Science Frontiers
2022; 3(2): 88-95
http://www.sciencepublishinggroup.com/j/sf
doi: 10.11648/j.sf.20220302.14

Terra Preta: Organic Manure from Septage for Improving Crop Productivity

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To cite this article:
Ravikiran Shet, Nand Nitin Kamat, Shree Sharan, Srikanth Mutnuri. Terra Preta: Organic Manure from Septage for Improving Crop Productivity. *Science Frontiers*. Vol. 3, No. 2, 2022, pp. 88-95. doi: 10.11648/j.sf.20220302.14

Received: May 13, 2022; **Accepted**: May 26, 2022; **Published**: June 9, 2022

Abstract: The lost nutrient rich top soil from the surface of the earth can be replenished by the use of organic fertilizers. Terra Preta (TP) is high quality organic fertilizer with potential to replace chemical fertilizers (CF). This organic fertilizer competes with CF in providing adequate nitrogen, phosphorous and potassium (NPK) to soil as well as crops. The present study focuses on production of TP using septage sludge, which was tested on two different agricultural crops at field scale. Field experiments were conducted at Santa Cruz, Goa, India, in two different crops namely *Capsicum frutescens* (chili) and *Oryza sativa* (paddy) at one acre capacity. In this, standard CF was treated with TP on yield and other plant growth parameters. Different ratios of CF with TP (TP, TP+50% CF, TP+75% CF, TP+100% CF), recommended dose of CF and farmer's practice were studied. The results of the study suggested that the use of TP increased yield by 15% and 16% for *C. frutescens* and *O. sativa* respectively when compared to control. The increase in other parameters such as plant height and leaf length was also significant with TP as 15% and 10% respectively. However for *O. sativa*, the plant height was found to be 10.7% higher than 23% more biological yield.

Keywords: Organic Fertilizers, Terra Preta (TP), Vermi-Composting, Septage and Nutrient Recovery

1. Introduction

The pressure is high on natural resources due to increasing population. About 854 million people in 46 countries are chronically hungry due to extreme poverty [1] and an estimated 2.2 billion people are suffering from micronutrient deficiencies. Unsustainable farming methods, such as monocropping and overuse of fertilizers and pesticides have resulted in extensive land degradation in India. A number of agricultural practices support the use of mineral fertilizers. Its use results in water pollution and soil erosion, increasing acidification and salinization of soils. Monocropping is leading to depletion of micronutrients resulting in soil infertility. The average annual soil loss in India is estimated be 16 t/ha. Population growth, intensified land use and climate change are increasing the pressure on agricultural land [2].

In developing countries, the increasing prices of chemical fertilizers coupled with growing concerns for sustaining soil productivity has led to renewed interest in use of organic manures as fertility-restorer [3]. Organic fertilizers are a vital resource not only for supplying plant nutrients but also for replenishing organic matter content in the agricultural soils, particularly in the tropics. This would further emphasize the need to use organic fertilizers in soil fertility maintenance for sustainable crop production [4]. The objective of this study is to select agricultural sites and sources for Terra Preta (TP) production from septage sludge in Goa, India and to explore the use of TP as a soil fertility enhancer to increase agricultural yields. Increasing soil fertility through the above processes will be more efficient compared to production of CF and its usage in terms of atmospheric carbon saved per unit of biomass [5].

Terra Preta do Indio or "black earth" is a soil rich in organic matter. TP is the anthropogenic black soil that was produced by ancient cultures through the conversion of bio-waste and faecal matter into long-term fertile soils [6, 7]. These soils have maintained high amounts of organic carbon even several thousand years after they were abandoned [8]. It consists of dark humus probably derived from a combination of excreta (animal and/or human), charcoal (~10% of the soil), organic waste (mainly woody materials) and lacto-fermenting bacteria [9]. It is a living soil with very little leaching of nutrients, and a high water storage capacity. The man-made dark humus production in the TP process is much more efficient than the humus production that naturally occurs in nature. Therefore use of TP is a way to speed up the formation of fertile, organic rich and resistant soils [10, 11].

Santa Cruz town selected for the study located in central part of Panaji, capital of Goa, India. It is situated near the banks of River Mandovi with laterite soil (red soil) having pH of 5.5-6.5 [12]. The crops selected were based on the seasonal agricultural practices.

The main focus of this pilot project was to increase soil fertility by applying TP and compare the crop productivity with CF and local crop cultivation practices used by at selected sites. The pilot study consisted of two phases: production of TP which involves addition of charcoal and lactic acid fermentation [13] at Baina, Goa and to test the quality of the product. The second phase studied the effectiveness of TP produced at site on agricultural crops like *Capsicum frutescens* (chili) and *Oryza sativa* (paddy) for improving the yield [14].

2. Materials and Methods

2.1. Location

The complete process of producing TP was carried out in Baina Sewage treatment plant, Baina, Goa, India (15.382855 N 7.808210E). For testing the performance of TP, *C. frutescens* and *O. sativa* plants were selected. The field experiments were undertaken at the field at Santa Cruz, Goa, India (15.477727 N, 73.841090 E) in co-operation with BacTreat Environmental Solutions LLP funded by BIRAC, India.

The soil type in the selected experimental plot was found to be laterite with a pH range of 5.5-7. The soil condition is tabulated in Table 1 [12].

2.2. Source of Septage Sludge

The sludge required for the preparation of TP was procured from the contents of night soil tankers. These tankers have a capacity of 8000-10000L each with solids varying between 4 to 6%. The solids and liquids were separated by leaving tank undisturbed for 24 hours. The liquid thus separated was collected in 1000L tanks which were then sent to vertical flow constructed wetlands (VFCW) for the treatment. The thick liquor obtained at the bottom of the tanks was pumped to the unplanted drying beds to get the concentrated sludge. Thus the produced sludge was used to prepare TP.

Charcoal and lactobacillus culture were procured from the local vendors from Goa. The Eudriluseugeniae species of earthworms and press mud were procured from the local farmers. Chemical fertilizers (Urea, Di Ammonium Phosphate i.e, DAP and Muriate of Potash i.e MOP) were also purchased locally from Panaji city, Goa. The crop selection was done based on the farmers practice and the seasonal crop variation to the particular location.

2.3. Preparation TP

2.3.1. TP

The TP production was carried out in two stage treatment starting with Lactic acid fermentation and vermicomposting. For every 1000 kg sludge, 15L of *Lactobacillus* culture and 100 kg charcoal were mixed to carry out lacto fermentation (LF) under anaerobic conditions. The Lactic acid production reduces the pH which helps in reducing the bad odor and conserve dissolved soil organic matter for later humus formation. Charcoal in turn helps in increasing the pH and provides higher surface area for the microbes to attach and grow. After 15-20 days of lacto fermentation, the mixture was transferred to composting beds where it was mixed with press mud (press mud: sludge in the ratio 2:1) and selected strains of earth worms (*Eudrilus eugeniae)* was introduced. Vermicomposting process was carried out for 30 days. The procedure followed to prepare the TP is shown in Figure 1.

The TP thus produced was tested for the following parameters like moisture, particle size, bulk density, pH, total organic carbon (TOC), C/N ratio, and conductivity, total N, available P and exchangeable K from ItaLab Goa. Pvt. Lt. The experimental procedures followed to analyze the characteristics of soil and fertilizers were based on the Fertilizer Control Order (FCO) guidelines [15, 16].

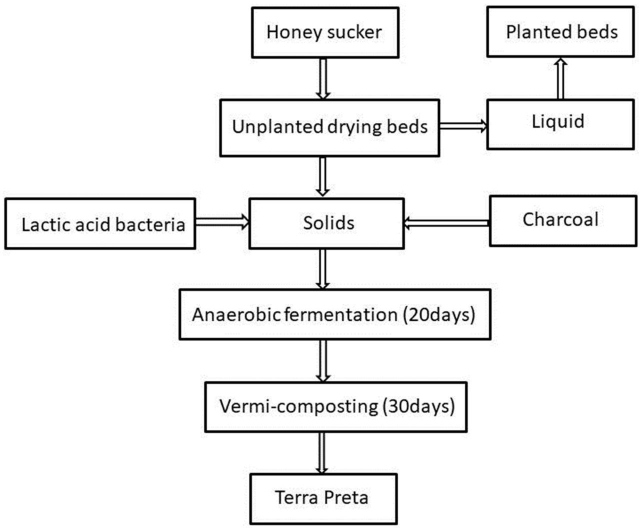


Figure 1. *Process diagram for the preparation of TP.*

2.3.2. Treatment of Liquid Separated from the Sludge Using VFCW

A 20 m^2 VFCW was constructed with the aim to treat the liquid separated from the solids during TP production. The setup is only of single stage as solids were aimed to be treated. The VFCW was filled with gravels of different sizes at three different heights from bottom to top. The gravel size of 10-40 mm constitutes the first layer of the bed of 20 cm thickness at the bottom, followed by 4-10 mm sized gravels of thickness 15-20 cm and finally 0-4 mm river sand for 40 cm height at the top. Ventilation was provided by perforated pipes at the bottom of wetland which was extended to 1 m vertically (top). The sand bed was planted with *Canna indica* [17, 18]. Post solid separation the liquid from the septic tankers passes into the wetland for treatment. The quality of the septic tank water after separating solids and post VFCW treatment were analyzed for different physico-chemical parameters.

2.4. Field Application of TP

Field application trials of above prepared TP were carried out on the agricultural plots at Santa Cruz. The crops *C. frutescens* and *O. sativa* were selected based on the local agricultural practices. Further crop selection was made according to the seasonal crop cultivation. This work was commenced from January 2020 till February 2021. Both chili and paddy were tested with seven treatments by varying ratios of CF and TP along with the traditional farmers practice and control (without any fertilizer) (Table 1). The CF used for the study was applied to the plots in a similar pattern that the farmers used them crop wise. The ratios of the N-P-K application rate of CF for *C. frutescens* and *O. sativa* by the farmers was 100-60-40 and 100-5-50 kg/ha respectively.

Table 1. *Different treatments studied for application of TP, with different CF rations and blank.*

No.	Treatments
1	Control with no application of any chemicals and/or organics
2	Recommended dose of CF
3	Farmer’s practice of adding cow dung, municipal waste and poultry waste in the ratio 2:5:1
4	TP
5	TP + 50% CF
6	TP + 75% CF
7	TP + 100% CF

The plot was subsequently divided into 18 equal parts for two different fertilizers (CF, TP) and 1 blank with 3 replicates. The nitrogen application rate depending on the crop corresponding to 60 kg of nitrogen/year/hectare was selected. Randomized field trial technique was employed for cultivating crops with 21 plots for each crop study. The plots were separated by 0.3 m spacing with 15 cm interplant spacing to avoid any possible mixing with the surrounding plots. The calculations and the design for the field trial are as follows.

7 treatments x 3 replicates = 21 plots (https://www.random.org/lists/).

During the experimentation, the plant height (cm) at regular intervals was recorded, by measuring the main shoot from the ground level up to the tip of the largest leaf stretched, along with leaf length (cm) and yield (t/ha).

2.5. Statistical Analysis

To compare the performance of all the treatments with respect to the blank and CF, statistical analysis was carried out using IBM SPSS Statistics 21 software to find out the correlation matrix between the parameters for treatments studied.

3. Results and Discussions

3.1. Soil Sample

The soil from the test field was analyzed for different parameters. The soil sample was collected by random sampling; the sample was sieved through 5mm mesh to remove the bigger stones. The results are tabulated in Table 2.

Table 2. *Physico-chemical parameters of soil.*

Parameter (mg/L)	Units	Results
Organic Carbon	%	0.6133±0.0390
Available Nitrogen	Kg/ha	202.11±17.44
Available Phosphorous	Kg/ha	16.62±.0164
Available Potassium	Kg/ha	185.99±33.46
pH	-	6.89±0.0241
Electrical conductivity	µS	137.9±6.22
Calcium	ppm	0.73±0.2264
Magnesium	ppm	0.83±0.0339
Available Sulphur	ppm	14.68±1.58

3.2. TP Analysis

The produced TP was analyzed for different chemical parameters to know the composition of the same. The results were found to be within the FCO limits [19] for the compost produced and are tabulated in Table 3. The physical parameters such as moisture, particle size and bulk density were 28.78±13.88%, 94.56±2.24% and 0.897±0.0601 g/cm^3 respectively. The heavy metals such as Cadmium, Chromium, Copper, Nickel and Zinc were found 4.92, 42.62, 109.75, 38.13 and 792.41 mg/g. The Arsenic and Mercury were below the detectable limits.

Table 3. *Physico-chemical parameters of TP.*

Parameters	Units	Results	Specifications (FCO 1985)
Moisture	%	28.78±13.88	25.0% max
Particle size	%	94.56±2.24 of the material passes through the sieve of 4.0mm size	Min 90% of the material should pass through the sieve of 4.0mm size
Bulk density	g/cm^3	0.897±0.0601	<1.0
Total organic carbon (TOC)	%	10.51±7.61	14% min
Total Nitrogen as N	%	1.18±0.6503	0.5% min
Total Phosphates as P_2O_5	%	1.35±0.6836	0.5% min
Total Potash as K_2O	%	0.2261±0.217	0.5% min
NPK	%	2.77±1.35	3% min
C:N ratio	-	8.63±2.08	<20
pH	-	6.59±0.9438	6.5-7.5
Electrical conductivity	dS/m	3.44±1.31	<4.0
Arsenic as AS_2O_3	mg/kg	Nil	10
Cadmium as Cd	mg/kg	4.92	5 max
Chromium as Cr	mg/kg	42.62	50 max
Copper as Cu	mg/kg	109.75	300 max
Mercury as Hg	mg/kg	Nil	0.15 max
Nickel as Ni	mg/kg	38.13	50 max
Zinc as Zn	mg/kg	792.41	

3.3. Treatment of Liquid Separated from Sludge Using VFCW

The results of treatment of separated liquid using VFCW are tabulated in Table 4. The treatment of the liquid using VFCW has shown exceptionally good results where COD removal was found to be 93% and 73.3% of Ammoniacal nitrogen. The phosphates were low as 0.0004 which can be negligible with nitrate and nitrite 7.6 and 1.6 mg/L. All the parameters were found to be within the CPCB discharge limits [16]. As the VFCW treatment has become a conventional way of treating different waste streams, it is a best way to remove most of the pollutants.

Table 4. *Physico-chemical parameters of liquid separated from sludge after VFCW treatment.*

Parameter (mg/L)	Filtrate	After VFCW
COD	161.63	11.43
Phosphate	0.005	0.0004
Ammoniacal Nitrogen	74.3	19.8
Nitrate	27.3	7.6
Nitrite	9.3	1.6
Coliforms (CFU/ml)	7 * 10^4	3.5 * 10^3

3.4. Field Trials

The Figure 2 [b] represents the plant height comparison for different treatments for *C. frutescens*. It was observed that the plants dosed with TP and farmer's practice were among the tallest as compared to the control and CF treated plants. For first 15 days of planting there was no noticeable difference in the plant height however the difference was noticeable at the 30th day. A maximum plant height of 49.5cm was reported for farmers practice and the lowest plant height 34.7cm was noted for control while the other treatments were proportionate with farmers practice with an average plant height of 47.5cm. Further the leaves of *C. frutescens* plants exposed with farmer's practice grew very quickly and maintained their size while that of TP and mixed dosed ones showed gradual increase and achieved their largest possible sizes by day 45 and were considerably bigger than that of control and CF dosed ones. The leaf lengths of different treatments were compared with the CF. Here it was reported that at the initial 15 days of plantation a significant increase on the leaf length was observed for 100%TP+75%CF and 100%TP+50%CF at 7.1cm. However, only TP was comparable with CF at 4.9cm. At the end of 45 days a height leaf length of 9.7 was seen for 100%TP+100%CF all the other treatments had an average leaf length of 9 cm which was comparable to CF (Figure 2 [a]). Figure 2 [c] represents the yield observed for different treatments. The yield generated by the plants dosed with the TP far outperformed that of control as well as CF dosed ones. The yield obtained for only TP was heights with 5.2t/ha followed by control. All other treatments had an average yield of 3.15 t/ha which was on a par with CF, the lowest yield of 2.9 t/ha was seen for 100%TP+75%CF.

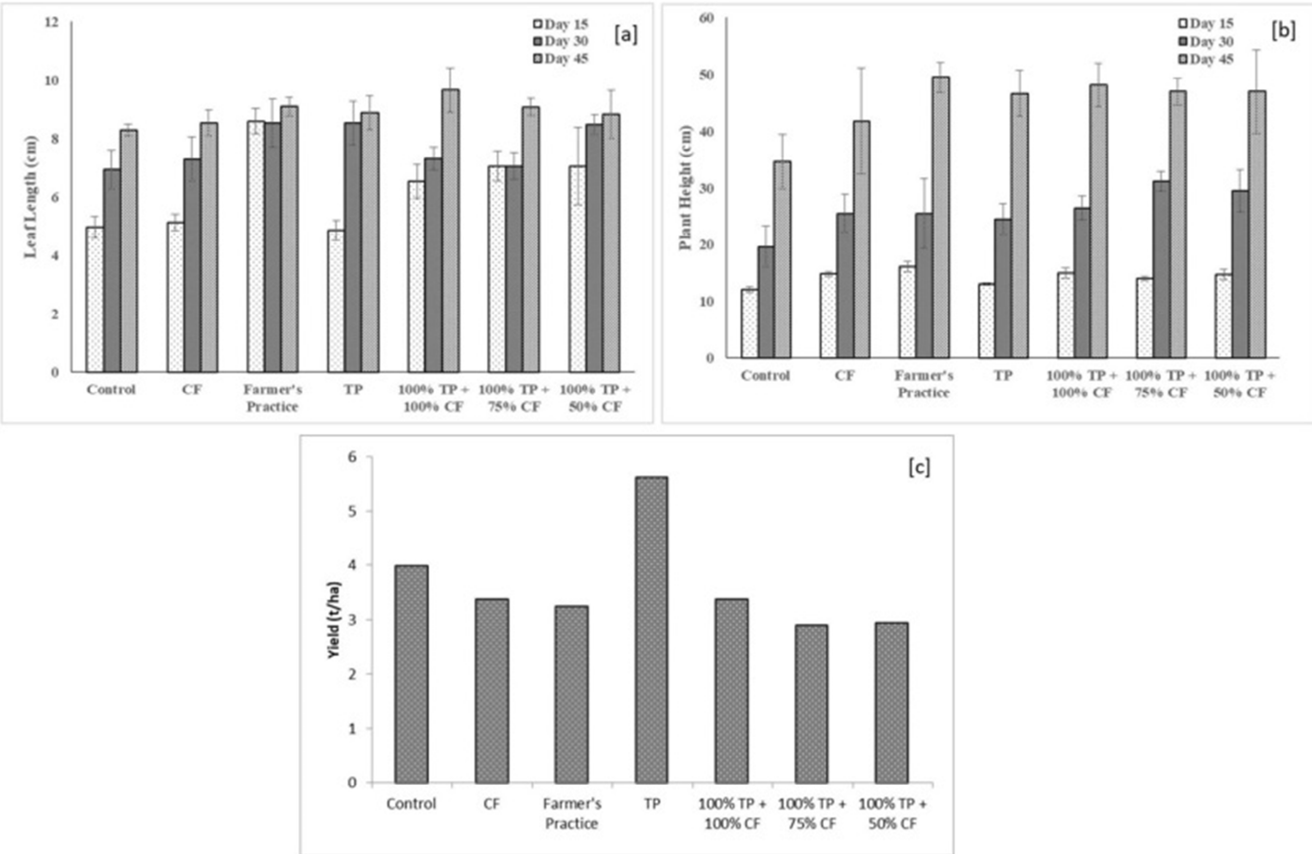
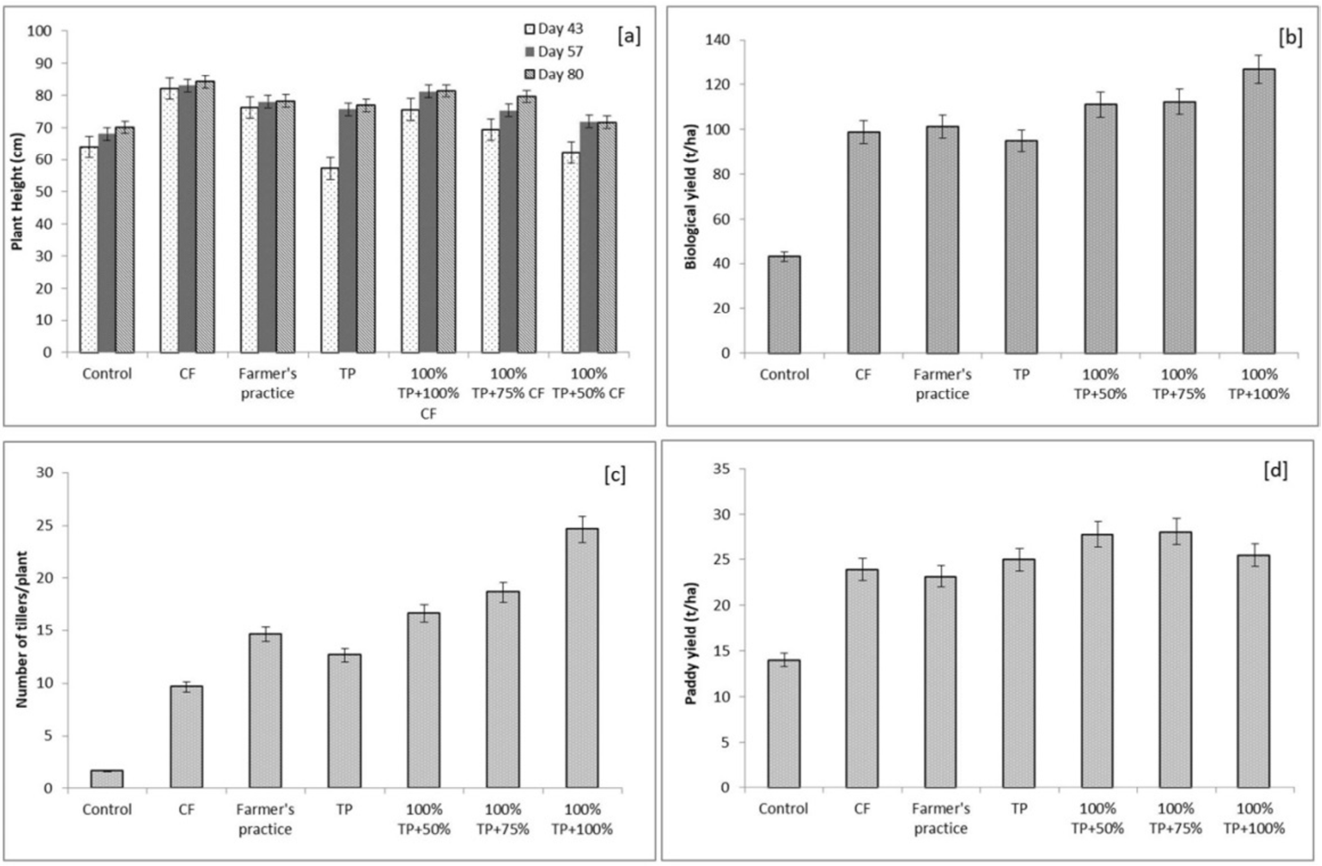


Figure 2. *Plant parameters such as [a] leaf length, [b] plant height and [c] yield of C. frutescens.*



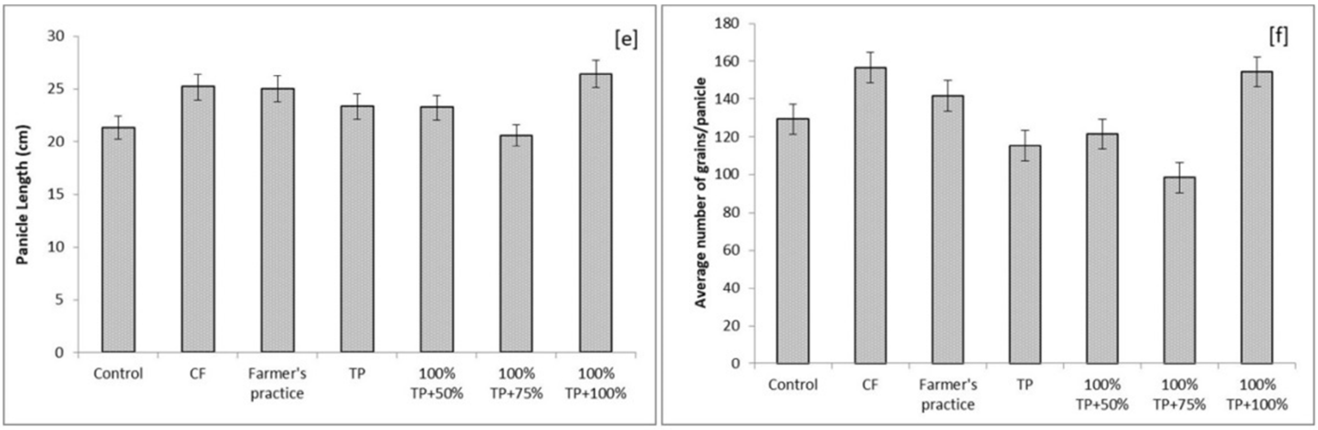


Figure 3. *Plant parameters such [a] plant height, [b] biological yield, [c] number of tillers/plant [d] yield, [e] panicle length and [f] average number of grains/ panicle for O. sativa.*

Figure 3 [d] represents the comparison between the *O. sativa* yields for different treatments. Here it was observed that the yield was higher for TP with 25 t/ha than CF with 23.9t/ha followed by farmers practice. The number of grains per panicle was higher for CF followed by farmers practice and TP as shown in Figure 3 [f]. However the total biological yield for TP was proportionate with CF and farmers practice as represented in Figure 3 [b]. When the panicle length was compared for different treatments represented in Figure 3 [e] it was observed that CF had highest length with 25.17cm followed by farmers practice with 25cm and TP with 23.33cm. Figure 3 [c] represents number of tillers per plant where the farmers practice had 14.7 tillers per plant followed by TP and CF with 14.7 and 9.7 tillers per plant respectively.

The concept of conversion of waste-to-energy or converting waste into valuable products containing essential nutrients in abundance and then using the same to increase the fertility of the soil and enhancing the plant yield with other different parameters brings two of the process together. One treatment of the waste stream which in time imparts pollution and other is producing nutrient rich products which help in bringing higher yield.

3.5. Statistical Analysis

The statistical analysis was carried out to compare different TP doses with CF for the different plant parameters. The Tables 5 and 6 indicates the effectiveness of different fertilizers on different crops. In case of plant height a significant difference was seen for CF and different TP doses ($p<0.05$) both of which varied significantly with blank ($p<0.05$). However in case of *C. frutescens*, the difference was less significant within the TP doses, different TP doses had a similar effect as that of CF on leaf length, only TP+100% CF was significantly different from other treatments ($p<0.05$). In case of yield only TP was significantly different from all the other treatment ($p<0.05$) however all the other treatments varied non-significantly with respect to control indicating a higher yielding potential for TP [20]. The *O. sativa* showed better plant height, biological yield and yield with $p<0.05$ for all TP doses with CF. However, TP alone also showed better growth but decrease in biological yield when compared to CF treatment alone and farmer's practice.

Table 5. *A matrix with qualitative analysis of different treatments against C. frutescens.*

Treatments	**Plant height**	**Leaf length**	**yield**
Farmer's practice	+++	++	+
CF	+	++	++
TP	++	++	+++
TP + 50% CF.	++	++	+
TP + 75% CF	++	++	+
TP + 100% CF	++	+++	++

Table 6. *A matrix with qualitative analysis of different treatments against O. sativa.*

Treatments	Plant height	Biological yield	Yield
Farmer's practice	++	++	++
CF	++	++	++
TP	++	+	++
TP + 50% CF.	++	++	+++
TP + 75% CF	++	+++	+++
TP + 100% CF	++	+++	++

4. Conclusions

The aim of this study was to treat faecal sludge in a sustainable manner. The conversion of this faecal sludge into TP will reduce the direct environmental impact on soil and water bodies. This treatment brings in the value addition to the product. The liquid separated from the solids treated using the VFCW have shown exceptional results in treating the same bringing all the physico-chemical parameters in the limits for environmental discharge. For both *C. frutescens* and *O. sativa,* the TP has shown significantly good yield in comparison with CF and farmers practice. Not only the yield was higher, the data suggested that the quality of the crops in terms of plant height, leaf length etc. is on par with that of CF and farmers practice.

The lower p-values ($p<0.05$) were seen for both of the crops which signifies that TP can be a potential alternative for CF which aren't environment friendly [20]. TP is not only organic, but also will be very effective in bringing the soil fertility up on long term applications [21]. TP could be better alternate organic fertilizers which not only reduces the usage of CF but also helps in waste (septage) management.

As TP was produced from the septage solids, this study can be further diversified to produce organic fertilizers using spent digestate from anaerobic digesters, the sludge from sequential batch reactor (SBR) etc. Also this study can be further optimized for different agricultural crops with seasonal variation.

Highlights

1) Terra preta (TP) was produced from septage solids.
2) Field trials were carried out on different parameters for agricultural crops.
3) The work was carried out for three consecutive seasons.
4) Results were compared with the inorganic fertilizers.
5) Statistical data showed better performance of Terra Preta.

Funding

This work was funded by Social Innovation programme for Products: Affordable & Relevant to Societal Health (SPARSH), BIRAC, India with Project no: BT/SPARSH0539/08/19.

Conflicts of Interest

The authors declare that they have no competing interests.

Consent for Publication

Not applicable.

Availability of Data and Material

All the data related to this work are presented in this manuscript.

Acknowledgements

The authors are thankful to the SPARSH, BIRAC for funding the project. The authors are also thankful for the support by Indian Center for Agricultural Research (ICAR) for their valuable insights. Authors are also grateful to the Public Works Department (PWD), Goa.

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