REJUVENATION OF COASTAL SANDY SOILS THROUGH ORGANICS

ABSTRACT

The coastal zone represents the transition from terrestrial to marine influences and vice versa. They are predominated by sandy soil texture. Due to the inherent properties of coastal sandy soils, their agricultural productivity is generally low and are also prone to severe coastal erosion. Effective maintenance of soil organic matter is found to be a pre-requisite to ensure soil health and crop productivity. Therefore, organics based rejuvenation methods for coastal sandy soils need to be developed. A pot culture experiment was done at Kochuveli, Industrial area, in the coastal belt of Thiruvananthapuram district, Kerala, with Amaranthus (variety: Arun) as test crop. The experiment was completely randomized design (CRD) with 12 treatments and 3 replications. In the study, effect of different organic manures such as FYM, coirpith compost, vermicompost, city compost, biochar and thermochemical organic fertilizer (TOF), with and without lime on plant growth and yield, soil organic carbon and nutrient dynamics in the southern coastal sandy soils were studied. Soil management using organic manures had considerable impact on the growth and yield characteristics of the crop. Also the analyses of post-harvest soil for nutrient parameters showed that the highest value for organic carbon, nitrogen and potassium were recorded in soil treated with lime+TOF, while the highest value for available phosphorous was recorded in treatment lime+vermicompost. The study showed that soil test based lime application and basal application of TOF @ 25 t ha^{-1}, along with 272.7 kg rock phosphate and 122.5 kg potassium sulphate ha^{-1} was the best treatment to improve the soil quality, growth and yield of amaranthus in coastal sandy soils in Thiruvananthapuram district.

Keywords: Coastal soils, sandy soils, organic farming, amaranthus, soil quality, soil fertility

INTRODUCTION

The coastal zone serves as a transition area from terrestrial to marine influences and vice versa. Total coastline of the world is 3,56,000 km and the coastal region covers more than 10 per cent of the earth's surface. According to Fourth Assessment Report (AR4) by the Intergovernmental Panel on Climate Change (IPCC) (Parry *et al*., 2007), low-lying areas and coastal systems are predicted to be more at risk as they are particularly exposed to a variety of climate related hazards. The uncertain impacts of the climate change will have negative effects on crop production in these area, which have high potential to be used in the biomass production.

The sandy coastal plains are a unique type of soil and hydrological environment that represents nearby coastal lands where sand is of the dominant soil type, which is acidic, well drained with moderate salinity due to seawater intrusion. They are composed mainly of primary minerals, especially quartz (SiO_2), which is resistant to decomposition and contain little nutrients. One of the primary concerns with the coastal sandy soil is that, it has poor water holding capacity, poor content of clay minerals, organic matter, and nutrient retention (Ismail and Ozawa, 2006; Slavich *et al.,* 2010). As the coastal sandy soils fails to produce soil aggregates due to poor ability to bind particles, the soil has high leaching capacity, which causes majority of the nutrients to move downward through gravitational water. Also, the low CEC, buffering capacity and easily leached cations cause inadequate biological diversity in these soils (Havlin *et al*., 2005; Hoang, 2008). Thus, the properties of sandy soils restrict plant growth and local economic development (Zhou, 2016). Therefore, a sustainable management system for improving the fertility and productivity of coastal sandy plains need to be developed.

Soil health and fertility/productivity of the soil is dependent mainly on its organic matter content and microbial population present in the soil. Maintaining soil organic matter is a pre-requisite to ensure soil health and crop productivity. Organic manures are applied as a source of nutrients, and to supply organic carbon in the form of humic substances which help to improve the physical, chemical and biological properties of soil (Abou El-Magd *et al*., 2006).

Application of organic manures to crop plants have many benefits such as balanced supply and availability of nutrients, enhanced soil microbial activity which promotes plant growth, degradation of toxic substances and chemicals, improved soil structure and root development (Han *et al*., 2016). There is a need for continuous application of organic manures in tropical soils as they are poor in organic matter to improve its soil organic carbon (SOC) and NPK content (Kaur *et al*., 2005). The decrease in SOC caused by intense leaching of coastal sandy soil decreases the nutrient availability and aggregate stability of the soil thereby increasing its erosion potential. Therefore, effective maintenance of soil organic matter (SOM) in soils can help in preserving soil fertility and reducing erosion susceptibility, by promoting soil aggregation stability, improving hydraulic conductivity and water retention ability (Auerswald *et al*., 2003).

Biochar is the stable carbon compound obtained by the thermal decomposition of organic materials under little or no oxygen and at relatively low temperatures (< 700 ^{0}C), by the process of pyrolysis (Lehmann, 2007). Due to thermal degradation during pyrolysis, volatile compounds present in the original biomass could be lost, leading to increased content of nutrients in biochar compared to the source materials (Chan and Xu, 2009). Also the porous nature of biochar imparts enhanced surface area, which facilitates its effective and efficient retention of plant nutrients and maintain plant availability of nutrients over a longer period. Adding biochar to the soil can have benefits like raising soil pH, increasing water holding capacity, improving retention and availability of soil nutrients, boosts soil fertility which results in improved crop yield (Chan *et al*., 2007). It also enhanced the rate of soil carbon sequestration which helped to mitigate global warming (Bhattarai *et al*., 2015; Purakayastha *et al*., 2015; Zhang *et al*., 2017).

Vermicompost is another type of organic manure that is produced from biowaste by the action of earthworms like *Eisenia foetida* and *Eudrillus euginae*, and it contains macro (N, P, K, Ca, Mg and S) and micro (Fe, Mn, Cu, Zn and Na) nutrients that are essential for the growth and production of crop plants (Theunissen *et al*., 2010). Vermicompost enhances soil biodiversity by promoting the beneficial microbes which in turn enhances plant growth directly by production of plant growth-regulating hormones and enzymes, and indirectly by controlling plant pathogens, nematodes and other pests, thereby enhancing plant health and minimizing the yield loss (Pathma and Sakthivel, 2012).

Rapid population growth increases the need for sustainable food production, reduction of waste generation, and efficient utilization of waste as a renewable resource. The utilization of municipal solid biowaste as organic fertilizer is a solution for the proper disposal of biodegradable waste in urban areas and it also brings economic benefits by enhancing soil productivity. Composting is an ideal method for producing organic fertilizer from biowaste as it narrows down the C: N ratio, concentrates the nutrient content, stabilize the heavy metals, transform the phytotoxic biomolecules, kill pathogenic microorganisms and suppress other potential contaminants that cause environmental pollution (Zia *et al*., 2003; Jimenez and Wang, 2006). Tibu *et al*. (2019) reported that composting of municipal solid waste as a reliable strategy to reduce environmental pollution and to promote vegetable production in urban areas.

The Department of Soil Science and Agricultural Chemistry, Kerala Agricultural University, India has developed a novel technology for the conversion of degradable organics to value added organic fertilizer through chemical decomposition at 100 ^{0}C (Sudharmaidevi *et al.*, 2017). All parameters of the customized organic fertilizer were within the safe limit as prescribed by FAI (2018). Chemical characterization of thermochemical organic fertilizer revealed that it contains more lignin compared to other organic fertilizers, which provides a more recalcitrant nature to it (Jacob, 2018). The fortified thermochemical organic fertilizer contains N - 3.27 %, P - 0.81 %, K - 2.88 %, Ca -1.69 %, Mg - 0.25 %, S - 42.70 mg kg^{-1}, Fe - 4392 mg kg^{-1}, Mn - 244.36 mg kg^{-1}, Zn - 219.76 mg kg^{-1}, Cu - 4.79 mg kg^{-1} and B -13.88 mg kg^{-1} (Jacob, 2018).

In order to accomplish the objective of rejuvenating coastal sandy soil with organic manures, a pot culture experiment was conducted with Amaranthus as test crop in the Thiruvananthapuram district of state Kerala, India. Twelve treatment combinations involving different organic manures, i.e., farmyard manure, vermicompost, coirpith compost, city compost, thermochemical organic fertiliser and farmyard manure+biochar, with and without lime, along with a control were tested in completely randomized design (CRD). This study was aimed at determining the effect of lime and different organic amendments on the crop growth, yield and nutrient availability in soil after its incorporation in coastal sandy soils.

MATERIALS AND METHODS

Experimental setup

Kerala, a south-western coastal state of India, has nearly 590 km of Arabian Sea shoreline distributed all along the western border, and it constitutes 1.52 per cent of entire geographical area of the state. Predominant soil texture of the Southern Coastal Plains is sandy, with tropical humid monsoon type climate (mean annual temperature 27.6 °C; rainfall 2360 mm). A preliminary study was conducted to assess the soil quality of southern coastal plains of Thiruvananthapuram district, Kerala in AEU 1 lying between 8°28′58.872″and 8°47′ 26.5956″ N latitude and 76°43′20.7588″ and 76°56′47.292″E longitude, and it showed that the majority of soils belonged to medium and low soil quality class in fertility with coastal sandy plains as of poor quality (Athulya *et al.,* 2023).

Pot Culture Experiment

A pot culture experiment was conducted with amaranthus (*Amaranthus tricolor*) as test crop to study the effect organics based cultivation practices on soil properties and crop growth in coastal sandy soils. Potting mixture for the experiment was prepared with coastal sandy soil from Kochuveli in Thiruvananthapuram district, Kerala, and basal dose of different organic manures @ 25t ha^{-1} as per Package of Practices Recommendation (Organic) of the Kerala Agricultural University (KAU, 2017), with and without lime was used. Along with that, 272.7 kg rock phosphate and 122.5 kg potassium sulphate ha^{-1} were applied. Organic amendments such as farmyard manure, vermicompost, coirpith compost, city compost, thermochemical organic fertilizer and (FYM+biochar), each with and without lime application were used for the experiment. FYM, coirpith compost, vermicompost and thermochemical organic fertilizer were prepared by the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, Kerala Agricultural University under standard conditions, while biochar was commercially purchased. Plants were grown under partial shade for 50 days and the pots were laid out in a completely randomised design, irrigated on a daily basis. To ensure data quality, three replicates were used in the pot experiment for plant growth monitoring, yield comparison and post-harvest soil analysis.

Analyses of organic manures, plant yield characteristics and soil

Analyses of different organic manures were done for pH, EC, organic carbon, available N, P, K and C:N ratio. For studying the effect of different organic manures on growth and yield characters, characters like plant height, dry matter production and yield from the observational plants were recorded. From each pot, two plants were randomly chosen and tagged as observational plants. They were uprooted and made free of soil. Fresh weight and oven dry weight of plant samples were recorded for calculating dry matter production.

Soil samples were collected, air dried under shade, sieved through 2 mm sieve and analysed for various physical and chemical parameters using standard procedures (Table 1).

Table 1. Methods followed in physical, chemical and biological analysis of soil.

Sl. No.	Parameter	Method	Reference
1.	Soil texture	Bouyoucos hydrometer method	Bouyoucos (1936)
2.	Bulk density	Undisturbed core samples	Blake and Hartge (1986)
3.	Particle density	Pycnometer method	Vadyunina and Korchagina (1986)
4.	Water holding capacity	Core method	Dakshinamurthy and Gupta (1968)
5.	Soil aggregate stability	Yoder's wet sieving method	Yoder (1936)
6.	Soil pH	pH meter (1:2.5 soil water ratio)	Jackson (1973)
7.	Soluble salts (EC)	Conductivity meter (1:2.5 soil water ratio)	Jackson (1973)

8.	Organic carbon	Walkley and Black wet oxidation method	Walkley and Black (1934)
9.	Available N	Alkaline permanganate method	Subbiah and Asija (1956)
10.	Available P	Bray No.1 extraction and estimation using spectrophotometer	Bray and Kurtz (1945)
11.	Available K	Neutral normal ammonium acetate extraction and estimation using flame photometry	Jackson (1973)

Statistical Analysis

Based on the procedure explained by Cochran and Cox (1965), the data obtained from different observations were subjected to statistical analyses. ANOVA was done by applying the analysis of variance technique for Completely Randomized Design (CRD) with three replications. The results of pot culture experiment was statistically analysed using the GRAPES software tool (Gopinath *et al*., 2021).

RESULTS AND DISCUSSION

Characterization of organic manures

The organic manures used in the pot culture experiment were characterised for their electro-chemical and nutritional properties (Table 2).

Table 2. The properties of soil manures used in the experiment

Organic manures	pH	EC (dS m^{-1})	TOC (%)	Available primary nutrients (kg/ha)			C:N ratio
				N	P	K	
FYM	6.19	0.07	24.4	1.84	0.77	0.54	13.26
VC	7.00	0.58	31.0	2.44	1.10	1.52	12.71
CPC	5.57	0.37	20.7	1.04	0.11	0.40	19.91
CC	6.84	0.61	39.0	2.89	0.57	0.76	13.50
TOF	7.49	0.80	40.0	3.27	1.08	2.88	11.21
FYM + Biochar	7.40	0.64	31.0	2.01	0.57	0.89	15.93

The organic manures recorded pH levels that ranged from slightly acidic to neutral, with TOF having the highest value for pH (7.49). Short-chained organic acids created by fermenting microorganisms through many weeks of storing organic manures is the main cause of acidity (Aasen *et al.*, 2006). According to Mohee *et al*. (2015), the safe range of EC for compost is less than 3.5 dS m^{-1}. In accordance with FAI (FAI, 2018), pH of organic fertilizers should be in the range of 6.5-7.5, and EC as < 4 dS m^{-1}, which makes all these organic manures safe to use.

Total organic carbon (TOC) is an important quality parameter of organic fertilizers. TOC decreases during composting as organic compounds are degraded and mineralized to CO_2 by microbial action (Azim *et al.*, 2018). As per FCO standards (FCO, 1985), the TOC content of organic fertilizers should be >12 per cent. Among the organic fertilizers, TOF had the highest TOC (40 %), followed by CC (Table 2). TOF recorded higher TOC as the method of waste processing does not rely on biological activity for organic matter decomposition. Also during thermochemical degradation, leaching and volatilization loss of organic carbon is comparatively less due to the rapidness in production resulting in a higher TOC content. The addition of coirpith and charcoal during the production also enhances its TOC content. The lowest TOC was shown by CPC due to its higher C:N ratio, which slows down the degradation rate compared to other organic manures used. C:N ratio was the highest for CPC (19.91), followed by (FYM+Biochar).

The total nitrogen content of organic manure is an important property and it determines how nutrients are mineralized and immobilised when applied to soil. The thermochemical organic fertilizer had the highest nitrogen content being 3.27 kg ha^{-1}, followed by CC, VC, FYM+Biochar, FYM and CPC. The P content was found to be varying with VC having the highest content (1.10%), with organic acid chains acting as adsorptive sites which function as nutritional ion reservoir. P content (1.08%) and K content (2.88%) in TOF were also higher as a result of fortification with nutrients (Table 2).

Effect of organic manures on growth and yield characteristics

Changes in the availability of inorganic N to plants due to mineralization of organic N from the applied organic manures might explain the differences in plant growth (Fig. 1 & 2). Biometric observations such as plant height, dry matter production and yield were noted towards interpreting the direct influence of organic fertilizers on amaranthus (Table 3). All these parameters were positively influenced by the incorporation of organics, with and without lime. In the case of growth and yield, Lime+TOF proved to be a better alternative than the other conventional organic manures in amaranthus cultivation. Similar results in crop production had also been observed by Jayakrishna and Thampatti (2016) and Leno *et al.* (2016).

Table 3. Effect of organic manures on growth and yield characteristics of amaranthus

Treatments	Plant height (cm)	Dry matter production	Yield (g per plant)

		(g per plant)	
T_1 - Control	8.30	1.06	10
T_2 - FYM	28.63	5.97	96
T_3 - VC	32.43	6.73	122
T_4 - Lime + VC	34.67	7.40	129
T_5 - CPC	10.40	1.96	28
T_6 - Lime + CPC	13.60	2.36	38
T_7 - CC	29.60	6.25	96
T_8 - Lime + CC	35.03	6.59	106
T_9 - TOF	33.27	6.98	125
T_{10} - Lime + TOF	34.50	8.16	138
T_{11} - FYM + Biochar	16.77	5.93	85
T_{12} - Lime + FYM + Biochar	21.97	6.54	98
SEm ±	0.56	0.09	0.04
CD (5%)	1.643	0.286	1.158

Plant height is considered as one of the major traits for plant growth and vigour. Regarding plant height, T_8 (Lime+CC) showed the highest value, followed by T_4 and T_{10}. The treatments T_8, T_4 and T_{10} were also found to be statistically on par, while the lowest plant height was recorded by absolute control (T_1).

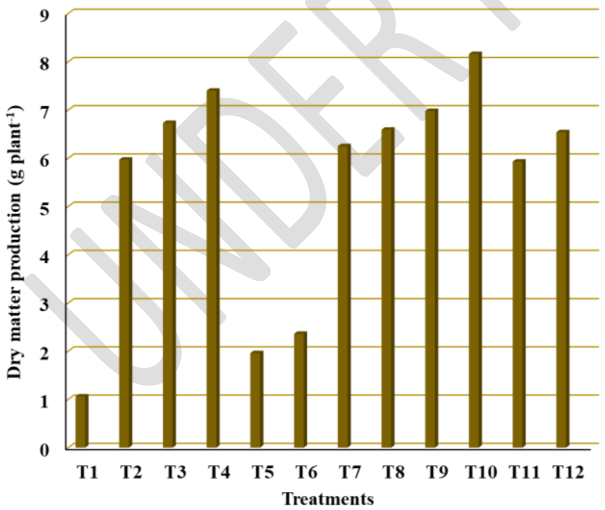


Fig. 1. Effect of treatments on dry matter production of amaranthus

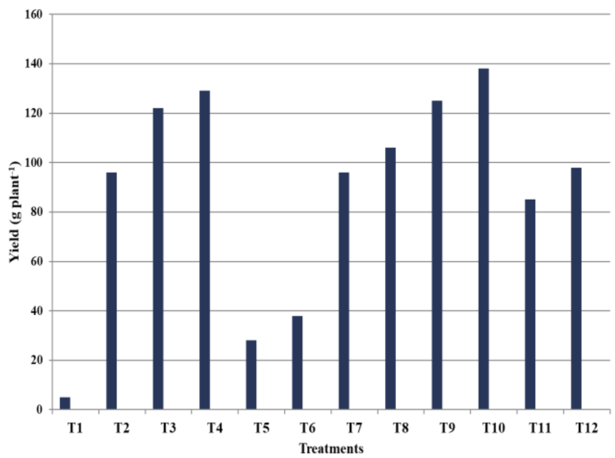


Fig. 2. Effect of treatments on yield of amaranthus

The study showed that dry matter production and yield varied according to the biochemical and nutritional properties of different organic manures. There was a significant difference between treatments and T_{10} (Lime+TOF) recorded the highest value in both dry matter production (8.16 g plant^{-1}) and yield (138 g plant^{-1}), followed by T_4 (Fig.1 & 2). The treatment absolute control (T_1) which received no manures or fertilizers produced the lowest yield, which might be the direct effect of decreased supply of nutrients to the growing plants besides the poor soil physical and biological conditions in coastal sandy soils.

All treatments except the absolute control with applied organic manures showed an enhancement in crop growth. Lime+TOF had a higher ability to boost the availability of nutrients to crop, stimulating the growth and yield of crop, compared to other manures. Application of organic fertilizers enhanced the organic matter content of soil, thereby improved soil properties and resulted in better nutrient availability and higher crop yield (Li *et al*., 2011).

Effect of organic manure application on physical properties of coastal sandy soil

In the initial soil analysis, sandy coastal soil of the experimental site recorded high values for soil density. Post-harvest analysis of the same soil showed that the application of organic manures did not produce any significant variation in both soil bulk density and particle density. But still, there was a noticeable decrease in soil densities of soils which received organic amendments (Table 4). The lowest bulk density (1.50 Mg m^{-3}) and particle density (2.64 Mg m^{-3}) was recorded by the treatment T_4, while the highest was recorded for absolute control (T_1). Higher bulk density indicates the sandy soil texture and is unfavourable for crop growth. Askin and Ozdemir (2003) reported that sand content was found to be the most effective soil fraction that influenced soil bulk density and the clay content and organic matter content have significant negative relation with bulk density. An increase in organic matter resulted in a decrease in the bulk density and particle density of soil, making it favourable for crop growth (Das and Agarwal, 2002). The bulk density might get reduced due to better soil aggregation and aeration brought about by organic amendments (Kadalli *et al*., 2000).

Table 4. Effect of organic manures on physical properties of post-harvest soil

Treatments	BD (Mg m^{-3})	PD (Mg m^{-3})	WHC (%)	WSA (%)
Initial soil	1.59	2.73	37.65	41.5
T_1 - Control	1.61	2.73	37.60	40.1

T_2 - FYM	1.51	2.66	48.40	46.5
T_3 - VC	1.51	2.65	49.80	47.1
T_4 - Lime +VC	1.50	2.64	49.90	48.1
T_5 - CPC	1.52	2.69	48.10	45.3
T_6 - Lime + CPC	1.53	2.68	47.30	45.6
T_7 - CC	1.55	2.69	44.80	48.2
T_8 - Lime + CC	1.54	2.68	45.10	48.9
T_9 - TOF	1.52	2.67	43.10	49.0
T_{10} - Lime + TOF	1.51	2.65	43.60	49.4
T_{11} - FYM + Biochar	1.56	2.70	41.70	46.8
T_{12}- Lime + FYM + Biochar	1.58	2.69	42.60	47.3
SEm ±	0.03	0.02	0.02	1.38
CD (5%)	NS	NS	0.055	4.018

As a result of low organic carbon content in initial soil, the coastal sandy soil was very weak in aggregate stability, indicating that it had poor water retention, with a water holding capacity (WHC) of 37.65 per cent. Upon organic manure addition, treatments showed a significant variation in water holding capacity of the soils. It was observed that soil treated with Lime+VC recorded the highest WHC (49.90%), followed by T_3 (VC alone), while the absolute control (T_1) recorded the lowest WHC. Herawati *et al.* (2021) reported that application of organic amendments like rice husk biochar and cow dung increased the moisture holding capacity and aggregate stability of sandy soils. Aggregate stability of soil was also found to be increased with organic matter addition. The highest value of water stable aggregates (WSA) was recorded in T_{10} (49.40%). All other treatments, except T_5 and absolute control, were found to be statistically on par with T_{10}, which showed that organic manures bind the soil particles together and increased the aggregate stability of soil. The aggregate stability of each treatment that received organic manure application was higher than its initial value prior to the experiment.

Effect of organic manure application on electro-chemical properties of coastal sandy soil

Table 5 shows the electro-chemical properties of analysed soil samples. The properties varied significantly among the various treatments.

Table 5. Effect of organic manures on electro-chemical properties of post-harvest soil

Treatments	pH	EC (dS m^{-1})	OC (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
Initial soil	6.45	0.065	0.11	89.0	49.0	96.0
T_1 - Control	6.46	0.063	0.08	86.0	41.0	87.0
T_2 - FYM	6.85	0.143	0.57	175.0	93.2	254.6
T_3 - VC	6.97	0.247	0.75	287.7	114.9	368.5
T_4 - Lime + VC	7.21	0.253	0.79	301.6	126.4	379.0
T_5 - CPC	6.55	0.067	0.16	109.0	78.9	120.7
T_6 - Lime + CPC	6.74	0.113	0.19	123.7	83.4	142.3
T_7 - CC	7.00	0.173	1.17	236.7	110.2	365.6
T_8 - Lime + CC	7.40	0.153	1.20	230.0	104.4	345.2
T_9 - TOF	7.03	0.347	1.22	246.0	101.3	334.0
T_{10} - Lime + TOF	7.41	0.370	1.25	310.7	118.2	388.9
T_{11} - FYM + Biochar	7.21	0.120	0.55	148.0	86.2	166.0
T_{12}- Lime + FYM + Biochar	7.37	0.243	0.63	162.0	89.6	222.8
SEm ±	0.02	0.01	0.02	1.62	1.53	1.47
CD (5%)	0.063	0.014	0.054	4.733	4.472	4.296

pH and EC

Prior to cultivation, pH of the sand was 6.45 (slightly acidic). As shown in Table 5, pH of the soil improved after crop cultivation. Among the treatments, pH of post-harvest soil was the highest (7.03) for T_{10} (Lime+TOF), which was on par with T_8 (Lime+CC) and T_{12} (Lime+FYM+biochar). This might be due to the combined application of lime and organic manures. Along with lime, the increase in pH might be due to the increase in bases by the active degradation of organic matter, and thus the activity of iron and aluminium oxides and hydroxides has been suppressed, which plays a vital role in protonation and de-protonation mechanism controlling H^+ ion concentration in soil solution. This is in agreement with the observation by Dahia *et al.* (2003).

In case of biochar application, the reason behind the rise in soil pH might be due to the dominance of carbonates of alkali and alkaline earth metals (Jabin, 2022). The lowest pH was recorded in absolute control (6.46), which was statistically on par with T_5 (CPC alone).

EC measures the salinity of soil system and acts as the main indicator of soil health. With application of various organic manures with or without lime, the soil EC increased but remained within safe limits. After the harvest of crop, T_{10} (Lime+TOF) recorded the highest

EC value (0.370 dS m^{-1}), and the lowest value (0.063 dS m^{-1}) was with T_1 (absolute control), which was lower than the initial value. Addition of organic manures increased the EC of soil, which may be due to the release of bases and soluble organic fractions to soil system by mineralisation. This is in agreement with the findings of of Carmo *et al.* (2016). Similar responses indicating the effect of organic fertilizers in supplying and retaining nutrients in the soil with vermicompost, microbial compost and TOF addition, thereby increasing the electrical conductivity of soil had been reported by Ajayan (2021). The lowest EC with the control treatment (T_1) was mainly due to the nutrient depletion by cropping.

Organic carbon content

Soil organic carbon (SOC) is a major indicator of soil health. Addition of organic amendments enhances the SOC content of soil (Agele *et al.*, 2015). After harvest, organic carbon content among the treatments were observed to vary significantly (Table 5). Application of Lime + TOF (T_{10}) was found to increase the organic carbon content of soil to a greater level than the other organic manures (Fig. 3), and is due to its recalcitrant nature, with its higher lignin content (Ajayan, 2021). Also in SOC, T_{10} was statistically on par with T_8 and T_9. Similarly, addition of other manures raised the OC content of post-harvest soil in the order $T_{10}> T_9> T_8> T_7> T_4> T_3> T_{12}> T_2> T_{11}> T_6> T_5> T_1$.

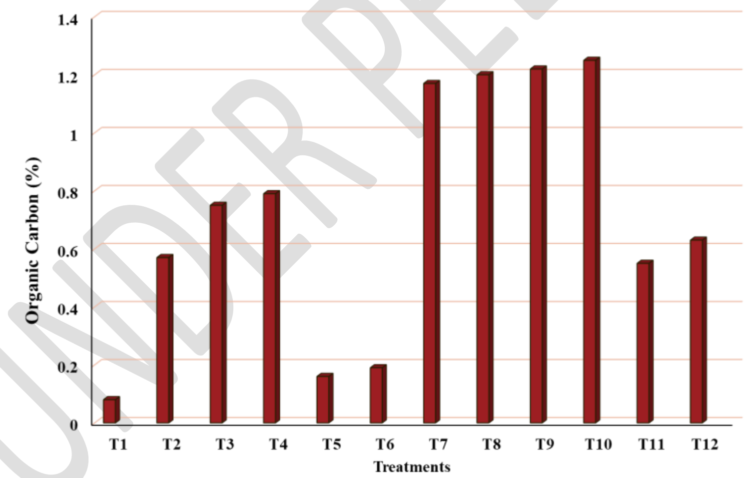


Fig. 3. Effect of treatments on available organic carbon content of soil after harvest.

Because of the uniqueness in production technology, TOF had a higher TOC and hence maintained a significant amount of organic carbon content in the applied soil. Also the thermochemical organic fertiliser with a significant high carbon pool index, shows carbon sequestration potential acquired through the thermochemical decomposition process (Leno, 2017).

Available plant nutrients

In the initial soil analysis, available primary macro nutrients such as N (89 kg ha^{-1}), P (49 kg ha^{-1}) and K (96 kg ha^{-1}), were having low potential for soil fertility (Table 5). Main issue with sandy soils is that the major sand fractions are having lower nutrient content and are poorer in soil water retention.

The use of organic amendments to support plant nutrient requirements highly depends on the mineralization of organic N (Bar-Tal *et al*., 2004; Escudero *et al*., 2012). Mineralization of organic N after manure application is related to the C:N ratio of the feedstock, and conditions and duration of the composting process (Amlinger *et al*., 2003).

Availability of nutrients in the post-harvest soil indicates the amount of nutrients unutilized by the crop and retained in the soil for succeeding crops. There was an appreciable increase in the soil fertility at the end of experiment as confirmed by the results of post-harvest soil analysis. The effect of application of different organic manures on available primary nutrient, i.e., N, P and K in post- harvest soil is shown in Table 5 and Fig. 4.

There was a build-up of available N when soil samples were analysed after harvest, and the higher value (310.7 and 301.6 kg ha^{-1}) were recorded by treatments T_{10} (Lime +TOF) and T_4 (Lime + VC) respectively, while the absolute control (T_1) recorded the lowest. In a pot culture experiment by Ananthu (2022), TOF recorded the highest soil available nitrogen content compared to other conventional organic manures like FYM, VC and CPC. Similar results were also observed by Ajayan (2021). The higher value indicates the ability of TOF to conserve and maintain a higher level of nitrogen in the soil.

Similarly, there was a significant difference between the treatments for available P (Table 5). All the treatments involving application of organic manures recorded a higher value for available P in post-harvest soil sample than the initial value. But, for absolute control, the value declined from its initial value before crop cultivation. The highest value for available P (126.4 kg ha^{-1}) was recorded with treatment T_4 (Lime + VC), followed by T_{10} (Lime +TOF). It was mainly due to the higher P content in the VC (Table 2). The significant increase in available P content could also be attributed to the organic manure mediated complexation of cations like Cu, Mg, and Al responsible for the fixation of P in soil (Sushma *et al*., 2007). Similar results with higher P content in post-harvest soil with vermicompost in comparison with other organic manures was shown by Ajayan (2021).

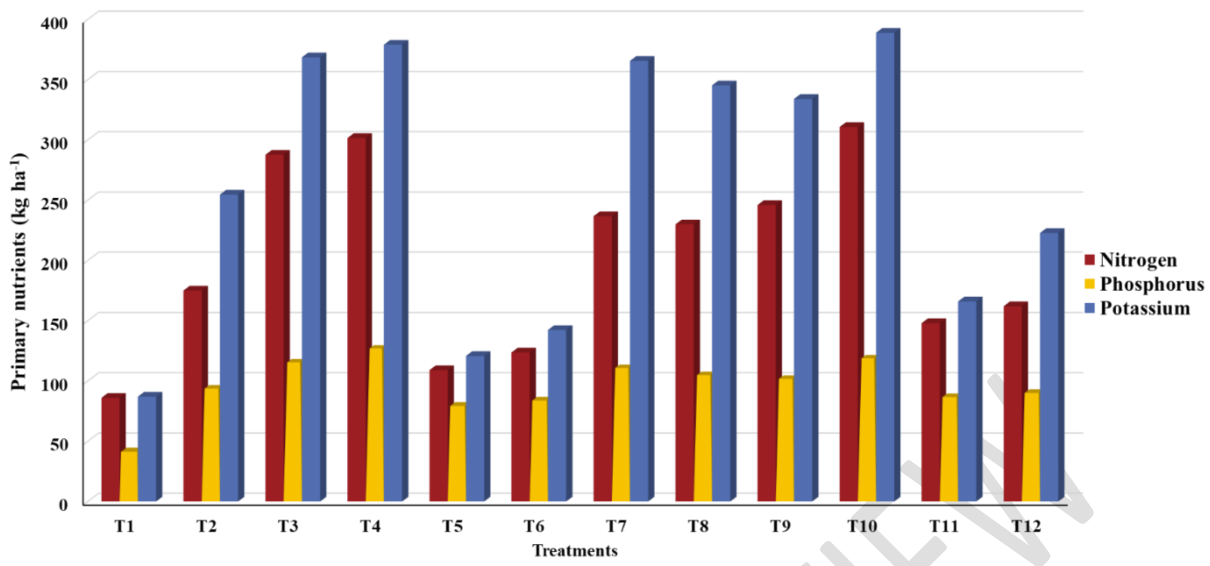


Fig 4. Effect of treatments on available N, P, K of soil after harvest.

All the treatments showed a general rise in soil available K content, compared to the initial level (Table 5). In post-harvest soil, the highest value for available K (388.9 kg ha^{-1}) was recorded by treatment T_{10} (Lime +TOF) and the lowest was with absolute control (T_1). This contributed to the improved morphological characteristics and yield components of plants cultivated with amendments at the mentioned levels. Similar results were also observed from Ajayan (2021) which reflected on crop yield, showing the highest yield in amaranthus on soils treated with TOF.

As organic manure application enhanced the plant growth and nutrient availability, an attempt was made to find a correlation between soil physical and chemical properties after cultivation and the yield of plants, along with available soil nutrients. A negative correlation was found in both bulk density and particle density with organic carbon content, while organic carbon showed positive correlation with water holding capacity and aggregate stability. Also the chemical properties and nutrient contents were enhanced on organic manure addition, which resulted in better plant growth. In other words, the higher the nutrient content in manure, higher was the soil available nutrients and greater was the plant growth rate.

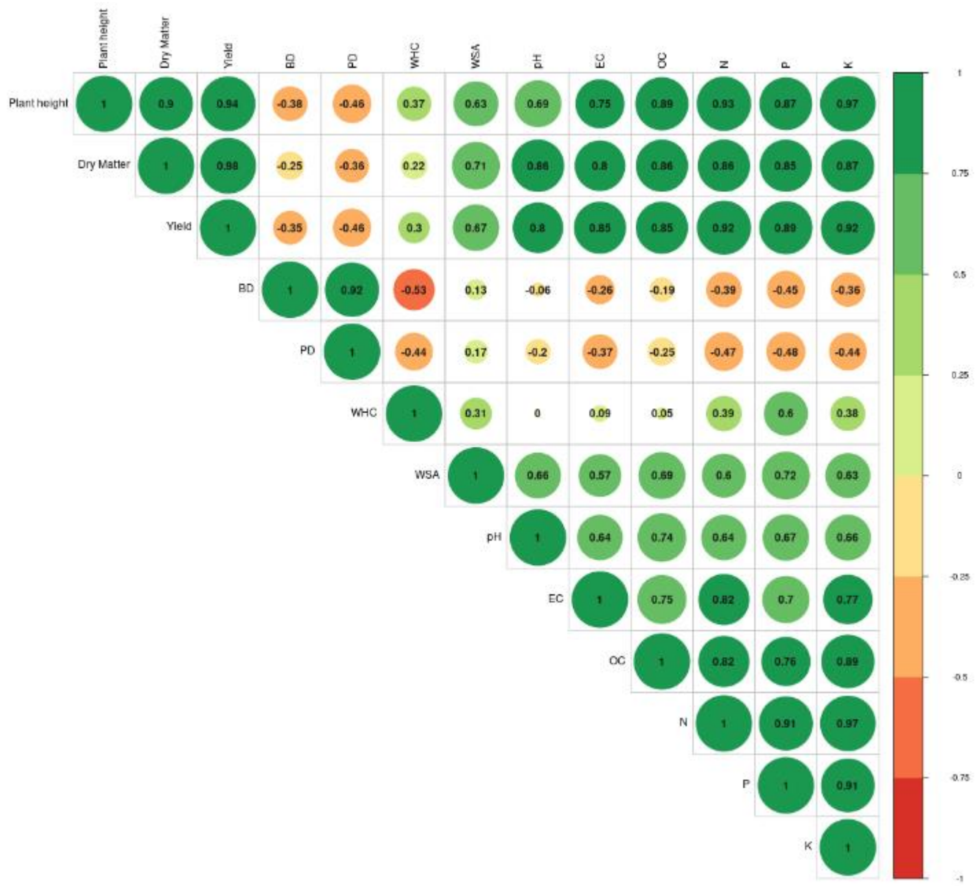
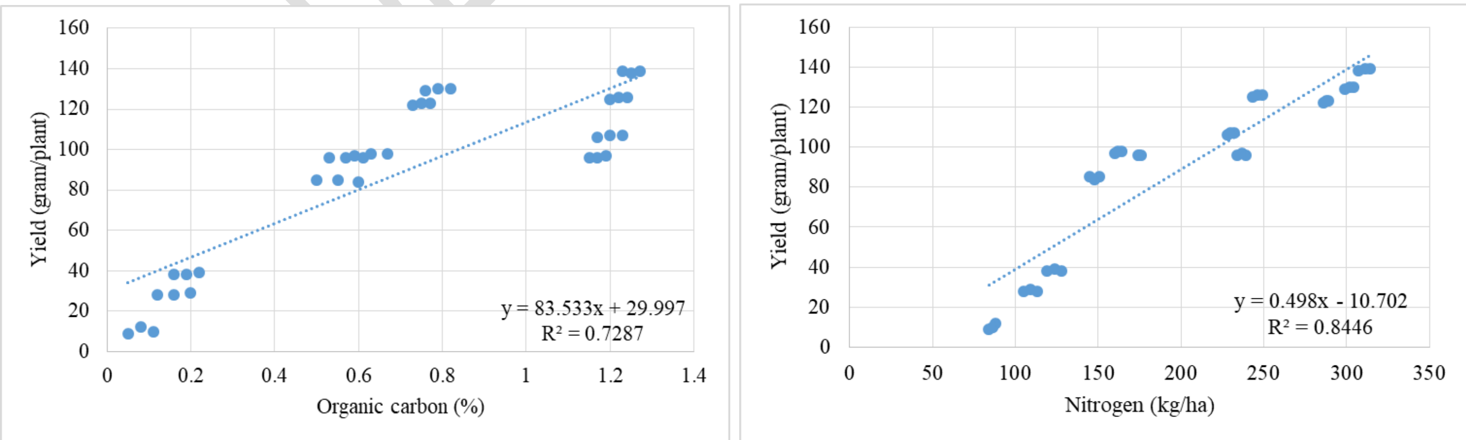


Fig. 5. Correlogram showing Pearson's correlations between the plant yield and various properties of coastal sandy soils after organic manure addition. Green and red represents positive and negative correlations, respectively. The size of circle indicate the strength of correlation (r) ($p \leq 0.5$).



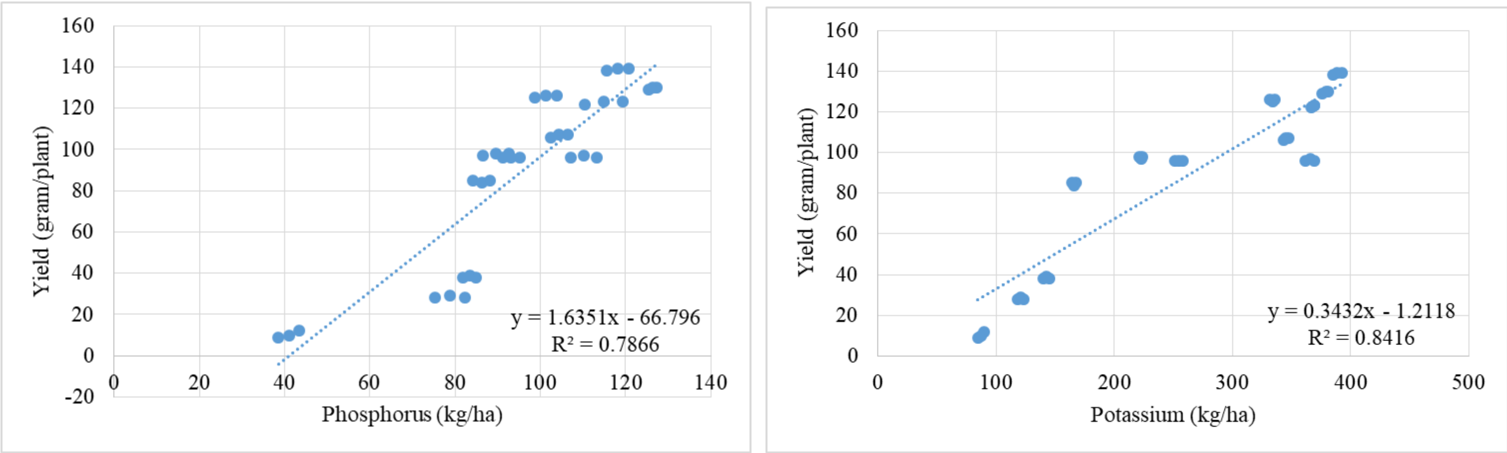


Fig. 6. Relationship between soil organic carbon content and soil nutrients availability plant yield. Slopes were calculated by linear regression. For plant yield: slopes (and regression coefficients) are 83.533 (0.7287), 0.498 (0.8446), 1.6351 (0.7866) and 0.3432 (0.8416) for organic carbon, available primary nutrients, i.e., nitrogen, phosphorus and potassium in manure amended soil, respectively (Linear correlations were observed).

To summarize, application of organic manures is an important agricultural practice as an alternative source of chemical fertilizers, aiming to enhance the soil health and productivity of coastal sandy soils. Also the application of thermochemical organic fertilizer along with lime has greater economic benefits for crop production in coastal sandy soils, and it can be used as an alternative to other conventional organic fertilizers that are commonly used for crop production.

CONCLUSION

Results obtained from the present study indicates that on organic manure addition, there were significant difference in the morphological components such as plant height, dry matter production and yield on amaranthus. Also in soil chemical properties: pH, EC, available nitrogen, phosphorus, potassium and organic carbon content were greatly influenced with organic manure addition, and were higher for TOF, VC and CC. TOF application showed the best performance of amaranthus on coastal sandy soil. It showed that the addition of organic manures in coastal sandy soils is helpful to improve soil fertility as well as productivity. From the study, soil test based lime application and basal application of thermochemical organic fertilizer @ 25 t ha^{-1}, top dressing with fresh cow dung slurry @ 1kg per 10 litres, along with 272.7 kg rock phosphate and 122.5 kg potassium sulphate ha^{-1} can be recommended to farmers as a better treatment than the other conventional organic manures in coastal areas.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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