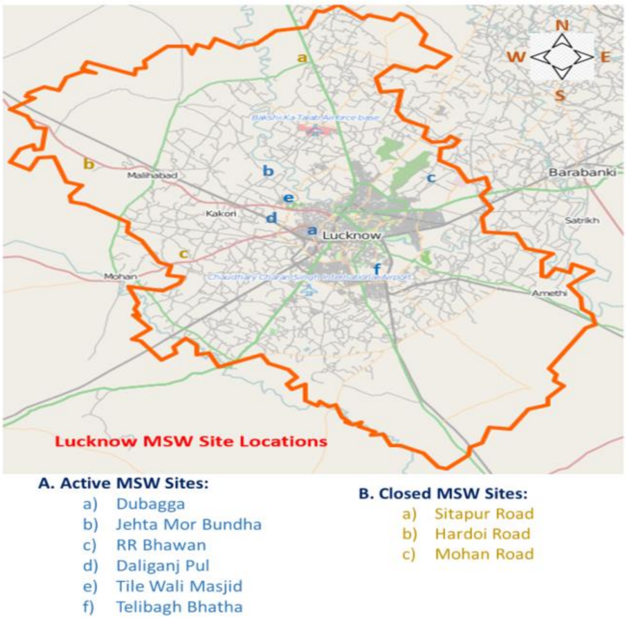

Fig. 1 MSW dumping sites in Lucknow city including closed sites

The study area is depicted on the map (Fig. 1). Additionally, a pre-made questionnaire was used to gather the necessary secondary data from the Lucknow municipal authorities. The initial planning and scheduling of the field visits for the sample collection was done through a reconnaissance study at every area in Lucknow city. Several steps in the process are listed below to help them understand the existing state of waste generation and management:

i. Identifying primary sources of waste generation through fieldwork and stakeholder discussions.
ii. Estimating the amount and types of waste generated from different categories like low income, medium income and high income groups of residential areas, commercial and industrial areas at the final disposal point as well as at the prime/identified source.

iii. Waste quantification and characterization results are analyses.
iv. Study was carried out on waste management and handling from the point of generation to disposal.

Various wastes generated in the Lucknow city were collected separately from various sources, including homes, businesses, parks, gardens, and street sweepers. At the storage bins, hospital and abattoir waste is combined with MSW. Many open collection sites exist, which lead to unhygienic circumstances and put the safety of the surrounding populace and employees at risk (Gupta, 2001).

Several factors, including dietary patterns, lifestyle choices, cultural customs, climate, and income, influence the composition of waste (Gupta et al., 1998). Following consultation with the municipal authorities for each municipality, sampling points were chosen in affluent neighbor hoods as well as places with a medium and poor standard of living. These represented various market, industrial, residential, and commercial areas. Employ IS standard 9234-1979 for physical characterization. The method involves collecting 1000 kg of typical MSW from the dump locations, thoroughly mixing it, and then dividing it into four equal portions. Two sections that are diagonally opposed were kept for analysis, while the other two were thrown away. The pieces that were kept were once again well combined and divided into four equal portions.

2.2 Vermicompost production

MSW were collected from Lucknow city. Once collected, solid waste was sorted into biodegradable organic waste and non-biodegradable waste. The vermi-technology was implemented to handle waste and generate a valuable by-product known as vermicompost. *Perionyx excavatus* and *Lampito mauritii,* two indigenous epigeic and anepigic earthworm species, were employed in this vermicomposting procedure. Earthworms and aerobic microbes work together to stabilize organic waste through a process called vermitech. Vermicompost is a stabilized humus-like material made from complicated and energy-dense organic sources using an ecological biotechnology process. Complete decomposition requires about 45 days. The food consumed is further broken down in the worms' digestive tract, leading to a reduction in particle size. Vermicompost is a fine, odorless, granular material which can be used as a nutrients in agriculture.

2.3 Materials used in experimentation

One of the medicinally important rhizomatous crops *i.e.*, sweet flag (*Acorus calamus*) used in dry herbal therapy.It is a perennial wetland monocot of the Acoraceae family and also known as buksh. Sweet flag plants were grown in pots at varying vermicompost and sodic soil levels (pH 10.12 and ESP 54), namely T_1 act as control (100% soil), T_2 contains 75% soil and 25% VC, T_3 contain 50% soil and 50% VC, T_4 contain 25% soil and 75% VC while T_5 contains 100% VC in a completely randomizeddesign (CRD). The sodic soils used in the experiment had the following chemical characteristics: 10.12 soil pH, 0.69 dSm^{-1} EC, 0.09% organic C, 54.5% ESP, 7.82 cmol kg^{-1} Exch. Na, 0.5 cmol kg^{-1} Exch. K, 394.5 available K, 19.12 kg ha^{-1} available P and micronutrients, specifically Fe, Zn, Cu, and Mn, which were 9.75 ppm, 0.27 ppm, 0.63 ppm, and 6.4 ppm, respectively (Table 1). Table 1 also listed the vermicompost chemical characteristics.

2.4 Plant yields and growth

The plant height, dry matter yield (oven-dried at 70°C for 24 hours), and rhizome yield were recorded. The height of the plant was measured from the top of the leaf flag to the soil level. At harvest, the yield was noted. After being cleaned and carefully sorted into roots, rhizomes, and leaves, the harvested plants were oven-dried at 70°C for 24 hours.

Table 1 Chemical properties of sodic degraded soil and vermicompost before experiments

Properties	Soil properties	Vermicompost properties
Soil pH (1:2)	10.13 ± 0.04	6.34±0.84
EC (dSm^{-1})	0.755 ± 0.03	0.25±0.053
Org. C (%)	0.173 ± 0.02	1.47±0.15
Avail. K ($kgha^{-1}$)	364.5 ± 16.7	459±1.5
Avail. P ($kgha^{-1}$)	37.85±1.34	81.26±2.34
Exch. Na ($cmolkg^{-1}$)	8.46 ± 0.24	-
Exch. K ($cmolkg^{-1}$)	0.501 ± 0.04	-
Exch. Ca^{2+} and Mg^{2+} ($cmolkg^{-1}$)	8.83 ± 0.580	-
Cation Exchange Capacity ($cmolkg^{-1}$)	15.45 ± 0.58	-
Exchangeable Sodium Percentage (%)	54.5 ± 3.49	-
Sodium Adsorption Ratio (%)	40.33 ± 2.41	-
Iron (mg/L)	9.15±1.121	39.50 ± 2.65
Manganese (mg/L)	10.0 ± 1.403	18.56 ± 2.10
Copper(mg/L)	1.80 ± 0.14	5.84 ± 0.89
Zinc(mg/L)	2.32 ±0.042	7.325± 0.76

2.5 Analysis of soil

The soil sample was analyzed before the experiment and after harvest. Samples of soil were taken to the lab and left to dry in the shade after loose stubbles, grasses, and larger clods were removed. Before being analyzed, the dried soil samples were grind into a powder using an agate mortar and grinder and sieved using a 1.0 mm sieve. Soil sample were kept in polythene packages in a dark location after grinding. Total nitrogen, available phosphorus, and available K were measured in order to assess fertility. Processed samples were analysed for various physico-chemical-chemical properties of soil i.e., pH and EC (Jackson, 1973), organic carbon (Wakley and Black's, 1934), available phosphorus (Olsen el at. 1954), exchangeable cations, cations exchange capacity (CEC), and ESP (Bower et al. 1952; Jackson, 1973). Soil analysis was conducted using standar d procedures (Piper, 1967).

2.6 Photosynthetic pigments estimation

The photosynthetic pigments like chl. 'a', chl. 'b' and carotenoids content were measured in an 80% acetone extract of the young, completely grown fourth leaf (Lichtenthaler, 1987). The homogenate was centrifuged for 10 minutes at 4000x g and residue was removed. For carotenoids, chl. 'a', chl. 'b' the colour intensity of clear supernatants was measured at 470 nm, 646.8, and 663.2 nm, respectively. The result was reported in mg g^{-1} fresh weight.

2.7 Extraction and estimation of antioxidative enzymes

The fresh leaf tissue (2.5g) was homogenized in 10mL of cold 50mM potassium phosphate buffer (pH 7.0) with 1.0% insoluble Polyvinyl Pyrrolidone (PVP) using a chilled pestle and mortar in an ice bath. After filtering the homogenate using a double-fold muslin cloth, it was centrifuged at 20000x g for 10 minutes at 2°C in a chilled centrifuge. Within four hours, the supernatant was used for enzyme tests after being kept at 2°C (Bisht, 1972). Enzyme activity was measured as μ mole H_2O_2 decreased unit fresh matter or protein weight.The peroxidase activity was measured by modified procedures (Luck, 1963).

2.8 Proline, starch and sugar contents estimation

The acid ninhydrin complex in toluene was used to measure the amount of free proline in fresh leaf tissue (Bates, 1973). The homogenate's protein content was measured using bovine serum albumin (BSA) as a reference in Tri Chloro Acetic Acid (TCA) precipitate (Lowery, 1951).Calorimetric measurements of sugars were made (Nelson, 1941).

2.9 Statistical analysis

Statistical method and test of significance were used to the data for discriminating the treatment effects from chance effects. The level of significance was calculated by the ANOVA test using Sigma stat 3.

3. Results and discussions

3.1 Solid waste characterization

Residents of Lucknow gather rubbish in open dump sites, dustbins, dhalaos, and plastic buckets. Additionally, street sweeps are gathered in community garbage bins. There are currently 110 wards with 39 bins, 58 dhalaos, and 303 open garbage sites. Waste paper, plastic and other materials are not collected in separate bins.Waste from a varioussource, including homes, offices, retail malls, parks, gardens, and street sweepings, were collected separately in the city of Lucknow. At the storage bins, hospital and abattoir waste is combined with MSW. There are several open collecting locations, which result in unhygienic circumstances and present health risks to the employees and the community (Gupta, 2001).

Waste characterization was a critical step in adequate management of solid wastes. The composition of the wastes not only varies from location to location but also as a function of income level as was shown in Fig. 2. Plastic waste generation was ranged from 9% to 29% of total waste generation depending on location and income levels. The maximum generation of plastic waste(29%of total waste) was observer in office waste (Fig. 2f) while on the basis of function of income it was high in middle and higher income group which showed that packed material used plastics than the lower income groups (Fig.2a,b and c).

The paper waste was ranged from 4% to 18% depending on location and income levels. The garbage production was ranged 39 % to 86 % in different location. Maximum waste generation (86% of total waste) was observed in market waste (Fig. 2e) while least garbage generation (39% of total waste) was observed in industrial waste (Fig.2f). Inspite of these waste, some other waste was also observed eg., inorganic waste(0-8%), metals(1-7%), glass(0-4%) and hazardous waste(0-1%) varies from location to location but also as a function of income levels (Fig. 2a-f).Thus the garbage generation was highest of total MSW and disposed of landfills of legacy garbage posing a hazard to the environment through continual emissions of greenhouse gases(GHG's) and pollution of surface and ground water through leachates.

3.2 Effects of vermicompost (VC) on growth and yields

Result indicated that the use of vermicompost in sodic degraded land had a substantial impact on the plant height of sweet flag. It increased dramatically as vermicompost levels increases, reaching their maximum at T_4, while T_5shows a somewhat smaller growth than T_4 (Table 2). Comparable patterns were also noted in the quantity of leaves and tillering of plant. The dry weight of the leaves, rhizome, roots, and total biomass were significantly increased. When vermicompost levels were raised, the maximum dry weight of the roots was recorded at the T_4 level, however at the T_5 level, it was much lower than at the T_4 level. Biomass yields showed a similar trend (Table 2). Singh et al. (2019) found similar results for mango ginger (*Curcuma amada*). Significant amounts of organic matter and macro and micronutrients were present in VC (Table 1), which probably enhanced sweet flag production and growth. By boostingorg. C, nutrient status and water-holding capacity, VC has been shown to enhance biomass production on sodic degraded land, which in turn increases plant height (Cavender et al., 2003; Arancon et al., 2006; Kumawat et al., 2006).The growth, development, and height of a variety of crops and medicinal plants have been indicated to be enhanced by optimal levels of VC (Arancon et al., 2006; Arguello et al., 2006; Singh et al., 2019).

3.3 Effect on photosynthetic pigments

As vermicompost dosages increased, the amounts of photosynthetic pigments *e.g.*, carotenoids, total chlorophyll, and chlorophyll a and b, increased noticeably. While all of the pigments in T_5 were below the T_4 level, the highest amount of photosynthetic pigments was seen in T_4 level (Fig. 3 a). The carotenoid/chlorophyll ratio was decreased upto T4 levels while at T5 it was slightly higher but chlorophyll /carotenoid ratio was significantly increased upto T4 and further it was decreased (Fig.3b). In the current study, rhizome yield was increased and other growth indicators were also observed most likely caused by an increased in rate of photosynthesis. The higher concentration of all photosynthetic pigments may lead one to draw this conclusion. This amply illustrates how well VC works to mitigate the negative effects of high ESP on plant health (Darzi et al., 2007; Haj Seyed Hadi et al., 2011;Darzi et al., 2012; Singh et al., 2019).

3.4 Antioxidative enzymes

Two anti-oxidative enzymes i.e., catalase (CAT), peroxidase (POX) and one anti-oxidant i.e. proline were assessed. Result indicated that catalses (CAT) and peroxidase (POX) activities were significantly increased up to T_4 but in T_5these enzymes weredecreased than the other treatment. The peroxidase activity ranged from 143.3 to 185.35 µM/100 mg FW, whereas catalase activity ranged from 864 to 1280 µM H_2O_2 decomposed/100 mg FW, with T_4 showing the highest amount (Fig. 3d). T1 (control) showed the lowest POX activity, while T_4 showed the highest (Fig. 3e). Up to T4, the proline level was considerably higher; however, in T_5, it was lower. The range of proline content is 15.1–27.05 mg g^{-1} (Fig. 3f). The results showed that an increasing the dosages of vermicompost resulted in a considerable rise in reducing sugars level.

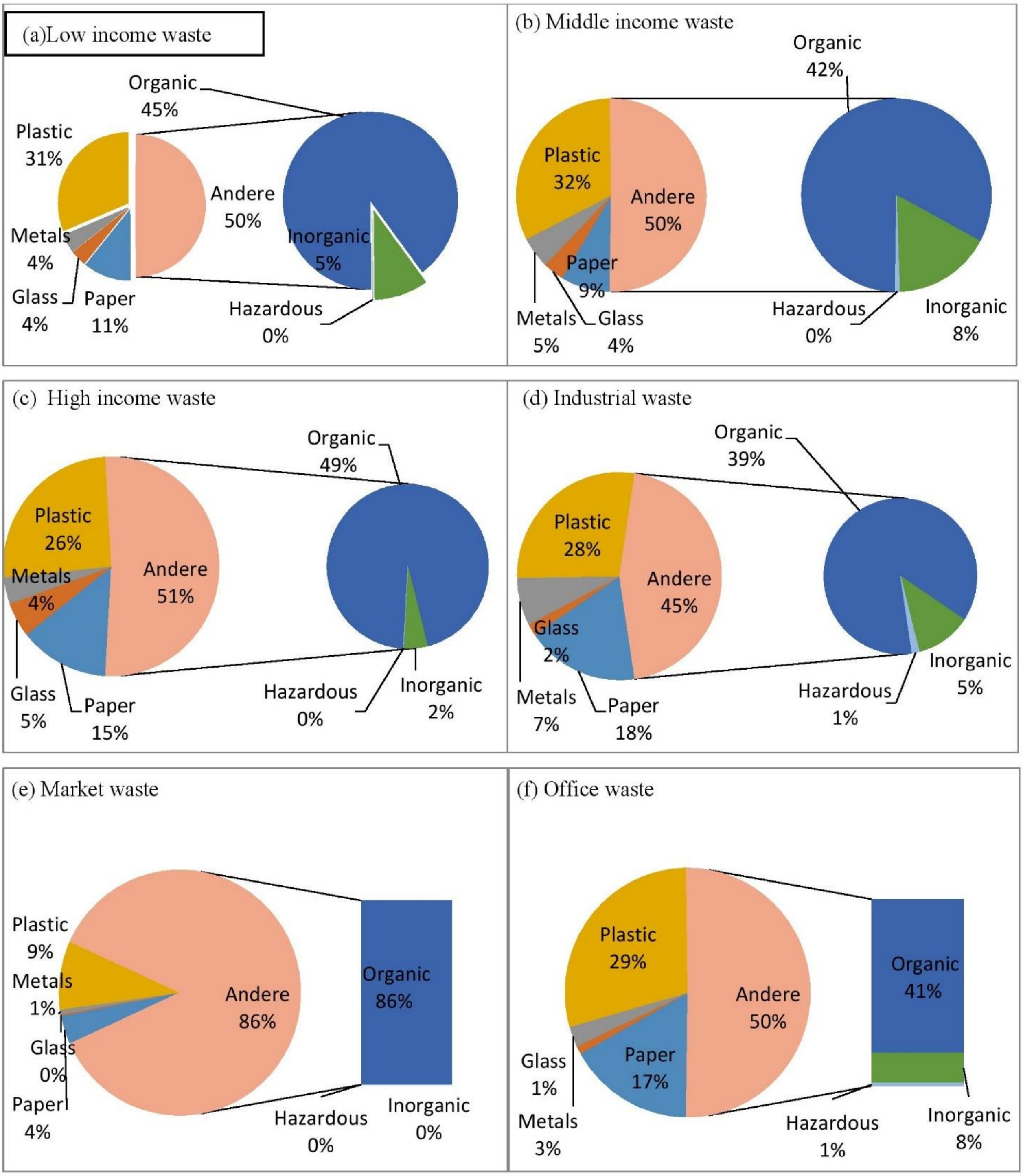

Fig. 2 Average composition of disposed MSW in Municipality in Lucknow city

However, T_5 showed the highest levels of reducing sugars. As the dosage of vermicompost was increased, the total carbohydrate content similarly increased, reaching its maximum in T_4 (Fig. 3c).

Table 2 Vermicompost induced changes on vegetative growth of sweet flag (*Acorus calamus*) plants grown in sodic soils

Vegetative growth and yields	T_1	T_2	T_3	T_4	T_5
Plant height(cm)	26.33±1.23	35.66±0.96	35.7±0.59	35.33±0.26	34±0.75
Number of leaves/plant	9.5±1.56	12.5±0.89	13.16±0.65	14.16±0.85	12.16±1.15
Number of tillers/plant	1.0±0.3	3.16±0.12	2.5±0.08	4±0.85	3.5±0.25
Leaf dry weight(g/plant)	12.24±1.85	35.25±0.89	36.38±0.76	73.43±2.56	38.91±3.56
Root dry weight(g/plant)	18.13±2.50	36.88±1.54	39.46±1.35	83.34±2.36	55.79±1.85
Rhizome weight(g/plant)	30.39±3.25	72.13±2.65	72.84±1.85	156.77±3.56	93.86±4.65
Total biomass(g/plant)	60.75±2.35	144.27±1.03	148.68±1.85	313.55±2.35	188.55±3.45

The current study found that the application of VC has enhanced biomass production and rhizome yield, most likely via increasing the rate of photosynthesis. Similar results were also observed in mango ginger (Singh et al., 2019) and found that contents of carbohydrate were increased on increasing vermicompost amount in sodic degraded soils while reducing sugar was drastically lowered. Other studies have also reported similar findings (Darzi et al., 2012). Photosynthesis in plants was increased with the addition of vermicompost in sodic soil (Roy and Singh, 2006). Several aromatic and medicinal crops have demonstrated that adding VC to sodic soil enhances biological activity, which in turn improves mineral element absorption and ultimately boosts biomass and productivity (Migahed et al., 2004; Jat and Ahlawat, 2004; Zaller, 2007; Pandey, 2005).This finding is consistent with previous researchers(Moradi et al., 2010;Saeid and Rezvani, 2011). Vermicompost has good water and minerals like nitrogen and phosphorusholding capacity which speeds up growth and increases biomass yield.

Table 3 Changes in physico-chemical properties of soils after harvesting of the sweet flag (*Acoruscalamus*) plants grown in sodic degraded soils

Properties of soil	T1	T2	T3	T4	T5
Soil pH	9.3±0.141	8.15±0.071	7.97±0.099	7.88±0.028	7.6±0.141
EC (dSm^{-1})	0.3635±0.005	0.314±0.001	0.3675±0.046	0.361±0.049	0.4785±0.04
Organic carbon (%)	0.675±0.042	0.8175±0.03	0.9825±0.032	1.8±0.382	2.39±0.544
Exch. Na (kg/ha)	73.3±8.91	50.75±6.152	54.4±7.354	98.25±17.324	129.9±11.455
Av. K (kg/ha)	416.64±9.504	513.52±30.8	497.84±18.215	769.26±32.951	1107.94±239.5
Av. P (kg/ha)	36.45±7.0	29.25±4.455	22.95±0.636	26.6±4.384	22.95±0.636
Fe (mg/L)	8.92±2.121	10.445±1.84	15.065±6.654	27.995±1.280	37.085±5.339
Mn (mg/L)	9.905±0.403	10.48±0.792	13.705±0.799	15.495±0.955	15.595±0.346
Copper (mg/L)	1.49±0.014	1.985±0.460	2.49±0.042	4.045±0.431	4.77±0.071
Zinc (mg/L)	1.17±0.042	2.56±0.057	2.715±0.163	5.335±0.332	7.325±0.078

3.5 Changes in soil properties

After harvesting of crops, soils were analyzed. The results indicated that application of VC and crop growth improved soil properties *i.e*., soil pH was 10.12 before experiment which decreased to 9.3 in T_1 (control, or without VC), and it was decreased as the dose of vermicompost increased. The organic carbon was found to be 0.09% before experiment which was increased up to 0.65% in T_1 (control), wise versa it was increased on increasing the dose of vermicompost. The other soil properties were also improved by the use of vermicompost and the growth of sweet flag, as shown in Table 3. The soil properties of sodic degraded land was improved by both i.e., sweet flag which is tolerant to alkalinity and capable to survive at high soil sodicity and use of vermicompost which improve the soil condition.

4. Conclusions

The generation of solid waste and its proper managements are major issues of metropolitan citieswith millions of tons of legacy garbage posing a hazard to the environment through continual emissions of greenhouse gases (GHG's) vice ver 103 contamination of in ground and surface water through leachate. Garbage are ranged from 46% to 70% of total solid waste generated from municipal areas depending on source of generation like categories of income group, industrial areas and commercial areas. Garbage contains biodegradable organic waste which may be good source of organic matter for sodic degraded land if it convert into vermicompost. The application of vermicomposting sodic degraded land improves the amount of organic matter, nutrients, and water-holding capacity while lowering the pH and ESP (soil sodicity). If sweet flag used to grow in sodic degraded land by using vermicompost may be good remedy for sodic soil reclamation. Sweet flag crops absorb exchangeable salt, lowering the sodium level of the soil, and contributing organic matter in the form of dead root and leaf wastes which also enhances the qualities of the soil. Vermi-technology can therefore be used to manage municipal solid waste in a sustainable manner, and vermicompost can be added to sodic soil for increasing organic matter and improve soil quality by which sweet flag (*Acorus calamus*) crops. This crop can easily grow without any negative effect on yield and quality of crop production.

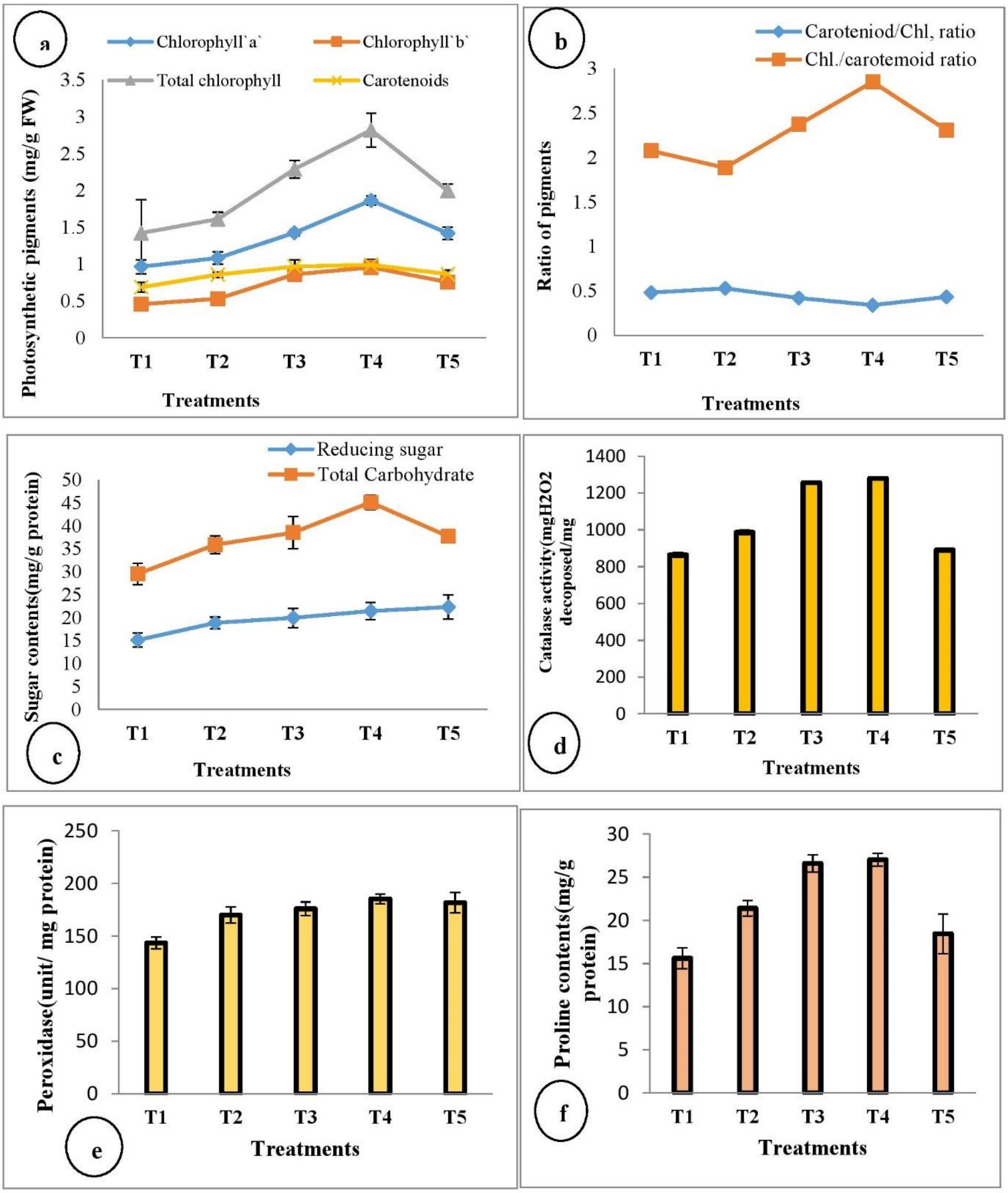

Fig. 3 **Effect of vermicompost on photosynthetic pigments, ratio of carotenoids and chlorophyll, sugar contents and some antioxidants i.e., catalase, peroxidase and proline contents in Sweet flag (*Acorus calamus*) plant grown in sodic degraded soil**

Author Contributions

All authors contributed significantly to the development of this research article. Their specific contributions are as follows: **Kamal Nabh Tripathi:** Conceptualization, Methodology, Writing – Original Draft; **Rupal Shepherd:** Investigation, Visualization, So ftware Development, Formal Analysis;

Vinod Kumar: Visualization, Data Curation, Writing – Review & Editing; **Shalini G Pratap:** Supervision, Review the research & Project Administration **and Pramod Kumar Singh:** Resources, Validation, Writing – Review & Editing.

Conflict of Interest

The authors declare that we have no competing interests.

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Cite this article:
Tripathi, K.N., Ma, R.S., Kumar, V., Pratap, S.G., Singh P.K., 2024. Municipal solid waste characterization and vermitech-based management of garbage in Lucknow city: Effects of vermicompost on rhizomatous aromatic crops grown in sodic degraded soil. J. Appl. Sci. Innov. Technol. 3 (2), 97-105.