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ABSTRACT
In India, cassava cultivation is confined in South India. In Tamil Nadu, tubers are used as raw material for starch and sago industry. About 8–10 large-scale starch factories and 150–200 small-scale starch and sago production units are generating nearly 40–60 tonnes of solid waste (thippi) per annum creating serious environmental pollution. A study undertaken to manage it through composting to a nutrient-rich organic manure revealed thippi as acidic with low major and micronutrient concentration, high water-holding capacity, good porosity, low bulk density, high starch, fiber, low protein, and cyanide. Composting of thippi with different combinations of raw materials, microbial cultures, and earthworms indicated that thippi enriched with gliricida and cassava leaves and composted with earthworm had the highest nutrient concentration with narrow carbon to nitrogen (C:N) ratio. The mean concentrations of N, phosphorus (P), potassium (K) calcium (Ca) and magnesium (Mg), iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) in thippi compost were 1.32, 3.82, 0.40, 2.18, 0.96, 1.11, 0.08%, 11.23, and 89.93 mg/kg, respectively, which is 3.5, 49,7, 32.5, 8, 185, 100, 2.5, and 12 times than thippi. Thippi compost had low bulk density, starch, without fiber and cyanide but high protein suggesting this protocol as a possible alternative for the management of thippi.

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Bulk density; C:N ratio; cellulose; earthworm; protein

Introduction

Among the tropical tuber crops, cassava (*Manihot esculenta* Crantz) is an annual root crop which provides food for hundreds of millions of people in the tropical and subtropical areas of the world. Cassava has a strong competitive advantage in the tropical and subtropical cultivation system because of its high efficiency in transforming solar energy into bioenergy with high yield potential, tolerance to drought, wide adaptability to different climates and cropping systems, and high starch extraction rate, and its excellent physicochemical characteristics. Presently, cassava production system is changing from a small-scale subsistence level to a large-scale commercial status because of the recent characterization of cassava starch properties. In India, cultivation of cassava is confined mostly in South India with Kerala, Tamil Nadu, and Andhra Pradesh having more than three-fourth of the total area. While cassava tubers are mainly utilized for human consumption in Kerala, in the other two states, the harvested roots are mostly used as an industrial raw material for starch and sago industries.

In Tamil Nadu, during the last two decades, cassava is grown as an industrial crop for the large-scale production of sago and starch. It is known that, besides about 8–10 large-scale starch factories, around 150–200 small, family-size sago and starch production units are in operation in Tamil Nadu, generating about 40–60 tonnes of solid waste per annum (Tapasnandy, Santhosh, and Sunitha 1996).

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Hence, the cassava processing industry often is perceived by local populations as contributing significantly to environmental damage especially to soil biological health due to cyanide content of the residue. Among the various residues ejected from the starch factory, the solid waste called 'thippi' is very hazardous. As such, there were no systematic studies on the extent of soil damage due to cassava starch factory solid waste (thippi) as well as on the positive or negative impact of these residues on crop production. Hence, studies were initiated to find out possible ways to utilize the solid residue for plant nutrition in a recycling mode so that along with the disposal of the waste, its utilization in a better way also was envisaged. This paper narrates the extent of environmental pollution due to the waste, physicochemical, biochemical, and biological characterization of thippi, composting of thippi undertaken with different raw materials and microbial cultures and organisms (earthworms), characterization of the thippi compost with respect to the parameters evaluated for thippi, and a comparison between thippi and thippi compost with respect to physicochemical, biological, and biochemical properties.

Materials and methods

A rapid survey was conducted in Salem district of Tamil Nadu where large-scale starch factories and small-scale starch and sage production units are concentrated. A rapid appraisal of the environmental pollution caused by the solid waste was made by interviewing the factory owners, laborers, and people residing near the factory areas. The samples of thippi collected from different starch factory premises of Salem district, Tamil Nadu, were mixed, and a representative sample was formed. These samples were analyzed for their physical properties, viz., color using Munsell color chart (Anonymous 1975) (for specific characterization of the dominant spectral color of the material with respect to relative brightness and purity or strength), water-holding capacity (WHC), bulk density, and porosity (Iswaran 1980). The chemical properties, viz., pH, organic carbon (OC), primary nutrients, viz., total nitrogen (N), phosphorus (P), potassium (K), secondary nutrients, viz., calcium (Ca), magnesium (Mg), and micronutrients, viz., iron (Fe), copper (Cu), manganese (Mn), and zinc (Zn) were analyzed following standard analytical procedures for organic manures (FAI 2011). The biological properties, mainly the count of bacteria, fungi, and actinomycetes colonies, were taken following the procedure of Wollum (1982) using specific media. The biochemical properties, viz., carbohydrate, starch, cellulose, fiber, protein, and cyanide, also were determined (Sadasivam and Manickam 1991).

Composting procedure

As thippi was very poor in all essential elements, first it was enriched with N-, P-, and K-rich raw materials, viz., cow dung, cassava leaves, *Gliricidia sepum* (Jacq.) leaves and *Azolla pinnata* (R. Br.) as N source, Mussooriphos (naturally occurring tricalcium phosphate mined from Mussoorie district of Uttarakhand, India) as P source, and rock powder as K source. Enrichment of thippi with nutrient (N, P, K)-rich sources as mentioned above was done based on the reports of Jimenez and Garcia (1989) that, for proper decomposition, the C:N ratio of the mixture has to be reduced by adding nitrogen-rich materials.

Different composting agents such as microbial cultures, viz., microbial consortium containing *Trichoderma* spp., P and K solubilizers and waste management culture and earthworm (*Eudrilus eugeniea*) were also tried (The two cultures used were ready-made bacterial strains used for waste composting, composting procedure described below.). The mixed inoculum contained nutrient use efficient microbes, viz., N fixers (*Bacillus cereus*), P solubilizer (*Bacillus megaterium*), and K solubilizer (*Bacillus subtilis*). There were nine treatment combinations which included three combinations of raw materials and three composting agents (Table 1).

As regards the proportion of different components for composting, for every 2.5 kg thippi, 500 g of cow dung along with 100 g each of Mussooriphos and rock powder were used in treatments uniformly. In addition, as N source, either 500 g *Azolla pinnata* or 500 g *Gliricidia sepum* leaves, or

Table 1. Treatment details of thippi composting.

Treatments	Components	Culture/organism used
T1	Thippi, cow dung, Mussooriphos, rock powder	Microbial consortium
T2	Thippi, cow dung, Mussooriphos, rock powder	Earthworm
T3	Thippi, cow dung, Mussooriphos, rock powder	Waste management culture
T4	Thippi, cow dung, gliricidia leaves, cassava leaves Mussooriphos, rock powder	Microbial consortium
T5	Thippi, cow dung, gliricidia leaves, cassava leaves Mussooriphos, rock powder	Earthworm
T6	Thippi, cow dung, gliricidia leaves, cassava leaves Mussooriphos, rock powder	Waste management culture
T7	Thippi, cow dung, azolla, Mussooriphos, rock powder	Microbial consortium
T8	Thippi, cow dung, azolla, Mussooriphos, rock powder	Earthworm
T9	Thippi, cow dung, azolla, Mussooriphos, rock powder	Waste management culture

250 g each of cassava and gliricidia leaves were used. The composting agents, viz., waste management culture/mixed inoculum/earthworm were added @ 100 g to the above mixture. The experiment was replicated twice. The raw materials, viz., cow dung, cassava leaves/gliricidia leaves, azolla, Mussooriphos, and rock powder, were also analyzed for their nutrient contents following standard analytical procedures (FAI 2011).

Composting was done for 2 months in large plastic basins of 0.8 m diameter and 0.5 m height with fabricated, metallic wire mesh lids to ensure aeration and protection from pests. Proper moistening of the mixture was done at periodic intervals to maintain sufficient water for enabling decomposition. After the stipulated period, the decomposed mixture was dried under shade for 1 week, passed through 2 mm sieve, and the compost obtained was kept in dry polythene bags for further studies.

The nine different types of compost formed were analyzed for their physicochemical, biological, and biochemical properties as in the case of thippi. The count of beneficial microbes, viz., N fixers (Jensen 1950) and P and K solubilizers (Girgis, Akheli, and Sharaf 2008), was taken.

The nutrient as well as biochemical constituents of thippi compost under different treatments were statistically analyzed using analysis of variance (ANOVA) and the multiple comparison of the means was carried out using Duncan's Multiple Range Test (DMRT) (Duncan 1955). All the analyses were carried out using SAS 9.3 (SAS 2010).

Results and discussion

Rapid appraisal of the environmental pollution due to thippi

Cassava processing industry was found to have negative mainly site-specific effects on the environment by producing unpleasant odors and unsightly display of waste. However, the long-term and broad-based impact on the environment is generally minimal and can be corrected by proper waste treatment with technologies which are either presently available or under development. As thippi is presently used for making poultry feed, the chances of piling up of thippi near starch factory premises and its consequent pollution of ground water is limited (FAO 2004). No systematic studies were so far undertaken to quantify the extent of solid waste discharge per annum from these factories including its hazardous effect on soil environment. Such a study also forms a part of this work.

Physicochemical, biological, and biochemical properties of thippi

The physicochemical, biological, and biochemical properties of thippi are presented in Table 2.

Physical properties

Based on Munsell color chart, the color of thippi was 10YR8/3 (whitish cream). Analysis of physical properties of thippi indicated high WHC (89% volume basis (v/v)), good porosity (95%), and low bulk density (0.58 g/cm^3).

Table 2. Physicochemical, biological, and biochemical properties of thippi.

Physical	Chemical	Biochemical (% dry weight basis)	Biological (colony forming units/g soil)
Color-10YR8/3	pH: 3.61	Carbohydrate: 32 Starch: 60	Bacteria: 3 × 10^4
	EC: 2.8 dS m^{-1}		Fungi: nil
Water-holding capacity: 89% (v/v basis)	OC: −31%	Cellulose: 22	Actinomycetes: nil
		Fiber: 10	
Porosity: 95%	N: 0.38%		
Bulk density: 0.58 g/cm^3	P: 0.070%	Protein: 2.4	
	K: 0.057%		
	Mg: 0.06%		
	Cu: 4.3 mg/kg		
	Zn: 7.5 mg/kg		
	Fe: 60 mg/kg		
	Mn: 7.8 mg/kg		
	C:N ratio: 82:1		

Chemical properties

The chemical properties indicated thippi as acidic in nature with a pH of 3.6 with very poor concentration of both major and micronutrients (Table 2). The organic carbon content of thippi was 31%, and the electrical conductivity was 2.8 dS/m. The major, secondary, and micronutrient concentration in thippi is given in Table 2. The C:N ratio of thippi was very wide (82:1) indicating that it is not at all suitable for soil application as a manure as it can immobilize the soil available nutrients during decomposition (Allison 1973).

Biochemical properties

The biochemical analysis revealed high percentage of starch (60%), carbohydrate (32%), cellulose (22%), fiber (10%), low protein (2.4%), and negligible cyanide (10.7 mg/kg) on dry weight basis (Table 2).

Microbiological properties

Microbiological characterization revealed very few bacterial colonies (3 × 10^6 CFU/g soil) and no evidence of actinomycetes and fungi (Table 2).

Nutrient composition of the raw materials used for composting

The raw materials, viz., cow dung, gliricidia, cassava leaves, azolla, Mussooriphos, and rock powder used for enriching thippi while composting were analyzed for their nutrient contents (Table 3). The N content of the N sources, viz., azolla, gliricidia, and cassava leaves, showed a very high concentration of N to the tune of 3.01–3.71%. Mussooriphos added to enrich P in the compost had a P content of 34%. Rock powder used as a source to supplement K through its solubilization by K solubilizer (K solubilizing bacteria can dissolve the fixed soil K to exchangeable form and hence available for plant

Table 3. Nutrient content of organic materials used for composting.

Materials	N	P	K	Ca	Mg %	Fe	Mn	Cu	Zn
Cow dung	1.02	1.13	0.65	0.172	0.85	0.586	0.075	0.0105	0.0241
Azolla	3.01	0.33	1.4	0.671	0.241	0.386	0.108	0.0021	0.0077
Gliricidia leaves	3.71	0.24	1.9	0.611	0.21	0.068	0.040	0.0009	0.0023
Cassava leaves	3.22	0.51	0.68	0.417	0.221	0.126	0.048	0.0005	0.0097
Mussooriphos		34.00							
Rock powder			0.021						

uptake) contained available K to the tune of 0.021% only. In general, it was also seen that the above N sources used had comparatively high content of both major and micronutrients.

Manios (2004) recommended the incorporation of nutrient-rich organic wastes to ensure a good final product of the composted manure (This reference is given to justify for the enrichment of thippi with nutrient-rich organic manures which we have done to get the final composted produce to be nutrient rich.). Jeyabal and Kuppuswamy (2001) also used different organic materials, viz., cow dung, and bio-digested slurry from biogas plant, sugarcane press mud, weeds, and coir pith for composting.

Physicochemical, biological, and biochemical properties of thippi compost

According to Brinton (2000), the compost quality is determined by its physical, chemical, and biological characteristics.

Physical properties

The physical properties, viz., color, water content, porosity, WHC, and bulk density, evaluated for the compost under different treatments are presented in Table 4 which is compared using DMR test.

In the case of color, the hue values were 5, 7.5, 10YR with value as 3, 4, 5 and chroma as 2, 3, 4 and 6 respectively. The color was mostly brownish black. According to Dick and McCoy (1993), color is one of the most important aspects determining the maturity of the compost and the ideal color for mature compost is brown to black and crumbly with an earthy smell. The thippi compost sticks to these qualities and can be regarded as a mature compost.

As regards the water content, treatment involving thippi, cow dung, azolla, Mussooriphos, and rock powder composted with earthworm (T8) had the significantly highest (19%) water content, which was not different from all treatments except thippi, cow dung, Mussooriphos, and rock powder composted with microbial consortium (T1) and thippi, cow dung, Mussooriphos, and rock powder composted with earthworm (T2). Porosity was significantly highest for thippi, cow dung, gliricidia leaves, cassava leaves, Mussooriphos, and rock powder composted with earthworm (T5) (71%), which was not different from thippi, cow dung, gliricidia leaves, cassava leaves,

Table 4. Physical properties of thippi compost.

Treat. no.	Moisture %	Porosity %	Water-holding capacity %	Bulk density g cm^{-3}	Color
T1	14.57^{d}	69.12^{c}	72.51^{d}	0.241^{a}	10YR3/6
T2	15.32^{dc}	69.21^{c}	72.88^{bdc}	0.236^{ba}	7.5YR3/4
T3	17.38^{bac}	69.02^{c}	73.25^{bac}	0.240^{a}	10YR4/3
T4	16.83^{bdac}	70.34^{b}	73.71^{a}	0.230^{b}	10YR3/4
T5	18.83^{a}	71.14^{a}	73.08^{bdac}	0.233^{ba}	5YR3/3
T6	16.24^{bdc}	70.77^{ba}	73.52^{ba}	0.236^{ba}	5YR4/3
T7	18.05^{ba}	69.06^{c}	72.73^{dc}	0.241^{a}	10YR5/2
T8	19.13^{a}	69.40^{c}	72.67^{dc}	0.239^{a}	10YR3/4
T9	16.84^{bdac}	70.34^{b}	73.21^{bdac}	0.238^{ba}	5YR3/2
Mean	17.02	73.80	70.10	0.236	
P(0.05)	0.0303	0.002	0.0025	0.1068	
CV(%)	5.95	0.37	0.39	1.35	

The mean values with superscript containing the same alphabet are not significantly different at $P = 0.05$.
T1: Thippi, cow dung, Mussooriphos, rock powder composted with microbial consortium.
T2: Thippi, cow dung, Mussooriphos, rock powder earthworm.
T3: Thippi, cow dung, Mussooriphos, rock powder composted with waste management culture.
T4: Thippi, cow dung, gliricidia leaves, cassava leaves Mussooriphos, rock powder composted with microbial consortium.
T5: Thippi, cow dung, gliricidia leaves, cassava leaves Mussooriphos, rock powder composted with earthworm.
T6: Thippi, cow dung, gliricidia leaves, cassava leaves Mussooriphos, rock powder composted with waste management culture.
T7: Thippi, cow dung, azolla, Mussooriphos, rock powder composted with microbial consortium.
T8: Thippi, cow dung, azolla, Mussooriphos, rock powder composted with earthworm.
T9: Thippi, cow dung, azolla, Mussooriphos, rock powder composted with waste management culture.

Mussooriphos, and rock powder composted with waste management culture (T6). Thippi, cow dung, gliricidia leaves, cassava leaves, Mussooriphos, and rock powder composted with microbial consortium (T4) recorded the highest WHC of 73.71% which was not different from thippi, cow dung, Mussooriphos, and rock powder composted with waste management culture (T3), thippi, cow dung, gliricidia leaves, cassava leaves Mussooriphos, rock powder composted with earthworm (T5), thippi, cow dung, gliricidia leaves, cassava leaves Mussooriphos, rock powder composted with waste management culture (T6) and thippi, cow dung, azolla, Mussooriphos, rock powder composted with waste management culture (T9). Bulk density was reduced significantly in thippi, cow dung, gliricidia leaves, cassava leaves Mussooriphos, rock powder composted with microbial consortium (T4) (0.230%) which was not different from thippi, cow dung, Mussooriphos, rock powder composted with earthworm (T2), thippi, cow dung, gliricidia leaves, cassava leaves, Mussooriphos, rock powder composted with earthworm (T5), thippi, cow dung, gliricidia leaves, cassava leaves, Mussooriphos, rock powder composted with waste management culture (T6) and thippi, cow dung, azolla, Mussooriphos, rock powder composted with waste management culture (T9). However, the mean values of water status, WHC, porosity, and bulk density were 17.02, 73.8, 70.1%, and 0.236 g cm^{-3}, respectively.

Among the physical properties, according to Brinton (2000), particle size, texture, and content of non-decomposable debris define compost quality. As bulk density determined for thippi compost was influenced by these properties, the reduction in bulk density of thippi compost over thippi indicates an improvement in texture and particle size.

Chemical properties

The thippi manure obtained under different treatment combinations indicated that the compost is substantially very high in all nutrients. The N, P, and K concentrations in compost prepared under treatments, viz., thippi, cow dung, gliricidia leaves, cassava leaves Mussooriphos, rock powder composted with earthworm (T5), thippi, cow dung, Mussooriphos, rock powder composted with earthworm (T2), and thippi, cow dung, gliricidia leaves, cassava leaves, Mussooriphos, rock powder composted with waste management culture (T6), had the highest concentration of these nutrients as 2.38%, 3.78%, and 0.51%, respectively (Table 4). The nutrient concentration revealed that the N, P, and K content in the composted thippi ranged from 0.85% to 2.38%, 2.98% to 3.86%, and 0.3% to 0.51% with mean values as 1.32%, 3.82%, and 0.4%, respectively, which is 2–6, 40–55, and 5–10 times more than that in thippi. However, thippi enriched with gliricida and cassava leaves and composted with either earthworm or waste management culture had the highest NPK concentration.

The concentration of secondary nutrients, viz., Ca and Mg, and micronutrients, viz., Fe, Cu, Mn, and Zn, was satisfactorily high in the composted thippi in comparison to the concentration of these nutrients in commonly available composts such as vermicompost and coirpith compost. However, thippi, cow dung, Mussooriphos, rock powder composted with microbial consortium (T1) and thippi, cow dung, azolla, Mussooriphos, rock powder composted with microbial consortium (T7) had significantly the highest concentration of Ca and Mg whereas thippi, cow dung, Mussooriphos, rock powder composted with earthworm (T2) contained all micronutrients to the maximum. The mean Ca and Mg content of thippi compost was 2.18% and 0.96%, respectively, with ranges of 1.42–2.66% and 0.77–1.16%, respectively. The mean Fe, Mn, Cu, and Zn content of the thippi compost was 1.11, 0.08%, 11.23, and 90 mg/kg, respectively. Manios (2004) evaluated the nutrient content of mature compost made from single unmixed source or mixtures and found that the nutrient composition depends on the source materials. Brinton (2000) reported the metal concentration limit permitted in composts for metals such as Cu and Zn as 100–1500 and 280–2800 mg/kg, respectively. The thippi compost contained a still lower level of these nutrients to the range of 10 and 90 mg/kg, respectively.

The C:N ratio of the composted thippi manure was 8:1. Dick and McCoy (1993) reported the C:N ratio of a mature compost as 10:1, and according to Hue and Sobieszczyk (1999), C:N ratio of <15:1 strongly favors mineralization.

Among the different treatment combinations, thippi enriched with cow dung, cassava leaves, and gliricidia leaves along with Mussooriphos and rock powder (all these materials were added at once together) composted with earthworms was the best as it is more economical (as the raw materials are cheap and easily available) and high with respect to the plant nutrient concentration. According to Jeyabal and Kuppuswamy (2001), vermicomposting using earthworms can accelerate the mineralization rate and can convert the raw materials into casts with higher nutritional value than traditional composting methods. The nutrient concentration in thippi manure prepared under different treatment combinations is presented in Table 5.

Biological properties

The microbiological analysis also showed enormous amount of bacteria, fungi, actinomycetes, and a few N fixers and P solubilizers (Table 6). The treatments, viz., thippi, cow dung, Mussooriphos, and rock powder composted with microbial consortium (T1), thippi, cow dung, gliricidia leaves, cassava leaves, Mussooriphos, and rock powder composted with microbial consortium (T4), and thippi, cow dung, gliricidia leaves, cassava leaves, Mussooriphos, and rock powder composted with earthworm (T5), where microbial consortium containing Trichoderma as one of the component microbes was used, there was the presence of the fungus Trichoderma in the compost which in turn indicates its survival even after composting. The presence of Trichoderma in the compost is a beneficial factor as it is a bio control agent against many fungal pathogens.

In treatments, viz., thippi, cow dung, Mussooriphos, and rock powder composted with earthworm (T2), thippi, cow dung, gliricidia leaves, cassava leaves, Mussooriphos, and rock powder composted with earthworm (T5), and thippi, cow dung, azolla, Mussooriphos, and rock powder composted with earthworm (T8), where earthworms were used for composting, there was two- to threefold increase

Table 5. Nutrient content in the composted thippi under different treatments.

						Fe			
Treat. No.	N	P	K	Ca	Mg	%	Mn	Cu	Zn
T1	0.85^{d}	3.025^{c}	0.32^{ef}	2.655	1.07^{b}	1.013^{ab}	0.0754^{bc}	0.00124^{ab}	0.0081^{b}
T2	1.075^{cd}	3.775^{a}	0.35^{def}	1.995^{d}	0.98^{d}	1.329^{a}	0.0872^{a}	0.00153^{a}	0.0106^{a}
T3	0.89^{d}	3.68^{ab}	0.305	2.415^{ab}	1.05^{c}	1.103^{ab}	0.0804^{ab}	0.00082^{ab}	0.0086^{ab}
T4	1.425^{b}	2.685^{d}	0.4^{bcd}	2.52^{ab}	0.83^{g}	0.803^{b}	0.0638^{d}	0.00076^{b}	0.0083^{b}
T5	2.38^{a}	2.975^{c}	0.47^{ab}	1.42^{e}	0.77^{h}	0.93^{b}	0.066^{cd}	0.00095^{ab}	0.0092^{ab}
T6	1.545^{b}	3.18^{c}	0.51^{g}	2.29^{bc}	0.98^{d}	1.111^{ab}	0.078^{ab}	0.00105^{ab}	0.0087^{ab}
T7	1.175^{bc}	3.475	0.41^{bcd}	2.63^{a}	1.16^{a}	1.071^{ab}	0.0845^{ab}	0.00128^{ab}	0.0089^{ab}
T8	1.495^{b}	3.86^{a}	0.43^{bc}	1.64^{e}	0.92^{e}	1.33^{a}	0.0885^{a}	0.00134^{ab}	0.0095^{ab}
T9	1.065^{cd}	3.94^{a}	0.38^{cde}	2.055^{cd}	0.91^{f}	1.294	0.0798^{ab}	0.00114^{a}	0.0092^{ab}
Mean	1.32	3.40	0.40	2.18	0.97	1.11	0.08	0.001	0.009
P (0.05)	<0.0001	<0.0001	0.0011	<0.0001	0.0173	0.0015	0.0014	0.2609	0.3684
CV (%)	7.29	3.36	7.03	5.07	6.87	7.09	4.71	25.14	10.58

The mean values with superscript containing the same alphabet are not significantly different at $P = 0.05$.

Table 6. Microbiological analysis of thippi compost in various treatments.

			Actinomycetes			
Treat. no.	Bacteria	Fungi	CFU/g soil	N fixers[a]	P solubilizers[b]	K solubilizers[c]
T1	14×10^{8}	3×10^{6}	9×10^{6}	3×10^{7}	1×10^{6}	–
T2	16×10^{9}	5×10^{5}	8×10^{6}	1×10^{7}	–	–
T3	14×10^{9}	3×10^{6}	19×10^{5}	8×10^{6}	–	1×10^{6}
T4	12×10^{8}	4×10^{6}	16×10^{6}	8×10^{7}	3×10^{6}	1×10^{6}
T5	11×10^{8}	2×10^{7}	4×10^{6}	12×10^{6}	–	–
T6	21×10^{9}	3×10^{5}	28×10^{6}	5×10^{7}	–	–
T7	44×10^{9}	1×10^{6}	12×10^{6}	8×10^{6}	1×10^{6}	–
T8	15×10^{7}	4×10^{6}	22×10^{6}	9×10^{7}	3×10^{6}	–
T9	16×10^{8}	2×10^{6}	4×10^{6}	8×10^{7}	–	–

[a]*Bacillus cereus*; [b]*Bacillus megaterium*; [c]*Bacillus subtilis*.

in their number during the final stage of composting compared to the number added initially. Among the three earthworm-composted treatments, the maximum number of earthworms was found in T5, as there is more leafy and organic material together in the mixture with other favorable environmental factors which in turn promoted the growth of earthworms. As composting is a microbiologically mediated process carried out by bacteria, fungi, and actinomycetes (Epstein 1996), it is quite natural that their population will enhance during composting. The kind of population as observed in the present study depends on the stage of degradation, characteristics of materials used, and temperature (USDA 2000). Moreover, the diversity in nutrient content of the raw materials can result in diverse microbial population as observed in the present study as per the reports of Griffin (1985).

Biochemical properties

The biochemical properties, viz., starch, carbohydrate, cellulose, fiber, protein, and cyanide, analyzed indicated a substantial reduction of all unfavorable traits except protein due to composting. The starch, carbohydrate, and cellulose concentrations in the thippi compost are reduced to 4%, 1.72%, and 2%, respectively; there was no fiber and cyanide concentration detected in the compost. However, the protein concentration of the compost was raised to 8.3%. The biochemical properties of the thippi compost are presented in Table 7. Statistical analysis of the biochemical properties indicated significant difference among treatments. Thippi, cow dung, Mussooriphos, and rock powder composted with earthworm (T2) registered the lowest starch concentration (2.97%) followed by thippi, cow dung, gliricidia leaves, cassava leaves, Mussooriphos, and rock powder composted with earthworm (T5) and thippi, cow dung, azolla, Mussooriphos, and rock powder composted with earthworm (T8). Carbohydrate concentration was found reduced to minimum in thippi, cow dung, gliricidia leaves, cassava leaves, Mussooriphos, and rock powder composted with earthworm (T5) (0.93%) which in turn was not different from thippi, cow dung, Mussooriphos, and rock powder composted with earthworm (T2) (1.04%). Cellulose concentration was significantly reduced in thippi, cow dung, azolla, Mussooriphos, and rock powder composted with earthworm (T8) (1.77%). The protein enrichment was highest with thippi, cow dung, gliricidia leaves, cassava leaves, Mussooriphos, and rock powder composted with earthworm (T5) (14.87%) followed by thippi, cow dung, gliricidia leaves, cassava leaves, Mussooriphos, and rock powder composted with waste management culture (T6) (9.65%) which in turn was not different from thippi, cow dung, azolla, Mussooriphos, and rock powder composted with earthworm (T8) (9.90%).

The significant observation as regards the biochemical properties in the case of earthworm compost as noticed in treatments from thippi, cow dung, Mussooriphos, and rock powder composted with earthworm (T2), thippi, cow dung, gliricidia leaves, cassava leaves, Mussooriphos, and

Table 7. Biochemical properties of thippi compost.

Treat. no.	Starch	Carbohydrate %	Cellulose	Protein
T1	5.02[a]	2.82[b]	3.38[d]	5.31[f]
T2	2.97[f]	1.04[f]	1.96[h]	6.71[e]
T3	4.48[c]	3.03[a]	4.04[b]	5.57[f]
T4	4.03[d]	2.34[c]	4.23[a]	8.90[c]
T5	3.14[e]	0.93[f]	2.31[g]	14.87[a]
T6	4.99[a]	2.35[c]	3.13[e]	9.65[b]
T7	5.10[a]	2.88[b]	3.59[c]	7.34[d]
T8	3.11[e]	1.74[e]	1.77[i]	9.90[bc]
T9	4.74[b]	2.09[d]	2.99[f]	6.65[e]
Mean	4.18	2.14	3.04	8.32
P(0.05)	<0.0001	<0.0001	<0.0001	<0.0001
CV(%)	1.50	2.29	1.52	2.85

The mean values with superscript containing the same alphabet are not significantly different at $P = 0.05$.

rock powder composted with earthworm (T5), and thippi, cow dung, azolla, Mussooriphos, and rock powder composted with earthworm (T8) is that they had the lowest starch (2.97–3.14%), cellulose (1.77–2.31%), and carbohydrate (0.93–1.74%) concentration and highest protein (6.71–14.87%) concentration compared to the compost obtained with other two composting agents, viz., microbial consortium (starch: 4.03–5.10%, carbohydrate: 2.34–2.88%, cellulose: 3.38–4.23%, protein: 5.31–8.90%) and waste management culture (starch: 4.48–4.99%, carbohydrate: 2.09–3.03%, cellulose: 2.99–4.09%, protein: 5.57–9.65%).

As composting finally results in the production of a mature, stabilized product, there is a reduction in the carbohydrate, hemicelluloses, and cellulose, during composting as suggested by Chefetz et al. (1998). The substantially low concentration of the above decomposition products with vermicomposting can be due the fact that earthworms accelerate mineralization and humification compared to other methods according to Jeyabal and Kuppuswamy (2001).

A comparison of the physicochemical, biological, and biochemical properties of thippi and thippi compost

Physical properties

The physical properties, viz., WHC and porosity showed a slight reduction to 17% and 26%, respectively, in thippi compost compared to thippi (relative measurement with respect to thippi). But the improvement in bulk density of thippi compost was remarkable as 41% (in comparison to the BD of thippi, the BD of thippi compost enhanced by 41%, a relative comparison) compared to thippi (Table 10). The improvement in physical properties of thippi compost over thippi was the modification of particle size of the same as indicated by Hogg et al. (2000) that it is one of the most important contributors for fast decomposition of compost in soil.

Chemical properties

A comparison of the nutrient content of thippi compost over thippi and the raw materials used for composting is depicted in Tables 8 and 9 (Replaced by Tables 8,9<PQ: Please confirm whether the highlighted text can be deleted.>). The percentage of nutrient concentration of all major, secondary, and micronutrients in thippi compost compared to the raw materials used for composting including thippi is presented in Table 8. The percentage increase/decrease of the above nutrients in thippi compost over the raw materials including thippi is presented in Table 9. ("+" sign indicates that thippi compost contains more of those nutrients than the raw materials and "–" sign indicates that thippi compost has less of those nutrients than the respective raw materials used.)

The N content in thippi, cow dung, azolla, gliricidia, and cassava leaves was 0.38%, 1.02%, 3.01%, 3.71%, and 3.22%, respectively. After composting, the thippi compost acquired an N content of 1.32% which is 3.48 times that of thippi. On an average, the N content in thippi compost was almost equal to that in cow dung. However, compared to the N-rich sources, viz., azolla, gliricidia, and cassava leaves, the N content in the compost ranged from 35% to 44% of that in those sources. The

Table 8. A comparison of the nutrient concentration in thippi compost over thippi and other raw materials used for composting.

Nutrients %	Thippi	Cow dung	Azolla	Gliricidia	Cassava	Thippi compost
N	0.38	1.02	3.01	3.71	3.22	1.32
P	0.07	1.13	0.33	0.24	0.51	3.4
K	0.057	0.65	1.4	1.9	0.68	0.4
Ca	0.067	0.172	0.671	0.611	0.417	2.18
Mg	0.12	0.85	0.241	0.21	0.221	0.97
Fe	0.006	0.586	0.386	0.068	0.126	1.11
Mn	0.0008	0.075	0.108	0.04	0.048	0.08
Cu	0.0004	0.0004	0.0021	0.0009	0.0005	0.0004
Zn	0.00075	0.0241	0.0077	0.0023	0.0097	0.00075

Table 9. Percentage increase/decrease of nutrients in thippi compost over thippi and other raw materials used for composting.

Nutrients	Thippi	Cow dung	Azolla	Gliricidia	Cassava leaves
%					
N	+247	+29	−56	−64	−59
P	+4757	+201	+930	+1317	+567
K	+602	−38	−71	−79	−41
Ca	+3154	+1167	+225	+257	+423
Mg	+708	+14	+302	+362	+339
Fe	+18400	+89	+188	+1532	+781
Mn	+9900	+7	−26	+100	+67
Cu	+150	+150	−52	+11	+100
Zn	+1100	−63	+17	+291	−7

"+" sign indicates the increase in thippi compost over thippi and other raw materials used for composting and "−" sign indicates the decrease in thippi compost over the raw materials and thippi.

Table 10. A comparison of the physical and biochemical properties of thippi and thippi compost.

	Physical properties			Biochemical properties					
	WHC	Porosity	BD	Starch	Cellulose	Fiber	Protein	Carbohydrate	Cyanide
Materials	%	%	(g/cc)	%	%	%	%	%	mg/kg
Thippi	89	94.6	0.581	60	22	10	2.4	32	10
Thippi compost	73.8	70.1	0.236	4	2	Nil	8.3	1.72	Nil
Decrease (%)	19	17	41	94	91	N/A	350[a]	95	N/A

[a]increase.
WHC: water-holding capacity; BD: bulk density; N/A: not applicable.
Though starch and cellulose are carbohydrates, they were determined separately.

greater supply of N in thippi compost compared to thippi was mainly from the above N-rich sources. It was due to the favorable C:N ratio of the mixture which resulted in faster degradation as reported by Allison (1973) coupled with the priming effect of N from other sources on C degradation (Agamuthu et al. 2000).

The high P content (3.4%) measured in thippi compost compared to the P content of all other sources used was due to the addition of Mussooriphos, which contained 34% phosphorus pentoxide (P_2O_5). Over thippi, the compost contained 49% P. Mussooriphos, which is tricalcium phosphate containing Ca (28–34%), contributed much to the decomposition process during composting through prevention of volatile organic acids, viz., acetic acid, and reduction in odor by raising the pH through Ca contained in Mussooriphos to a satisfactory level of 5 or above (in acid laterite soils like our Ultisol, lime containing Ca is applied to raise the soil pH) and might have favored the population of bacteria that contributed much to the degradation process as reported by Brinton (2000).

In the case of K, though the raw materials, viz., cow dung (0.65%), azolla (1.4%), gliricidia (1.9%), and cassava leaves (0.68%), used had substantially high content of K, the K acquired in the thippi compost was only very less as 0.4% which is 7 times than that in thippi. But the K concentration in the thippi compost compared to the K content in cow dung, azolla, gliricidia, and cassava leaves was less by 38%, 71%, 79%, and 41%, respectively (Rewritten<PQ: Please confirm whether the highlighted text can be deleted.>). Though the mixed inoculum containing K solubilizers was used for solubilizing the fixed K in rock powder (which is used as the K source for the K solubilizer to act), the extent of acquisition of K in the thippi compost was very low than thippi and other organic sources. The reason can be attributed to the wide C:K ratio of both thippi (wide C:K ratio of thippi means, thippi contains 82% C and 0.057% K or C:K ratio is 100:0.063) and the raw materials (low C:K ratio of the raw materials used for composting). Since the C:K ratio of thippi and the raw materials is wide, the enrichment of K in the thippi compost during the composting process was very less.

The concentration of secondary nutrients, viz., Ca and Mg, was very low in thippi (Table 2). The Ca concentration of thippi was 0.067%, but composting resulted in the enrichment of Ca to 33 times than that in thippi to a status of 2.18%. Compared to the Ca concentration in the raw materials used, the Ca concentration in thippi compost was very high and in turn came from Mussooriphos, which contains substantial amount of Ca (28–34% Ca). Comparing the Ca content in thippi compost over the different organic sources used for composting, viz., cow dung, azolla, gliricidia, and cassava leaves, the increase in Ca content of thippi compost was 13, 3.25, 3.57, and 5.3, respectively. It is very evident that the high concentration of Ca acquired in thippi compost came from Mussooriphos alone. As regards Mg concentration of thippi compost, compared to thippi it has 8.1 times more Mg than thippi. The thippi compost had 1.17, 4.02, 4.62, and 4.39 times Mg concentration than that of the raw materials, viz., cow dung, azolla, gliricidia, and cassava leaves, respectively, used for composting. Since the raw materials viz., cassava leaves, *Glyricidia* leaves and *Azolla* have enough Mg, the compost prepared could retain a substantially good Mg content.

Fe concentration of thippi compost was 185 times higher to that in thippi and 1.89, 2.88, 16.32, and 8.81 times higher than that in other sources, viz., cow dung, azolla, gliricidia, and cassava leaves, respectively (a comparison of the Fe concentration in thippi compost over the Fe concentration of the raw materials used). In the case of other micronutrients, viz., Mn, Cu, and Zn, though their concentrations in thippi compost were 100, 2.5, and 12 times, respectively, than that of the source used, viz., Azolla, in thippi compost there was a slight reduction in Mn and Cu contents. Similar was the result with respect to cow dung and cassava leaves in the case of nutrients, viz., Zn (Table 9.). As regards the metal concentration in composts, there is not much emphasis given to the status of Fe and Mn in the reports available. But as regards Cu and Zn their mean content was reported as 308 and 715 ppm, respectively (Epstein 1996). But in thippi compost, the acquisition of metals such as Cu and Zn is very less. The reason can be stated as these metals are associated with the organic carbon fractions of the compost, and hence increased the stability of these nutrients especially in the case of mature compost (Merritt and Erich 2003) and hence prevent its availability in solution (Giusquiani, Gigliotti, and Businell 1992).

Hence, in general, the thippi manure prepared through composting is highly nutritious for crops as it has severalfold of all nutrients than thippi due to high concentration of the nutrients during composting. Moreover, compared to the raw materials, viz., azolla, gliricidia, and cassava leaves in the case of N, cow dung, azolla, gliricidia, and cassava leaves in the case of K, azolla in the case of Mn and Cu, and cassava leaves in the case of Zn, a slight reduction was noticed in thippi compost due to the nutrient poor nature of these raw materials.

Biochemical properties

The biochemical properties, viz., carbohydrate, starch, cellulose, and protein, determined in the thippi compost (mean) were 2.14%, 4.18%, 3.04%, and 8.32% on dry weight basis, respectively (Table 10). There was not any fiber or cyanide content in the thippi compost (It indicates compared to thippi, the thippi compost had carbohydrate, starch 15 times less than thippi and cellulose 7 times lesser than thippi). But the enhancement in protein was remarkable to 3.5 times than that in thippi. Moreover composting nullified the cyanide and fiber content in thippi. Composting results in stabilization of organic wastes wherein the readily degradable organic wastes are degraded and stabilized with increased humification. Humification is accompanied by the increase in alkyl C, aromatic C, and carboxyl, phenolic, and carbonyl groups, which in turn resulted through the decomposition of the components, viz., cellulose, starch, carbohydrate, hemicelluloses, and fiber present in the thippi and also the raw materials (Chefetz et al. 1998)</linkEghball et al. (1997) indicated that the loss of C and N during composting ranged from 46% to 62% and 19% to 42% and the majority of C loss is from carbohydrates, hemicelluloses, and cellulose, which constitute the major plant C.

Microbiological properties

An enumeration of the microbiological characters especially the population of bacteria, fungi, and actinomycetes indicated substantially very high population of all of these organisms compared to that observed in thippi where bacteria alone were seen (though we have tried for counting all the three groups of microbes). All the treatments resulted in very high populations of all microflora and N fixers (based on the number of colony-forming units (CFUs) observed). But P solubilizers were noticed with microbial consortium and earthworm and K solubilizers with waste management culture and microbial consortium as composting agents. According to Gunapala and Scow (1998), the most important benefit of composting is increased microbial activity and biological processes where in the composts can harbor more diverse species of microbes and hence higher level of biological activity than in the original material.

Conclusion

As the preliminary survey indicated the upcoming hazardous effect of piles of thippi in the factory premises of Salem district where cassava is at present a cash crop, the safe disposal of cassava waste deserves special attention. This initiative in converting the starch factory solid waste into a nutrient rich organic manure helped in plant nutrition through its role as a substitute to commonly used organic manures and chemical fertilizers. In addition, it could help in subsiding the environmental pollution, reducing the input cost in the event of escalating fertilizer prices and diminishing natural resources for fertilizer manufacture. The physicochemical, biochemical, and microbiological studies revealed the superiority of thippi compost over thippi. The process of converting thippi to thippi compost is very cheap, practically feasible, and economic. Hence, this initiative undertaken will definitely find a place in its utilization for plant nutrition. Further studies are also in progress to understand the rate of nutrient release from this compost, and the extent to which thippi compost can be substituted with other commonly used organic manures and even chemical fertilizers. It is thought that the use of thippi compost for crop nutrition can definitely improve soil health.

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