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## *Results and Discussion*

Sago, the edible starch globules processed from the tubers of tapioca is the staple diet of the middle income groups in India. By virtue of its diversified uses, tapioca has become an important commercial crop in the agricultural economy of states like Tamil Nadu and Andhra Pradesh (Saravanane *et al.*, 2001). Processing of tapioca produces a fibrous residue (sago sludge) termed as '*thippi*' in Tamil alongwith an equal quantity of highly organic foul smelling acidic water (Banu *et al.*, 2006a). Overproduction of organic waste substances has led to inappropriate disposal practices. Such practices can cause serious environmental problems (Hutchison *et al.*, 2005).

The stabilization of organic wastes is often done by composting which is a microbial - mediated process. Composting process is a useful method for producing a stabilized organic material that can be used as a source of nutrient and soil conditioner (Castaldi *et al.*, 2005).

Composting enables sanitization of the waste and elimination of toxic compounds (Ndegwa and Thompson, 2001). Another appropriate technology in waste management for producing stabilized organic matter is the use of earthworms in composting. The result of this methodology using earthworm species (vermicomposting) is a high quality humified product which can be used as a soil organic amendment (Bajsa *et al.*, 2004). Vermicomposting is generally more efficient than other types of composting processes, because, earthworms feed on organic matter easily and create conditions that support the colonization and degradation of partially decomposed and fragmented materials by aerobic microorganisms (Dominguez and Edwards, 2004).

Microbes are key factors in nutrient transformation. Addition of suitable microbes alongwith residual microbes in the substrate mixture enhances the rate

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of nutrient transformation. Introduction of bacteria (*Bacillus polymyxa*) and fungi (*Trichoderma viridae*) alongwith the residual microbes in the waste enriches the nutrient content of the final compost. Microbes supply most of the enzymes and nitrogen fixing bacteriae increase the nitrogen and phosphorus contents of the vermicompost (Pramanik *et al.*, 2007).

The generation and accumulation of the sago solid waste '*thippi*', in and around sago processing industries is on the increase day by day (Kadirvelu *et al.*, 2004). The utilization of this waste for vermicomposting may give a solution to solid waste management in the sago industry.

Cattle manure is a valuable resource as a soil fertilizer since it provides high contents of macro and micro-nutrients for crop growth. It acts as a bulking agent and when mixed in an appropriate ratio with composts enhances its nutrient profile (Suthar, 2009).

On considering the unpleasant characteristic features of the tapioca solid waste, it was thought imperative to select this waste and recycle it to a more useful product, thus reducing the toxicity and abating pollution to some extent.

Thus the investigation was aimed at composting tapioca solid waste by using earthworms and microorganisms and studying selected biochemical parameters and macro and micronutrients in the composts obtained. The growth efficiency of a selected green leafy vegetable and leguminous plant grown in these composts by way of studying the biometric measurements was another focus of the study.

The study was carried out in three phases

In the first phase, the tapioca solid waste and cow dung were collected and dried.

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Varying proportions of the tapioca solid waste were then mixed with fixed amounts of cow dung (1:1, 2:1, 3:1, 4:1, 5:1 and 6:1) and given four treatments (C, M, V and M+V). C-represents control (natural composting), M-represents microbial composting where two types of microbes (*Trichoderma viridae* and *Bacillus polymyxa*) were used, V-represents vermicomposting where a mixture of three types of earthworms (locally available species namely *Eisenia fetida*, *Perionyx excavatus* and *Lampito mauritii*) were used and M+V-represents microbial vermicomposting where three types of earthworms (*Eisenia fetida*, *Perionyx excavatus* and *Lampito mauritii*) and two types of microbes (*Trichoderma viridae* and *Bacillus polymyxa*) were used. Four composting tanks were prepared for each ratio of substrate. The feed mixtures were allowed to partially decompose for 20 days before treatment. For each treatment, three replicates were maintained. The treated substrates were allowed to compost for a period of 75 days.

On the 75<sup>th</sup> day of composting, the composts were collected, dried, sieved and used for the analysis of various parameters such as pH, electrical conductivity, organic matter, organic carbon, total nitrogen, carbon nitrogen ratio, total phosphorus, total potassium, available nitrogen, available phosphorus, available potassium, sodium, calcium, magnesium, sulphur, iron, zinc, copper, molybdenum and boron.

The findings of the study are discussed under the following headings.

#### **4.1 PHASE I : PHYSICOCHEMICAL AND BIOCHEMICAL ANALYSIS**

##### **4.1.1 PHYSICOCHEMICAL CHARACTERISTICS OF UNDECOMPOSED TAPIOCA SOLID WASTE AND COW DUNG**

##### **4.1.2 PHYSICOCHEMICAL CHARACTERISTICS OF TAPIOCA SOLID WASTE COMPOSTS**

###### **4.1.2.1 pH**

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- 4.1.2.2 Electrical conductivity
  - 4.1.2.3 Organic matter
  - 4.1.2.4 Organic carbon
  - 4.1.2.5 Total nitrogen
  - 4.1.2.6 Carbon nitrogen ratio
  - 4.1.2.7 Total phosphorus
  - 4.1.2.8 Total potassium
  - 4.1.2.9 Available nitrogen
  - 4.1.2.10 Available phosphorus
  - 4.1.2.11 Available Potassium
  - 4.1.2.12 Sodium
  - 4.1.2.13 Calcium
  - 4.1.2.14 Magnesium
  - 4.1.2.15 Sulphur
  - 4.1.2.16 Iron
  - 4.1.2.17 Zinc
  - 4.1.2.18 Copper
  - 4.1.2.19 Molybdenum
  - 4.1.2.20 Boron

## **4.2 PHASE II : ACTIVITIES OF SELECTED ENZYMES AND COMPOST MATURITY IN 3:1 RATIO COMPOSTS**

### **4.2.1 SELECTION OF THE BEST SUBSTRATE**

### **4.2.2 ENZYMES IN THE COMPOSTS OF 3:1 RATIO TAPIOCA SOLID WASTE - COW DUNG MIXTURE**

- 4.2.2.1 Cellulase
- 4.2.2.2  $\beta$ - Glucosidase
- 4.2.2.3 Protease
- 4.2.2.4 Urease
- 4.2.2.5 Dehydrogenase
- 4.2.2.6 Acid phosphatase
- 4.2.2.7 Alkaline phosphatase

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### **4.2.3 COMPOST MATURITY OF 3:1 RATIO TAPIOCA SOLID WASTE - COW DUNG MIXTURE**

- 4.2.3.1 Humic acid
- 4.2.3.2 Carbondioxide evolution
- 4.2.3.3 Earthworm biomass
- 4.2.3.4 Number of earthworm cocoons
- 4.2.3.5 Number of earthworms
- 4.2.3.6 Compost yield

### **4.3 PHASE III : EFFECT OF THE 3:1 MICROBIAL VERMICOMPOST ON PLANT GROWTH**

#### **4.3.1 SELECTION OF THE POT MIXTURE FOR PLANT GROWTH**

#### **4.3.2 BIOMETRIC ANALYSIS OF BLACK GRAM (*Vigna mungo*)**

- 4.3.2.1 Germination index
- 4.3.2.2 Root length and shoot length
- 4.3.2.3 Root fresh and dry weights
- 4.3.2.4 Shoot fresh and dry weights
- 4.3.2.5 Nodule number and Seed number

#### **4.3.3 BIOMETRIC AND BIOCHEMICAL ANALYSIS OF GREEN LEAFY VEGETABLE (FENUGREEK-*Trigonella foenum gracum*)**

- 4.3.3.1 Germination index
- 4.3.3.2 Root length and shoot length
- 4.3.3.3 Root fresh and dry weights
- 4.3.3.4 Shoot fresh and dry weights
- 4.3.3.5 Soluble sugar content of root and shoot
- 4.3.3.6 Protein content of root and shoot
- 4.3.3.7 Amino acid content of root and shoot

## PHASE I

### 4.1 PHYSICOCHEMICAL AND BIOCHEMICAL ANALYSIS

#### 4.1.1 PHYSICOCHEMICAL CHARACTERISTICS OF UNDECOMPOSED TAPIOCA SOLID WASTE AND COW DUNG

Table 1 presents the values for pH, electrical conductivity and the contents of organic matter, organic carbon, nitrogen, carbon nitrogen ratio, phosphorus, potassium, sodium, calcium, magnesium, sulphur, iron, zinc, copper, molybdenum and boron, in the undecomposed tapioca solid waste and cow dung.

TABLE 1

#### PHYSICOCHEMICAL CHARACTERISTICS OF UNDECOMPOSED TAPIOCA SOLID WASTE AND COW DUNG

Parameters	Tapioca Solid Waste	Cow Dung	't' values
pH	6.4 ± 0.16	5.8 ± 0.03	2.05*
Electrical conductivity (ds m <sup>-1</sup> )	2.8 ± 0.39	3.3 ± 0.21	1.96*
Organic matter (g%)	95.92 ± 0.10	66.36 ± 0.80	8.57*
Organic carbon (g%)	54.34 ± 0.54	36.67 ± 0.40	6.61*
Nitrogen (g%)	0.83 ± 0.01	1.23 ± 0.20	2.43*
Carbon nitrogen ratio	65 ± 5.04	29 ± 2.79	10.18*
Phosphorus (g%)	0.39 ± 0.01	0.50 ± 0.010	2.82*
Potassium (g%)	0.20 ± 0.02	0.71 ± 0.024	14.14*
Sodium (g%)	0.80 ± 0.02	0.45 ± 0.02	17.5*
Calcium (g%)	0.70 ± 0.04	6.2 ± 0.09	37.25*
Magnesium (g%)	0.21 ± 0.03	0.50 ± 0.01	11.37*
Sulphur (g%)	0.11 ± 0.004	0.08 ± 0.001	5.20*
Iron (g%)	0.002 ± 0.0003	2.43 ± 0.09	114.39*
Zinc (ppm)	60 ± 3.0	900 ± 30	11.86*
Copper (ppm)	20 ± 1.0	3000 ± 300	14.08*
Molybdenum (ppm)	54 ± 4.0	800 ± 10	103.4*
Boron (ppm)	200 ± 30	300 ± 20	3.92*

Values are expressed as mean ± SD for triplicates \* - Significant at t<0.05

(ds m<sup>-1</sup>) : deci siemens per meter

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From the table it is clear that the pH, organic matter, organic carbon, carbon nitrogen ratio, sodium, calcium and sulphur contents of the tapioca solid waste were significantly ( $t < 0.05$ ) higher than the values exhibited by the undecomposed cow dung.

However, the electrical conductivity, nitrogen, phosphorus, potassium, magnesium, iron, zinc, copper, molybdenum and boron levels in the undecomposed tapioca solid waste were significantly ( $t < 0.05$ ) lower than those of the undecomposed cow dung.

In general, it can be observed from the table that majority of the elements especially nitrogen, phosphorus, potassium and trace elements were present in higher concentrations in the cow dung rather than in the tapioca solid waste. Hence, cow dung was used for mixing (as a bulking agent) with the tapioca solid waste for vermicomposting.

#### **4.1.2 PHYSICOCHEMICAL CHARACTERISTICS OF TAPIOCA SOLID WASTE COMPOSTS**

##### **4.1.2.1 pH**

The pH of the final compost plays an important role with regard to its application in soil for plant growth. It varies during the composting and vermicomposting process (Chhotu and Fulekar, 2008). A pH close to neutrality indicates that there is biological stabilization of the product. The decomposition of organic matter leads to the formation of ammonium ions and humic substances. These two components have exactly opposite effects on the pH. Presence of carboxylic and phenolic groups in humic acid causes lowering of the pH, while ammonium ions increase the pH. The combined effect of these two oppositely charged ions usually regulates the pH of vermicompost leading to a shift towards neutrality.

Table 2 shows the pH values of the composts obtained from various treatments of tapioca solid waste in different ratios with cow dung.

**TABLE 2**  
**pH OF TAPIOCA SOLID WASTE COMPOSTS**

<b>TSW:CD</b>	<b>C</b>	<b>M</b>	<b>V</b>	<b>M + V</b>
1:1	6.03±0.02	6.20±0.04	6.50±0.04	6.70±0.12
2:1	6.20±0.05	6.40±0.07	6.70±0.05	6.90±0.02
3:1	6.26±0.02	6.50±0.02	6.81±0.04	<b>7.04±0.02</b>
4:1	6.32±0.02	6.44±0.12	6.72±0.02	6.90±0.04
5:1	6.34±0.02	6.40±0.08	6.72±0.02	6.83±0.05
6:1	6.40±0.02	6.50±0.10	6.72±0.01	6.80±0.12
CD (P<0.05) = 0.58				

Values are expressed as mean ± SD for triplicates

**TSW:** Tapioca Solid Waste                      **CD** : Cow Dung  
**C** : Control (Natural composting)            **M** : Microbial composting  
**V** : Vermicomposting                              **M+V:** Microbial Vermicomposting

From the table, it is clearly understood that microbial composting (M) of tapioca solid waste showed no significant increase in the pH values for all the ratios of the samples when compared to those of the controls (C).

In the case of vermicomposting (V) of tapioca solid waste, all the ratios though they showed an increase in pH when compared to their respective controls (C) and microbial composts (M), the differences were not significant. Only the 3:1 ratio compost showed the maximum pH which was near neutrality when compared to the other ratios.

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Similarly, in microbial vermicomposting (M+V) of tapioca solid waste, the pH values of the 1:1, 2:1, 3:1 and 4:1 ratios were significantly ( $p < 0.05$ ) higher than those of the controls (C). Among these ratios, the maximum value towards neutrality was revealed by the 3:1 sample.

On comparison of the various treatments with ratios, the 3:1 ratio microbial vermicompost (M+V) also showed a pH value around neutrality. The percent increase in the pH value of the microbial vermicompost (M+V) was also the highest in the 3:1 (12.5 percent) sample.

Thus, from the results of Table 2, it can be stated that the neutral pH of the 3:1 ratio microbial vermicompost (M+V) sample reveals the correct proportion of tapioca solid waste and cow dung that could be taken for composting. At this pH, earthworms can convert the unavailable forms of nutrients into the available forms, which can be easily taken up by the plants.

The requirement of a neutral pH for microbial vermicompost as observed from the present study was supported by the observations of Komilis and Ham, (2006), who stated that a pH around neutrality provides valuable information about the decomposition stage of organic matter in wastes like paper and food wastes during the humification process.

Another study also confirmed that vermicomposting shifts the pH from acidic to neutral due to degradation of acid-type compounds like carboxylic and phenolic groups or mineralization of compounds such as proteins, amino acids and peptides to ammonia Gil *et al.*, (2007) and Fares *et al.*, (2005) found an increased pH at the end of the composting process of animal and municipal wastes, which was attributed to progressive utilization of organic acids and increase in mineral constituents of the waste.

#### 4.1.2.2 Electrical conductivity

Electrical conductivity is an important indicator to determine the compost maturity. Generally, the beneficial effect of composts like vermicompost is due to the formation of ions that are easily taken up by the plants. The ions in the media may be responsible for the increase in the electrical conductivity of the compost. During composting, the change in electrical conductivity may probably be due to the degradation of organic matter releasing minerals such as exchangeable calcium, magnesium, potassium, and phosphorus in the available forms (Guoxue *et al.*, 2001).

Table 3 presents the values for electrical conductivity of the composts produced from various treatments of tapioca solid waste in different ratios with cow dung.

**TABLE 3**  
**ELECTRICAL CONDUCTIVITY ( $\text{ds m}^{-1}$ ) OF TAPIOCA SOLID WASTE COMPOSTS**

TSW:CD	C	M	V	M + V
1:1	4.00±0.05	4.10±0.04	5.00±0.05	5.31±0.02
2:1	3.60±0.02	3.70±0.10	4.74±0.03	5.10±0.04
3:1	3.40±0.01	3.52±0.04	<b>4.55±0.02</b>	<b>4.93±0.02</b>
4:1	3.20±0.01	3.28±0.01	3.92±0.01	4.20±0.01
5:1	3.11±0.02	3.18±0.02	3.80±0.20	4.00±0.21
6:1	3.05±0.03	3.11±0.10	3.62±0.02	3.80±0.03
CD (P<0.05) = 0.155				

Values are expressed as mean  $\pm$  SD for triplicates

( $\text{ds m}^{-1}$ ): deci siemens per meter

TSW : Tapioca Solid Waste

CD : Cow Dung

C : Control (Natural composting)

M : Microbial composting

V : Vermicomposting

M+V : Microbial Vermicomposting

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From the table, it can clearly be said that microbial composting (M) of tapioca solid waste did not show any significant increase in electrical conductivity when compared to their controls (C).

Among the vermicompost (V) samples, all the ratios recorded significant ( $p < 0.05$ ) increases in electrical conductivity when compared to their respective controls (C) and microbial composts (M). However, among the various ratios, the highest percent increase (33.8 percent) was found in the 3:1 sample.

In the composts got from the degradation of tapioca solid waste through the action of microbes and earthworms (M+V), all the ratios showed significantly ( $p < 0.05$ ) higher electrical conductivity than their controls (C), microbial composts (M), and vermicomposts (V) with the 3:1 ratio again exhibiting the maximum percent increase (45 percent).

Thus, among all the types of composts, it can be said that the highest percent increase was in the 3:1 ratio (45 percent) microbial vermicompost (M+V) followed by the 2:1 (41.7 percent) and 1:1 (32.8 percent) ratio composts. Further increase in tapioca solid waste proportion reduced the percent increase in electrical conductivity in the 4:1 (31.2 percent), 5:1 (28.6 percent) and 6:1 (25.9 percent) samples.

The findings of the present study indicated that all types of composting increased the electrical conductivity of the samples. This can be correlated with the reports of Garg *et al.* (2006a), who stated that an increase in electrical conductivity during composting might be due to the loss of organic matter and release of different mineral salts like phosphate, potassium and ammonium in the available forms.

The results also indicated that the percent increase in the electrical conductivity was highest in the 3:1 ratio microbial vermicompost (M+V). This

shows that the earthworm action increased with increase in the proportion of tapioca solid waste upto 3:1 ratio, beyond which the activity declined as noted by the percent decrease in composting with increase in the tapioca solid waste proportion. Another report stated that an increase in electrical conductivity in vermicomposting pig manure and sawdust mixture was due to the release of mineral salts and ammonia ions through the decomposition of organic matter (Huang *et al.*, 2004).

#### 4.1.2.3 Organic matter

In composting and vermicomposting, earthworms and microbes modify the substrate, which consequently promote carbon loss from the substrate through microbial respiration in the form of carbondioxide (Nath *et al.*, 2009). This results in organic matter content alteration in the final compost.

Table 4 presents the organic matter of the composts produced by various treatments of tapioca solid waste in different ratios with cow dung.

**TABLE 4**  
**ORGANIC MATTER CONTENT (g%) OF TAPIOCA**  
**SOLID WASTE COMPOSTS**

TSW:CD	C	M	V	M + V
1:1	78.9±0.71	74.0±1.0	72.0±1.7	70.0±0.1
2:1	82.3±0.21	77.0±1.3	74.8±1.8	72.1±0.3
3:1	84.5±0.40	<b>78.7±1.0</b>	<b>75.5±0.5</b>	<b>72.4±0.5</b>
4:1	88.0±1.50	83.8±0.2	82.3±2.1	79.1±1.0
5:1	88.3±0.90	86.2±0.7	82.3±1.0	80.0±2.0
6:1	88.1±0.52	87.1± 4.0	83.1±1.0	82.1±2.2
CD (P<0.05) = 1.40				

Values are expressed as mean ± SD for triplicates

**TSW** : Tapioca Solid Waste

**CD** : Cow Dung

**C** : Control (Natural composting)

**M** : Microbial composting

**V** : Vermicomposting

**M+V** : Microbial Vermicomposting

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From the table, it is obvious that microbial composting (M) of tapioca solid waste significantly ( $p < 0.05$ ) decreased the organic matter contents of all the ratios except the 6:1 ratio on comparison with tapioca solid waste which was subjected to natural composting (C). The 3:1 sample marked the highest percent decrease (6.8 percent) in the organic matter content.

In the case of vermicomposting (V) of tapioca solid waste, the organic matter contents of all the ratios were significantly ( $p < 0.05$ ) decreased as compared to the natural composts (C) and microbial composts (M). On comparison of the various ratios of vermicomposts (V) the 3:1 sample showed the maximum percent decrease (10.6 percent).

As regards microbial vermicomposting (M+V) of tapioca solid waste, all the ratios exhibited significantly ( $p < 0.05$ ) lower organic matter contents when compared to their controls (C), microbial composts (M), and vermicomposts (V) except the 6:1 ratio sample whose value was not significantly ( $P < 0.05$ ) different from that of the 6:1 ratio vermicompost (V) sample. Among the various ratios of microbial vermicomposts (M+V), the compost obtained from 3:1 sample showed maximum percent decrease (14.2 percent) in the organic matter content.

The present results indicating decrease in organic matter on composting were on par with the reports of Romerio *et al.* (2007), who stated that the reduction in organic matter during composting might be due to organic matter mineralization in all substrates.

From the present study, it can be concluded that the high percent organic matter reduction in the 3:1 ratio of microbial vermicompost (M+V) as compared with the other types of composts might be due to the combined action of earthworms alongwith microbes. *Trichoderma viridae*, being a cellulolytic

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fungus promotes the organic matter degradation by its cellulolytic action and thus it is considered as an effective inoculant for composting (Anand *et al.*, 2006).

The decrease in organic matter on composting is also supported by the work of Kalamdhad *et al.*(2009), who stated that during vermicomposting of vegetable waste and tree leaves, the decrease in organic matter occurs in terms of carbondioxide evolution as well as water loss by evaporation due to heat evolution during the oxidation process. After maturation of the compost, most of the organic matter of vegetable waste and tree leaves is converted to stable humic substance.

#### **4.1.2.4 Organic carbon**

During composting, the microbes alongwith earthworms can assimilate carbon from the organic matter fraction causing carbon losses by mineralization. This produces a decrease in the amount of carbon in the organic matter (Nagavallema *et al.*, 2006).

Table 5 presents the organic carbon contents of the composts produced from various treatments of tapioca solid waste in different ratios with cow dung.

From the table, it is obvious that in the microbial composts (M) of tapioca solid waste the organic carbon values of the 1:1 to 5:1 ratio samples marked significant ( $p<0.05$ ) decrease when compared to their respective controls (C). Among the ratios, a high percent decrease (13.8 percent) in organic carbon value was shown by the 1:1 sample.

In the case of vermicomposts (V) from tapioca solid waste, the organic carbon contents of the 1:1 to 5:1 ratios were significantly ( $p<0.05$ ) lower than those of their comparative controls (C). Among the various ratios, a high percent decrease (13.2 percent) in carbon value was exhibited by the 3:1 sample.

**TABLE 5**  
**ORGANIC CARBON CONTENT (g %) OF TAPIOCA**  
**SOLID WASTE COMPOSTS**

TSW:CD	C	M	V	M + V
1:1	46.00±1.3	<b>40.70±1.2</b>	41.10±2.2	<b>35.20±1.0</b>
2:1	48.00±2.2	42.10±0.6	42.20±1.2	37.50±1.3
3:1	50.10±1.0	43.20±0.8	<b>43.50±1.0</b>	39.40±1.0
4:1	52.01±4.0	48.05±2.0	48.00±0.4	47.20±0.6
5:1	53.02±2.0	50.30±3.0	49.00±1.0	50.33±3.0
6:1	54.30±7.0	53.02±1.0	52.40 ±0.5	51.40±1.0
CD (P<0.05) = 2.21				

Values are expressed as mean ± SD for triplicates

**TSW** : Tapioca Solid Waste

**CD** : Cow Dung

**C** : Control (Natural composting)

**M** : Microbial composting

**V** : Vermicomposting

**M+V** : Microbial Vermicomposting

With reference to the microbial vermicomposts (M+V), the 1:1, 2:1 and 3:1 ratios showed significantly ( $p<0.05$ ) lower organic carbon values than all other treatments. Among the ratios, the highest percent decrease (23.5 percent) was observed in the 1:1 ratio.

The above results showed that the 1:1 ratio microbial vermicompost (M+V) expressed the lowest organic carbon content. This might be due to the presence of high proportion of cow dung in the substrate which contains low organic carbon. This finding was supported by the reports of Hait and Tare (2011), who observed a significant decline in the organic carbon content of the earthworm inoculated bedding material at the end of the composting period. Similarly, Aira and Dominguez (2008) reported the rate of carbon loss to be almost twice in vermicomposting pig slurry revealing faster decomposition of the organic matter.

The highest percent of organic carbon loss in the 1:1 ratio microbial vermicompost (M+V) could also be attributed to the rapid respiration rate in the cow dung by the inoculated bacteria and fungi because of the presence of more amount of cow dung in the 1:1 ratio sample than the other ratio samples. These results were on par with the reports of Suthar (2009), who stated that use of cow dung as bulking agent with vegetable-market solid waste causes high carbon loss and stabilization of organic waste as vermicompost.

#### 4.1.2.5 Total nitrogen

The action of microbes and earthworms in recycling organic waste causes the release of nitrogen as ammonia initially and finally as nitrate. This may cause alterations in the nitrogen levels of the compost as compared to the initial substrate. Vermicomposting employing *Eisenia fetida* alters the nitrogen contents of the feed mixtures (Gupta and Garg, 2010).

**TABLE 6**  
**TOTAL NITROGEN CONTENT (g %) OF TAPIOCA SOLID WASTE COMPOSTS**

TSW:CD	C	M	V	M + V
1:1	0.98±0.01	1.41±0.10	2.74±0.05	3.78±0.08
2:1	0.96±0.21	1.43±0.01	2.70±0.03	3.72±0.02
3:1	0.95±0.01	<b>1.45±0.05</b>	<b>2.69±0.03</b>	<b>3.69±0.03</b>
4:1	0.90±0.02	1.20±0.12	2.20±0.12	2.81±0.40
5:1	0.88±0.02	1.10±0.20	2.00±0.22	2.30±0.30
6:1	0.86±0.01	1.03±0.10	1.80±0.21	2.05±0.40
CD (P<0.05) = 0.29				

Values are expressed as mean ± SD for triplicates

TSW : Tapioca Solid Waste

CD : Cow Dung

C : Control (Natural composting)

M : Microbial composting

V : Vermicomposting

M+V : Microbial Vermicomposting

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Table 6 shows the total nitrogen contents of the composts obtained from various treatments of tapioca solid waste in different ratios with cow dung.

From the table, it is clearly understood that the total nitrogen contents in the microbial composts (M) of 1:1, 2:1, 3:1 and 4:1 ratios were significantly ( $p < 0.05$ ) higher than those of their controls (C). However, among the ratios, the highest percent increase (52.6 percent) was observed in the 3:1 sample.

The total nitrogen contents in all the ratios of the tapioca solid waste vermicomposts (V) were significantly ( $p < 0.05$ ) higher than their relative controls (C) and microbial composts (M) and among the ratios, the maximum percent increase (183.2 percent) was observed in the 3:1 sample.

In the microbial vermicomposts (M+V) of tapioca solid waste, the 1:1, 2:1, 3:1, 4:1 and 5:1 ratios of the samples marked significantly ( $p < 0.05$ ) high increases in the total nitrogen content when compared to their respective controls (C), microbial composts (M), and vermicomposts (V). Among the ratios, the percent increase in the total nitrogen value (288.4 percent) was the highest in the 3:1 ratio microbial vermicompost (M+V).

From the above findings, it was confirmed that the maximum percentage increase was in the 3:1 ratio microbial vermicompost (M+V). These results were supported by the findings of Yadav and Garg (2011), who stated that vermicomposting of 30 percent paper waste amended with cow dung resulted in an increase in total Kjeldhal nitrogen (2.0-2.4 fold), after 91 days of earthworm activity. The presence of more amounts of tapioca solid waste in the 4:1, 5:1 and 6:1 ratio samples may be responsible for the reduction in the activity of earthworms, which results in low nitrogen content in the resulting composts.

The maximum percent increase in nitrogen content in the 3:1 ratio microbial vermicompost (M+V) may be due to the presence of the substrates in

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optimum amounts for utilization by earthworms and microorganisms. The increase in nitrogen content on vermicomposting (V) and microbial vermicomposting (M+V) is in accordance with the reports of Tripathi and Bhardwaj (2004), who stated that in vermicomposting, the nitrogen content increases significantly due to mineralization of carbon - rich materials. It has also been reported that the earthworms add nitrogen in the form of mucus, nitrogenous excretory substances, growth stimulating hormones and enzymes during the fragmentation and digestion of organic matter, thereby enhancing the final nitrogen levels in the vermicompost (Gupta and Garg, 2009).

#### **4.1.2.6 Carbon nitrogen ratio**

The C:N ratio is an important criteria of good manure and should lie between 10 and 20. During organic matter degradation by microbes and earthworms, the C:N ratio gets altered due to the carbon loss and increase in the nitrogen content (Plaza *et al.*, 2008).

Table 7 depicts the carbon nitrogen ratios of the composts formed from various treatments in different ratios of tapioca solid waste and cow dung mixtures.

From the table, it is obvious that the C:N values in the microbial composts (M) were significantly ( $p < 0.05$ ) low in all the ratios when compared to the natural compost (C). While comparing the ratios, the C:N values in the 1:1, 2:1 and 3:1 ratios were found to be significantly ( $p < 0.05$ ) lower than in the other samples, but did not fall in the optimum range which is suitable for plants.

In all the ratios of vermicomposts (V), the C:N values were significantly ( $p < 0.05$ ) lower than their corresponding natural composts (C) and microbial composts (M). Among the different ratios of vermicompost (V), the C:N values of 1:1, 2:1 and 3:1 samples were significantly ( $p < 0.05$ ) lower than those of the



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with time whereas nitrogen content per unit material increases, which therefore results in a decrease in the C:N ratio.

In the present study, the change in C:N ratio reflects the organic matter decomposition and stabilization achieved during composting. It can also be concluded that the values in the 1:1, 2:1 and 3:1 ratios of vermicomposts (V) and in the 2:1, 3:1 and 4:1 ratios of microbial vermicomposts (M+V) fall in line with an appreciable range that can simply be taken up by plants. The optimum carbon nitrogen ratio in the range of 20:1 is supported by the study of Naddafi *et al.* (2004), who stated that if the C:N ratio of the compost is above 20, the excess carbon tends to utilize nitrogen in the soil to build cell protoplasm. This results in loss of nitrogen from the soil, which is known as ‘robbing’ of nitrogen. If on the other hand, the C:N ratio is below 10, the resultant product does not help to improve the structure of the soil. It is hence desirable to control the process, so that the final C:N ratio is less than or equal to 20.

#### **4.1.2.7 Total phosphorus**

Analysis of total phosphorus is considered to be an important parameter of the composting process. The presence of large number of microflora in the gut of earthworms might play an important role in changing the phosphorus levels in the vermicomposting process (Adi and Noor, 2009). Inoculation of phosphate fixing microbes may also alter the phosphorus content of the compost.

Table 8 represents the total phosphorus content of the composts obtained from various treatments of tapioca solid waste in different ratios with cow dung.

From the table, it is clearly known that the phosphorus values of 2:1 and 3:1 ratios microbial composts (M) exhibited significantly ( $p < 0.05$ ) high values when compared to controls (C). Among the two, the 3:1 ratio expressed a higher percent increase (19 percent) in the phosphorus content.

**TABLE 8**  
**TOTAL PHOSPHORUS CONTENT (g %) OF TAPIOCA SOLID WASTE COMPOSTS**

TSW:CD	C	M	V	M + V
1:1	0.50±0.01	0.53±0.03	0.55±0.02	0.59±0.02
2:1	0.44±0.02	0.48±0.01	0.52±0.02	0.58±0.02
3:1	0.42±0.02	<b>0.50±0.01</b>	<b>0.56±0.02</b>	<b>0.63±0.05</b>
4:1	0.41±0.02	0.44±0.01	0.45±0.02	0.48±0.01
5:1	0.40±0.01	0.42±0.20	0.43±0.02	0.45±0.04
6:1	0.39±0.02	0.41±0.02	0.41±0.02	0.43±0.02
CD (P<0.05) = 6.5				

Values are expressed as mean ± SD for triplicates

**TSW** : Tapioca Solid Waste

**CD** : Cow Dung

**C** : Control (Natural composting)

**M** : Microbial composting

**V** : Vermicomposting

**M+V** : Microbial Vermicomposting

On comparison of the total phosphorus contents of the composts obtained from vermicomposting (V) the 2:1 and 3:1 samples expressed significantly ( $p<0.05$ ) higher values than their respective controls (C) and microbial composts (M) with the maximum percent increase (33 percent) in the 3:1 sample.

In the case of microbial vermicomposts (M+V) of tapioca solid waste, the 1:1, 2:1 and 3:1 samples exhibited significantly ( $p<0.05$ ) higher total phosphorus contents than the controls (C), microbial composts (M) and vermicomposts (V). Hence, among the various ratios, the maximum percent increase (50 percent) was shown by the 3:1 ratio sample.

The above observations indicating the highest total phosphorus content and maximum percent increase in phosphorus to be in the 3:1 ratio microbial vermicompost (M+V) confirms the maximum action of earthworms and microbes

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in this sample. This finding was supported by the observations of Kaviraj and Sharma (2003), who mentioned that acid production during organic matter decomposition in municipal solid waste by microorganisms is a major mechanism for solubility of insoluble phosphorus. Moreover, the presence of large numbers of microflora in the gut of earthworms might also play an important role in increasing the total phosphorus content during vermicomposting. The present results were also on par with the reports of Zularisam *et al.* (2010), who stated that the increase in the total phosphorus content by the end of municipal solid waste vermicomposting process may be probably because of mineralization.

Another reason may be due to the inoculation of phosphate solubilising bacteria (*Bacillus polymyxa*) into the substrate that enriches the phosphate content of the final compost. The results co-ordinated with the reports of Le Bayon and Binet (2006), who inferred that the release of total phosphorus in the available form is performed partly by earthworm gut phosphatases and further release of phosphorus, might be attributed to the phosphate-solubilizing microorganisms present in worm casts.

#### **4.1.2.8 Total potassium**

Vermicomposting proves to be an efficient process for recovering potassium from organic waste.

Table 9 records the total potassium contents of the composts obtained from various treatments of tapioca solid waste-cow dung mixtures.

The table shows that, in microbial composting (M), a significant ( $p < 0.05$ ) increase in total potassium content was noticed only in the 3:1 ratio, which was higher than the control (C) value. It also exhibited high percent increase (13.9 percent) in the total potassium content.



wastes for optimum action. Further increase in tapioca solid waste proportion in 4:1, 5:1 and 6:1 ratios decreased the action of earthworms. These results were supported by the reports of Gupta and Garg (2009), who stated that the final potassium content of the vermicompost was about 2-fold higher than the initial substrate.

#### 4.1.2.9 Available nitrogen

During vermicomposting, the available nitrogen is altered because the nutrients locked up in the organic waste are changed into simple, more readily available and absorbable forms like nitrate (Atiyeh *et al.*, 2002).

Table 10 presents the available nitrogen contents of the composts formed by various treatments in different ratios of tapioca solid waste - cow dung mixtures.

**TABLE 10**  
**AVAILABLE NITROGEN CONTENT (g %) OF TAPIOCA SOLID WASTE COMPOSTS**

TSW:CD	C	M	V	M + V
1:1	0.55±0.04	0.89±0.05	1.54±0.10	2.36±0.20
2:1	0.56±0.06	0.87±0.02	1.60±0.03	2.43±0.09
3:1	0.54±0.03	<b>0.86±0.03</b>	1.40±0.05	<b>2.36±0.09</b>
4:1	0.51±0.03	0.76±0.05	<b>1.40±0.05</b>	1.67±0.03
5:1	0.48±0.01	0.67±0.03	1.28±0.03	1.41±0.05
6:1	0.47±0.01	0.61±0.03	1.20±0.13	1.27±0.04
CD (P<0.05) = 0.033				

Values are expressed as mean ± SD for triplicates

TSW : Tapioca Solid Waste

CD : Cow Dung

C : Control (Natural composting)

M : Microbial composting

V : Vermicomposting

M+V : Microbial Vermicomposting

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From the table, it can be observed that the available nitrogen content was increased significantly ( $p < 0.05$ ) in all the microbial composts (M) with the 3:1 ratio depicting the maximum percent increase (59.3 percent).

The available nitrogen contents in all the samples of tapioca solid waste vermicomposts (V) were significantly ( $p < 0.05$ ) higher than those of their corresponding microbial composts (M) and controls (C) with the 4:1 ratio recording the maximum percent increase (166.7 percent).

In the tapioca solid waste microbial vermicomposts (M+V), the available nitrogen contents in all the ratios were significantly ( $p < 0.05$ ) higher than in the controls (C), microbial composts (M) and vermicomposts (V) with the 3:1 ratio compost depicting the maximum percent (337 percent) increase.

The above results showing increase in available nitrogen content in the tapioca solid waste composts especially the microbial vermicomposts (M+V) are in accordance with the results of Savala *et al.* (2003), who emphasized that the amount of ammonium ions increased during the initial time of composting, then continually decreased as nitrates increased till the compost maturity. Vermicomposting exhibits a nitrification process that is almost three times more than that of other composting methods. Bacteria of the genera *Nitrosomonas* are more enhanced in vermicomposting than in microbial composting due to more availability of aeration in the vermicomposting process.

The increase in available nitrogen in all the treatments is also supported by the study of Khwairakpam and Bhargava (2009), who inferred that exchangeable ammonia nitrogen in the vermicompost is always greater than the nitrate nitrogen in the initial stage of the experimentation period. A decrease in ammonia nitrogen occurred which corresponds to an increase in nitrate nitrogen at the end of the

vermicomposting process. Thus the highest amount of available nitrogen was recorded by the microbial vermicompost (M+V) samples.

#### 4.1.2.10 Available phosphorus

Vermicompost possesses higher and more soluble levels of phosphorus compared to the substrate or underlying soil and normal compost (Reddy and Ohkura, 2004). So, analysis of available phosphorus is considered to be important in vermicomposting and other composting processes.

Table 11 presents the available phosphorus contents of the composts formed through various treatments of tapioca solid waste - cow dung mixtures.

**TABLE 11**  
**AVAILABLE PHOSPHORUS CONTENT (g%) OF TAPIOCA SOLID WASTE COMPOSTS**

TSW:CD	C	M	V	M + V
1:1	0.156±0.010	0.320±0.003	0.391±0.005	0.454±0.010
2:1	0.150±0.010	0.307±0.004	0.374±0.004	0.470±0.004
3:1	0.142±0.004	0.301±0.010	<b>0.384±0.003</b>	<b>0.480±0.020</b>
4:1	0.130±0.004	0.294±0.010	0.301±0.010	0.363±0.004
5:1	0.120±0.010	0.264±0.010	0.270±0.004	0.350±0.002
6:1	0.110±0.010	<b>0.252±0.010</b>	0.252±0.005	0.340±0.002
CD (P<0.05) = 0.011				

Values are expressed as mean ± SD for triplicates

**TSW** : Tapioca Solid Waste

**CD** : Cow Dung

**C** : Control (Natural composting)

**M** : Microbial composting

**V** : Vermicomposting

**M+V** : Microbial Vermicomposting

From the table, it can be stated that the action of microbes on tapioca solid waste significantly ( $p<0.05$ ) increased the available phosphorus levels in all the

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samples when compared to the controls (C) with the 6:1 ratio giving the maximum percent increase (129 percent).

Among the various samples of tapioca solid waste vermicomposts (V), the 1:1, 2:1 and 3:1 samples revealed significantly ( $p < 0.05$ ) higher values than their corresponding controls (C) and microbial composts (M). The 3:1 ratio compost recorded the maximum percent increase (170.4 percent).

The available phosphorus levels in all the ratios of tapioca solid waste microbial vermicomposts (M+V) were significantly ( $p < 0.05$ ) higher than the controls (C), microbial composts (M) and vermicomposts (V) with the 3:1 ratio exhibiting the maximum percent increase (238 percent).

The above results are in accordance with the reports of Garg *et al.* (2006a), who suggested that the available phosphorus contents increased 1.4 to 6.5 fold in vermicomposting different feed mixtures like kitchen waste, agro-residues, institutional and industrial wastes including textile industry sludge and fibers on comparison to control.

According to the present study, the highest percent increase in the level of available phosphorus in the 3:1 ratio microbial vermicomposts (M+V) of tapioca solid waste might be due to the optimum action of both microbes and earthworms in a substrate favourable to them. *Bacillus polymyxa* being phosphate solubilising bacteria might have promoted the conversion of the unavailable phosphorus to the available form. These results correlate with the observations of Chaudhuri *et al.* (2000), who emphasized that during vermicomposting, the increase in available phosphorus might have probably been due to the mineralization and mobilization of phosphorus due to bacterial and phosphatase activity in the earthworm gut. The available phosphorus would have increased to a greater degree in the bed soil with earthworms after 45 days. This indicates that the soluble nutrients would have leached out from the worm worked material,

such that their levels in the worm worked beds increased when compared to controls.

#### 4.1.2.11 Available potassium

The levels of available potassium were determined because it is known to be changed during vermicomposting (Bansal and Kapoor, 2000).

Table 12 presents the available potassium levels in the composts formed from various treatments in different ratios of tapioca solid waste - cow dung mixtures.

**TABLE 12**  
**AVAILABLE POTASSIUM CONTENT (g%) OF TAPIOCA SOLID WASTE COMPOSTS**

<b>TSW:CD</b>	<b>C</b>	<b>M</b>	<b>V</b>	<b>M + V</b>
1:1	0.110±0.001	0.270±0.02	0.370±0.020	0.48±0.01
2:1	0.093±0.005	0.230±0.01	0.310±0.020	0.42±0.01
3:1	0.060±0.008	0.210±0.02	0.280±0.020	<b>0.39±0.01</b>
4:1	0.056±0.004	0.200±0.01	<b>0.270±0.010</b>	0.30±0.01
5:1	0.053±0.004	0.190±0.01	0.240±0.004	0.27±0.02
6:1	0.043±0.004	<b>0.163±0.01</b>	0.190±0.010	0.21±0.02
CD (P<0.05) = 0.033				

Values are expressed as mean ± SD for triplicates

**TSW** : Tapioca Solid Waste

**CD** : Cow Dung

**C** : Control (Natural composting)

**M** : Microbial composting

**V** : Vermicomposting

**M+V** : Microbial Vermicomposting

From the table, it is evident that microbial composting (M) of tapioca solid waste revealed significantly ( $p < 0.05$ ) higher levels of available potassium in all the ratios when compared to the controls (C). The 6:1 ratio compost showed the maximum percent increase (279 percent).

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In the vermicomposts (V) of tapioca solid waste, the available potassium levels in all the ratios were significantly ( $p < 0.05$ ) higher than those of the controls (C) and microbial composts (M) with the 4:1 ratio recording the maximum percent increase (382 percent).

The available potassium levels in the 1:1 to 3:1 ratios of tapioca solid waste microbial vermicomposts (M+V) were significantly ( $p < 0.05$ ) higher than those of the natural composts (C), microbial composts (M) and vermicomposts (V). Among all the composts, the 3:1 ratio revealed the maximum percent increase (550 percent).

The results of the above study showed that the highest percent increase in the level of available potassium was in the 3:1 ratio of microbial vermicompost (M+V). This indicates that 3:1 ratio is a suitable ratio for the maximum activity of microbes and earthworms. These results correlate with the observations of Begum and Krishna (2010), who stated that as the time period increases during vermicomposting, maximum values of available potassium were obtained after 75 days of vermicomposting.

#### **4.1.2.12 Sodium**

Vermicomposting influences the sodium levels of the substrate and earthworms have the property of bioaccumulating metals. Therefore, determination of sodium was done.

Table 13 records the sodium contents of the composts obtained from various treatments of tapioca solid waste - cow dung mixtures.

From the table, it can be deduced that microbial composting (M) of tapioca solid waste did not affect the sodium content of any of the samples much when compared to the control (C).

**TABLE 13**  
**SODIUM CONTENT (g %) OF TAPIOCA SOLID WASTE COMPOSTS**

<b>TSW:CD</b>	<b>C</b>	<b>M</b>	<b>V</b>	<b>M + V</b>
1:1	0.65±0.02	0.64±0.03	0.33±0.024	0.29±0.03
2:1	0.73±0.02	0.76±0.02	0.36±.04	0.31±0.02
3:1	0.74±0.01	0.76±0.01	<b>0.34±0.03</b>	<b>0.29±0.02</b>
4:1	0.75±0.01	0.73±0.02	0.45±0.02	0.41±0.03
5:1	0.75±0.02	0.74±0.02	0.51±0.02	0.43±0.02
6:1	0.76±0.02	0.78±0.01	0.55±0.04	0.49±0.03
CD (P<0.05) = 0.04				

Values are expressed as mean ± SD for triplicates

**TSW** : Tapioca Solid Waste

**CD** : Cow Dung

**C** : Control (Natural composting)

**M** : Microbial composting

**V** : Vermicomposting

**M+V** : Microbial Vermicomposting

Composting of tapioca solid waste using earthworms (V) decreased significantly ( $p < 0.05$ ) the sodium contents of all the samples, when compared to the control (C) and microbial composts (M). Among the various ratios, the 3:1 sample revealed the highest percent decrease (54.1 percent) in the sodium content.

The combined action of earthworms and microbes (M+V) on tapioca solid waste decreased the sodium contents significantly ( $p < 0.05$ ) in all the samples, when compared to the other treatments with the 3:1 ratio microbial vermicompost (M+V) showing maximum percent decrease (60.8 percent).

The reduction in the sodium contents on vermicomposting (V) and microbial vermicomposting (M+V) might be due to the bioaccumulation of sodium by the earthworm tissues. These results were supported by the

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observations of Ramalingam and Ranganathan (2001), who stated that during vermicomposting, there was a reduction in the sodium content which may be due to its utilization for earthworm growth and biomass production.

From the results, it can also be concluded that the high percent reduction in the 3:1 ratio microbial vermicompost (M+V) might be due to the optimum activity of the earthworms in this sample. The high proportion of tapioca solid waste in 4:1, 5:1 and 6:1 ratios might be responsible for reducing the earthworm action, which in turn would have resulted in a lower reduction in the sodium content.

The report of Christy and Ramalingam (2005) also stated that the sodium content in the vermicompost prepared from tapioca solid waste was low when compared to its initial substrate mixture.

#### **4.1.2.13 Calcium**

The calcium levels were determined, because, during composting by earthworms, gut processes associated with calcium metabolism are primarily responsible for changing the calcium content of the worm casts (Garg *et al.*, 2006).

Table 14 depicts the calcium contents of the composts formed from various treatments of tapioca solid waste - cow dung mixtures.

From the table, it can be inferred that in the microbial composts (M) of tapioca solid waste, the increase in calcium contents were significant in the 2:1 and 3:1 ratio composts with the 3:1 ratio showing the highest percent increase (13.9 percent).

The vermicomposts (V) of tapioca solid waste recorded significantly ( $p < 0.05$ ) higher calcium values for all the ratios except 6:1 when compared to the



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calciferous glands of the earthworms have carbonic anhydrase which catalyze the fixation of carbon dioxide as calcium carbonate. This may also be responsible for the increased calcium level in the compost when compared to the initial feed mixture.

The above results were also supported by the findings of Kaushik and Garg (2004), who mentioned that the calcium content in vermicomposting solid textile mill sludge with cow dung and agricultural residues were higher than that of the initial feed mixture and that the highest increment was also observed in polyculture vermicomposting.

#### **4.1.2.14 Magnesium**

The action of microbes and earthworms on the organic matter of waste may lead to changes in the magnesium content of composts and vermicomposts. Recycling, of organic wastes by earthworms especially alters the magnesium level (Raphael and Velmourougane, 2010).

Table 15 records the magnesium levels in the composts formed from various treatments of tapioca solid waste - cow dung mixtures.

From the table, it can be said that in the microbial composts (M), the magnesium levels of the 1:1, 2:1 and 3:1 ratio composts were significantly ( $p < 0.05$ ) higher than those of the controls (C). Among the various ratios, the compost obtained from the 3:1 ratio sample revealed the highest percent increase (13.3 percent).

Vermicomposting (V) of tapioca solid waste significantly ( $p < 0.05$ ) increased the magnesium contents of the composts upto the ratio 3:1 as compared to their controls (C) and microbial composts (M). On comparison of the different ratios, the maximum percent increase (43.3 percent) in the magnesium content was revealed by the 3:1 ratio.

**TABLE 15**  
**MAGNESIUM CONTENT (g %) OF TAPIOCA SOLID WASTE COMPOSTS**

<b>TSW:CD</b>	<b>C</b>	<b>M</b>	<b>V</b>	<b>M + V</b>
1:1	0.36±0.03	0.40±0.02	0.44±0.04	0.46±0.01
2:1	0.31±0.01	0.35±0.04	0.41±0.02	0.43±0.03
3:1	0.30±0.01	<b>0.34±0.01</b>	<b>0.43±0.02</b>	<b>0.54±0.01</b>
4:1	0.31±0.03	0.33±0.03	0.36±0.03	0.38±0.01
5:1	0.21±0.02	0.22±0.03	0.24±0.01	0.26±0.02
6:1	0.21±0.02	0.22±0.01	0.23±0.03	0.26±0.02
CD (P<0.05) = 0.35				

Values are expressed as mean ± SD for triplicates

**TSW** : Tapioca Solid Waste

**CD** : Cow Dung

**C** : Control (Natural composting)

**M** : Microbial composting

**V** : Vermicomposting

**M+V** : Microbial Vermicomposting

In the case of microbial vermicomposts (M+V), the magnesium contents in all the ratios were significantly ( $p<0.05$ ) higher than those of the controls (C) and microbial composts (M). The 3:1 ratio compost alone recorded significantly ( $p<0.05$ ) the highest calcium content with maximum percent increase (80 percent) when compared to other treatments and ratios.

Thus, it can be stated that the highest magnesium content with maximum percent increase was observed in the 3:1 ratio microbial vermicompost (M+V). This may be due to the combined effective action of microbes and earthworms during vermicomposting which enhanced the degradation process and increased the magnesium content of the final compost.

The above results are in agreement with the observations of Dominguez (2004), who stated that the high magnesium content in vermicompost is due to

the transformation of the unavailable form of magnesium into the more available form by earthworms. A report by Parthasarathi and Ranganathan (2000) also showed that the magnesium content in the vermicasts was high, probably due to the increased microbial and enzyme activity in the gut of earthworms.

#### 4.1.2.15 Sulphur

The use of organic fertilizers improves the rate of germination of seeds. It may probably be due to the presence of macro elements like sulphur and plant growth promoting hormones produced by the beneficial microorganisms and earthworms (Thangaraj *et al.*, 2009). So determination of sulphur content was found to be effective in studying the quality of the compost.

Table 16 depicts the sulphur contents of the composts obtained from various treatments of tapioca solid waste- cow dung mixtures.

**TABLE 16**  
**SULPHUR CONTENT (g %) OF TAPIOCA SOLID WASTE COMPOSTS**

<b>TSW:CD</b>	<b>C</b>	<b>M</b>	<b>V</b>	<b>M + V</b>
1:1	0.56±0.02	0.57±0.07	0.48±0.01	0.40±0.01
2:1	0.63±0.03	0.65±0.03	0.53±0.012	0.42±0.01
3:1	0.67±0.01	0.70±0.05	<b>0.52±0.002</b>	<b>0.43±0.01</b>
4:1	0.71±0.02	0.74±0.01	0.63±0.04	0.57±0.002
5:1	0.73±0.02	0.75±0.01	0.68±0.02	0.66±0.001
6:1	0.78±0.01	0.79±0.01	0.73±0.01	0.71±0.01
CD (P<0.05) = 0.05				

Values are expressed as mean ± SD for triplicates

**TSW** : Tapioca Solid Waste

**CD** : Cow Dung

**C** : Control (Natural composting)

**M** : Microbial composting

**V** : Vermicomposting

**M+V** : Microbial Vermicomposting

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From the table, it is clear that microbial composting (M) did not have any significant effect on the sulphur content of all the ratio samples when compared to the controls (C).

However, in the vermicomposts (V) of tapioca solid waste, the sulphur contents of all the samples were significantly ( $p < 0.05$ ) lower than those of their respective controls (C) and microbial composts (M). Among the ratios, the sample that exhibited the highest percent decrease (22.4 percent) was the 3:1 ratio sample.

In the case of microbial vermicomposting (M+V) of tapioca solid waste, all the ratios gave composts with significantly ( $p < 0.05$ ) lower values than their corresponding controls (C). The microbial vermicomposts (M+V) from 1:1 to 4:1 ratios exhibited significantly ( $p < 0.05$ ) lower sulphur levels than the microbial composts (M) and vermicomposts (V). The 3:1 ratio microbial vermicompost (M+V) expressed the maximum percent reduction (35.8 percent) when compared to the other ratio composts.

The reduction of sulphur content in vermicomposting (V) and microbial vermicomposting (M+V) might be due to sulphur loss due to its utilization by earthworms for protein synthesis. These results were similar to the reports of Ramalingam and Ranganathan (2001), who mentioned that sulphur is an essential element for the synthesis of amino acids and vitamins and its reduction during vermicomposting may be due to its utilization for earthworm growth and biomass production.

#### **4.1.2.16 Iron**

The analysis of iron content is an important parameter to determine the activity of earthworms in the waste. Table 17 records the iron contents of the composts formed from various treatments of tapioca solid waste - cow dung mixtures

**TABLE 17**  
**IRON CONTENT (g %) OF TAPIOCA SOLID WASTE COMPOSTS**

<b>TSW:CD</b>	<b>C</b>	<b>M</b>	<b>V</b>	<b>M + V</b>
1:1	1.33±0.12	1.70±0.10	3.30±0.10	4.00±0.12
2:1	1.04±0.11	1.33±0.02	3.00±0.01	3.81±0.10
3:1	0.74±0.01	<b>1.20±0.04</b>	<b>2.83±0.01</b>	<b>3.92±0.02</b>
4:1	0.52±0.01	0.65±0.03	1.21±0.03	1.40±0.12
5:1	0.44±0.01	0.50±0.03	0.90±0.04	1.10±0.20
6:1	0.39±0.004	0.41±0.02	0.75±0.04	0.90±0.03
CD (P<0.05) = 0.13				

Values are expressed as mean ± SD for triplicates

**TSW** : Tapioca Solid Waste

**CD** : Cow Dung

**C** : Control (Natural composting)

**M** : Microbial composting

**V** : Vermicomposting

**M+V** : Microbial Vermicomposting

From the table, it can be deduced that, among the microbial composts (M) of tapioca solid waste, the 1:1 to 4:1 ratios showed significantly ( $p<0.05$ ) higher values for the iron content when compared to the controls (C). Among the various ratios, the maximum percent increase (61.5 percent) was exhibited by the 3:1 sample.

Degradation of tapioca solid waste by earthworms (V) resulted in composts with significantly ( $p<0.05$ ) higher iron contents than the controls (C) and microbial composts (M). Concurrently, among the various ratios, the 3:1 sample revealed the highest percent increase (280 percent) in the iron content.

In the case of microbial vermicomposting (M+V) of tapioca solid waste, the 1:1 to 3:1 ratios showed significantly ( $p<0.05$ ) higher iron contents than the controls (C) and all other treatments. On comparison of all the composts, the 3:1

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ratio microbial vermicompost (M+V) recorded the highest percent increase (427.5 percent) in the iron content.

From the above findings, it can be deduced that the maximum percent increase in the iron content was in the 3:1 ratio microbial vermicompost (M+V). This may be due to the organic matter reduction, loss of weight and conversion of ions into more available forms that can easily be taken by the plants. These results were supported by the observations of Ravikumar *et al.* (2008) and Sangwan *et al.* (2008), who reported that the iron content was also higher in the vermicompost than in the initial feed mixture. The iron value was higher in vermiash compost also irrespective of the organic sources used in the composting.

#### **4.1.2.17 Zinc**

The zinc contents of composts play a vital role in plant growth. Physicochemical properties of soil improve as macro and micronutrient availability markedly increases due to the combined application of vermicompost and zinc-enriched compost ( Sukhmal *et al.*, 2007).

Table 18 records the zinc contents of the composts produced from various treatments of tapioca solid waste - cow dung mixtures.

It can be inferred from the table that on microbial composting (M), the samples did not indicate any significant change as compared to the control (C) even though, the percent increase (14.2 percent) was high in the 3:1 ratio.

Vermicomposting (V) of tapioca solid waste also increased the zinc contents upto the 3:1 ratio when compared to their respective controls (C) and microbial composts (M). Among the ratios, the percent increase (73.2 percent) was the highest in the 3:1 ratio sample.

**TABLE 18**

**ZINC CONTENT (ppm) OF TAPIOCA SOLID WASTE COMPOSTS**

<b>TSW:CD</b>	<b>C</b>	<b>M</b>	<b>V</b>	<b>M + V</b>
1:1	450±40	480±10	620±20	720±20
2:1	340±30	380±10	500±40	600±40
3:1	254±20	<b>290±10</b>	<b>440±10</b>	<b>520±10</b>
4:1	220±10	240±10	300±10	340±10
5:1	200±30	210±20	240±10	280±10
6:1	180±10	185±20	190±10	220±20
CD (P<0.05) = 104				

Values are expressed as mean ± SD for triplicates

**TSW** : Tapioca Solid Waste

**CD** : Cow Dung

**C** : Control (Natural composting)

**M** : Microbial composting

**V** : Vermicomposting

**M+V** : Microbial Vermicomposting

Microbial vermicomposting (M+V) also increased the zinc values upto the 3:1 ratio significantly ( $p < 0.05$ ) as compared with the controls (C) and microbial composts (M). However no significant changes were observed in the zinc contents of microbial vermicompost (M+V) samples as compared to vermicomposts (V) though the percent increase was maximum (104.7 percent) in the 3:1 ratio microbial vermicompost (M+V).

Thus among all the composts, the percent increase was found to be highest in the 3:1 ratio microbial vermicompost (M+V). This confirms the ceiling action of earthworms in this sample. The above observations are in correlation with the study of Frederikson *et al.* (2007), who stated that the zinc content of the vermicompost prepared from paper and house hold waste was higher than that of the initial substrates. An increased content of zinc was also observed in the

vermicompost prepared from coffee grounds and kitchen waste (Adi, and Noor, 2009).

The findings that the highest percent increase in zinc content was in the 3:1 ratio microbial vermicompost (M+V) may probably be because the earthworms were able to tolerate tapioca solid waste only upto 3:1 ratio. This was supported by the reports of Sharma *et al.* (2005), who inferred that the *Eudrilus* compost had 36 percent more zinc than the conventional compost.

### 1.2.18 Copper

Determination of copper content in composts is important, because, the treatment of earthworms and microbes in the organic waste modifies the copper content of the substrate (Kitturmath *et al.*, 2007).

**TABLE 19**  
**COPPER CONTENT (ppm) OF TAPIOCA SOLID WASTE COMPOSTS**

TSW:CD	C	M	V	M + V
1:1	140±10	143±20	120±2.0	110±1.0
2:1	110±10	<b>120±2.0</b>	90±2.0	80±1.0
3:1	91±2.0	96±2.0	<b>70±4.0</b>	<b>40±1.0</b>
4:1	70±2.0	71±2.0	61±2.0	56±2.0
5:1	60±3.0	62±2.0	54±3.0	50±4.0
6:1	60±1.0	62±3.0	56±2.0	52±2.0
CD (P<0.05) =10.0				

Values are expressed as mean ± SD for triplicates

**TSW** : Tapioca Solid Waste

**CD** : Cow Dung

**C** : Control (Natural composting)

**M** : Microbial composting

**V** : Vermicomposting

**M+V** : Microbial Vermicomposting

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Table 19 records the copper contents of the composts produced from various treatments of tapioca solid waste -cow dung mixtures.

From the table, it is clearly understood that microbial composting (M), of tapioca solid waste did not evidently change the levels of copper when compared to the control (C). However, maximum percent increase (9.1percent) in the copper content was noted in the 2:1 ratio sample.

In the case of copper content of the vermicomposts (V), the 1:1, 2:1 and 4:1 ratios exhibited significantly ( $p<0.05$ ) lower values than their controls (C) and microbial composts (M). Among the various ratios, the maximum percent decrease (23.1 percent) was exhibited by the 3:1 ratio compost.

In the case of microbial vermicomposts (M+V) of tapioca solid waste, the copper levels upto the 3:1 ratio were significantly ( $p<0.05$ ) lower than the copper levels in the other ratio composts. Among all the composts, the 3:1 ratio microbial vermicompost (M+V) showed the lowest value with a maximum percent reduction (56 percent).

From the above findings, it can be said that maximum reduction of copper levels in the microbial vermicompost (M+V) might be due to its bioaccumulation of the metal in the earthworm tissues. These results were supported by the report of Rajesh *et al.* (2003), who mentioned that the total micronutrient content was higher in vermicompost than in the other composts, while the trend was the reverse with regard to copper.

It can also be concluded that the high percent reduction of copper in the 3:1 ratio microbial vermicompost (M+V) indicates the optimal activity of the earthworms in this sample. High proportion of tapioca solid waste in 4:1, 5:1 and 6:1 ratios might be responsible for the decline in earthworm action.

Khwairakpam and Bhargava (2009a) said that in the sewage sludge vermicompost, the copper content in the final products were lower than those of the initial feed mixtures.

#### 4.1.2.19 Molybdenum

During vermicomposting, the heavy metals tend to form complex aggregates with humic acids and this causes lower availability of these micronutrients for plant growth (Dominguez and Edwards, 2004). This implies the alteration in the micronutrient levels in composting and vermicomposting processes.

Table 20 presents the molybdenum contents of the composts produced from various treatments of tapioca solid waste - cow dung mixtures.

**TABLE 20**  
**MOLYBDENUM CONTENT (ppm) OF TAPIOCA**  
**SOLID WASTE COMPOSTS**

<b>TSW:CD</b>	<b>C</b>	<b>M</b>	<b>V</b>	<b>M + V</b>
1:1	90±1.0	98±2.0	160±1.0	200±30
2:1	60±3.0	<b>70±4.0</b>	120±1.0	140±10
3:1	60±5.0	<b>70±1.0</b>	<b>140±1.0</b>	<b>180±10</b>
4:1	50±1.0	54±2.0	80±1.0	120±10
5:1	45±2.0	48±2.0	60±2.0	80±1.0
6:1	44±2.0	46±2.0	52±2.0	60±4.0
CD (P<0.05) =9.0				

Values are expressed as mean ± SD for triplicates

**TSW** : Tapioca Solid Waste

**CD** : Cow Dung

**C** : Control (Natural composting)

**M** : Microbial composting

**V** : Vermicomposting

**M+V** : Microbial Vermicomposting

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From the table, it is understood that the 2:1 and 3:1 ratios of microbial composts (M) showed significant ( $P < 0.05$ ) increase in the copper content. A high percent increase (16.6 percent) was exhibited by the same samples.

In the case of vermicomposting (V), 1:1 to 5:1 ratios showed significantly ( $p < 0.05$ ) higher values for molybdenum than the controls (C). The 3:1 ratio revealed high percent increase (133 percent) in the molybdenum content.

On comparison of the molybdenum values of the compost got from the combined action of earthworms and microbes (M+V), with the controls (C), microbial composts (M) and vermicomposts (V) the samples upto 5:1 ratio showed highly significant ( $p < 0.05$ ) increase. The percent increase in the molybdenum value of the microbial vermicomposts (M+V) was the highest in the 3:1 ratio (200 percent).

The observations that the high percent increase in molybdenum occurred in the 3:1 ratio microbial vermicompost (M+V) might be due to maximum growth and action of earthworms in this ratio of substrates. These results are on par with the reports of Padmavathiamma *et al.* (2008), who concluded that micronutrients from feed materials are absorbed and tend to accumulate in the body. However, these nutrients are incorporated into the compost upon the death of the earthworms thus resulting in high molybdenum levels in the vermicompost than initial feed mixture.

#### **4.1.2.20 Boron**

Composting of wastes by earthworms shows modifications in the micronutrient (boron) concentration compared to the initial substrates (Venkatesh and Eevera, 2007). So determination of boron in the composts was considered to be important.



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As regards microbial vermicomposts (M+V) of tapioca solid waste, 1:1 to 4:1 ratios showed highly significant ( $p < 0.05$ ) increases in the boron values, when compared to all other treatments. Among all the composts, the percent increase in the boron value was the highest (135.3 percent) in the 3:1 ratio microbial vermicompost (M+V).

It is obvious from the above result that the high percent increase in the 3:1 microbial vermicompost (M+V) confirms that the earthworms were able to tolerate tapioca solid waste upto this ratio. This finding can be correlated with the observations of Rajesh *et al.* (2003), who explained that the total micronutrients were higher in vermicompost than in the other composts.

Thus, from the physicochemical characteristics of tapioca solid waste composts formed from various treatments, it can be concluded that microbes, earthworms and microbes with earthworms were able to utilize the organic waste of tapioca solid waste with cow dung upto 3:1 ratio. Further increase in the proportion of tapioca solid waste decreased the rate of composting. This was confirmed by the percent changes in the physicochemical and biochemical parameters of the composts.

## **PHASE II**

### **4.2 ACTIVITIES OF SELECTED ENZYMES AND COMPOST MATURITY IN 3:1 RATIO COMPOSTS**

#### **4.2.1 SELECTION OF THE BEST SUBSTRATE**

**In Phase I**, the physicochemical analysis of the composts obtained from different ratios (1:1, 2:1, 3:1, 4:1, 5:1 and 6:1) of tapioca solid waste - cow dung mixtures revealed that the 3:1 ratio compost showed the best results for most of the parameters. Hence this ratio was selected for further study in Phase II.

## 4.2.2 ENZYMES IN THE COMPOSTS OF 3:1 RATIO TAPIOCA SOLID WASTE - COW DUNG MIXTURE

### 4.2.2.1 Cellulase

The major constituents like cellulose and starch in organic wastes are degraded by specific enzymes. Therefore, the determination of enzyme activity during composting can reflect the dynamics of the composting process in terms of decomposition of organic matter (Tiquia, 2002).

Table 22 records the cellulase activities of the 3:1 ratio tapioca solid waste – cow dung composts at various stages.

**TABLE 22**  
**ACTIVITY OF CELLULASE\* IN TAPIOCA SOLID WASTE COMPOSTS AT VARIOUS STAGES OF COMPOSTING**

Days		C	M	V	M + V
Precompost		20.4±1.0	20.0±1.1	20.8±1.1	20.4±1.0
Composts	25	23.2±0.7	27.8±1.1	25.9±0.6	30.7±1.3
	50	25.5±0.6	36.4±0.7	62.7±2.7	67.5± 2.7
	75	31.8±0.6	46.0±0.7	<b>48.4±0.6</b>	<b>39.2±0.2</b>
CD (P<0.05) = 2.1					

Values are expressed as mean ± SD for triplicates

\* -  $\mu\text{g}$  of reducing sugar released  $\text{g}^{-1}$  dry weight  $24 \text{ h}^{-1}$

**C** : Control (Natural composting)

**M** : Microbial composting

**V** : Vermicomposting

**M+V** : Microbial Vermicomposting

From the values depicted in the table, it can be observed that in the microbial compost (M), the cellulase activity was significantly ( $p < 0.05$ ) higher than those of the control (C) on the 25<sup>th</sup>, 50<sup>th</sup> and 75<sup>th</sup> days of composting. The microbial composting (M) of tapioca solid waste produced a gradual and significant ( $p < 0.05$ ) increase in the enzyme activity upto the 75<sup>th</sup> day.

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In the vermicomposts (V), the cellulase activities on all the days were significantly ( $p < 0.05$ ) higher than in the control (C) and microbial composts (M). However, the activity increased upto the 50<sup>th</sup> day of composting and then decreased and reached a minimum on the 75<sup>th</sup> day.

In the case of microbial vermicomposts (M+V), the activity of cellulase was significantly ( $p < 0.05$ ) elevated on all the days of composting as compared to the controls (C). The activity was the maximum on the 50<sup>th</sup> day and reached a minimum on the 75<sup>th</sup> day.

Thus, from the table, it can be inferred that cellulase activity increased in all the types of composting with the highest value on the 50<sup>th</sup> day except the microbial compost (M) which had the highest value on the 75<sup>th</sup> day. The findings that cellulase activity was increased in all types of composting especially in microbial vermicomposting (M+V) is in agreement with the results of Aira *et al.* (2007), who mentioned that during composting, the earthworms and microbes play an important role in the activation of cellulase and  $\beta$ -glucosidase in two ways - by increasing the availability of the substrate and by the activation of the microbial metabolism.

Similarly, the reduction in enzyme activity in the vermicompost (V) and microbial vermicompost (M+V) on the 75<sup>th</sup> day of composting might be due to substrate scarcity and maturity of the final products as reported by Goyal *et al.* (2005), who stated that the cellulase activity increased during decomposition and reached a maximum on the 30<sup>th</sup> day and declined further on the 60<sup>th</sup> and 90<sup>th</sup> days.

#### **4.2.2.2 $\beta$ - Glucosidase**

The earthworms and microorganisms enhance the biodegradation of organic matter in the wastes. The activity of  $\beta$ -glucosidase plays an important role in determining the end point of the composting process (Kumar *et al.*, 2010).

Table 23 presents the  $\beta$ - glucosidase activities of the 3:1 ratio tapioca solid waste –cow dung composts at various stages.

**TABLE 23**  
**ACTIVITY OF  $\beta$  –GLUCOSIDASE\* IN TAPIOCA SOLID WASTE COMPOSTS AT VARIOUS STAGES OF COMPOSTING**

Days		C	M	V	M + V
Precompost		31.1±0.6	31.3±0.7	30.6±0.4	30.9±0.4
Composts	25	33.6±0.9	35.4±0.4	28.5±0.8	38.1±0.4
	50	36.6±1.2	38.1±0.4	38.1±0.4	45.3±0.3
	75	39.8±1.0	40.8±0.8	45.3±0.3	<b>22.3±0.3</b>
CD (P<0.05) = 1.2					

Values are expressed as mean  $\pm$  SD for triplicates

\* -  $\mu\text{g}$  of para nitrophenol released  $\text{g}^{-1}$  dry weight  $\text{h}^{-1}$

C : Control (Natural composting)      M : Microbial composting

V : Vermicomposting                      M+V : Microbial Vermicomposting

From the table, it can be stated that the  $\beta$ - glucosidase activity was significantly ( $p<0.05$ ) increased in the microbial compost (M), when compared to the controls (C). There was also a gradual increase in the enzyme activity from the 25<sup>th</sup> day to the 75<sup>th</sup> day of the composting process.

Similarly, in the vermicomposts (V) also, the  $\beta$ -glucosidase activity was significantly ( $p<0.05$ ) raised on all the sampling days when compared to the controls (C) and microbial composts (M) and the values progressively increased upto the 75<sup>th</sup> day of composting.

On analyzing the enzyme activity of the composts obtained from microbial vermicomposting (M+V), the values were significantly ( $p<0.05$ ) increased on the 25<sup>th</sup> and 50<sup>th</sup> days of composting on comparison with the controls (C), microbial

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composts (M) and vermicomposts (V), but the maximum activity was shown on the 50<sup>th</sup> day after which the value came down giving the least value on the 75<sup>th</sup> day of composting.

From the reports of  $\beta$ -glucosidase activities, it can therefore be concluded that microbial composting (M), vermicomposting (V) and microbial vermicomposting (M+V) raised the  $\beta$ -glucosidase activity of the samples reaching a maximum level on the 75<sup>th</sup> day for all the composts except microbial vermicompost (M+V) which recorded maximum activity on the 50<sup>th</sup> day itself and thereafter decreased on the 75<sup>th</sup> day.

In the above study, the increased enzyme activities in the control (C), microbial compost (M) and vermicompost (V) might be due to the availability of the substrate. This finding can be correlated with the report of Nannipieri *et al.* (2002), who inferred that the product of cellulase is the substrate of  $\beta$ -glucosidase. It catalysis the hydrolysis of glycosides and the activity is based on substrate availability.

The observations that after the 50<sup>th</sup> day of composting, the activity of  $\beta$ -glucosidase decreases is supported by the study of Ros *et al.* (2006), who said that a gradual increase in the synthesis of  $\beta$ -glucosidase was found during the initial stages of vermicomposting of pig slurry with a slight decrease at the end.

#### **4.2.2.3 Protease**

Protease activity highly depends on substrate availability and therefore, it is a very good indicator for the extent of decomposition of wastes.

Table 24 expresses the protease activities of the 3:1 ratio tapioca solid waste - cow dung composts at various stages.

From the values in the above mentioned table, it can be deduced that microbial composting (M) of tapioca solid waste significantly ( $p < 0.05$ ) increased

the protease activity on the 50<sup>th</sup> day of composting when compared to the control (C). The activity increased upto the 50<sup>th</sup> day of composting and then decreased by the 75<sup>th</sup> day.

**TABLE 24**

**ACTIVITY OF PROTEASE\* IN TAPIOCA SOLID WASTE COMPOSTS AT VARIOUS STAGES OF COMPOSTING**

Days		C	M	V	M + V
Precompost		19.2±0.05	19.1±0.2	19.1± 0.2	19.3±0.2
Composts	25	20.1±0.2	20.1±0.4	20.4±0.3	14.4±0.4
	50	20.4±0.3	21.5±1.2	14.5±0.4	11.4±0.3
	75	20.7±0.2	<b>17.4±0.4</b>	<b>10.7±0.07</b>	<b>10.3±0.4</b>
CD (P<0.05) = 0.92					

Values are expressed as mean ± SD for triplicates

\* - µg of tyrosine released g<sup>-1</sup>dry weight 2 h<sup>-1</sup>

C : Control (Natural composting)      M : Microbial composting

V : Vermicomposting                      M+V : Microbial Vermicomposting

In the case of vermicomposting (V) of tapioca solid waste, the protease activity was significantly (p<0.05) low on the 50<sup>th</sup> and 75<sup>th</sup> days of composting when compared to controls (C) and microbial composts (M).

The protease activity in the microbial vermicomposts (M+V) of tapioca solid waste revealed a similar trend like that of vermicompost (V) with significant (p<0.05) decrease as compared to controls (C) and microbial composts (M) and vermicomposts (V).

Hence, from the above results of protease activities, it can be accomplished that microbial composting (M), vermicomposting (V) and microbial vermicomposting (M+V) reduced the protease activity in the final

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composts. The finding that the activity of protease decreases with increase in the days of composting for all the types of composts unlike the controls where the activity was vice versa was supported by the fact that tapioca solid waste contains low protein and therefore decreased secretion of protease on the final day of the composting process. These results were on par with the reports of Lazcano *et al.* (2008), who stated that the protease activity increased sharply at the beginning of the vermicomposting period and reached the peak value followed by a sharp decline subsequently which may be due to the decreasing protein content in the substrate.

#### 4.2.2.4 Urease

Characterizing and determining the activity of urease during composting can reflect the rate of the composting process in terms of the decomposition of organic matter and may also provide information about the maturity of the composted product (Devi *et al.*, 2009).

Table 25 presents the activity of urease in the 3:1 ratio tapioca solid waste – cow dung composts at various stages.

Activity of urease in the microbial composts (M) of tapioca solid waste were significantly ( $p < 0.05$ ) increased upto the 75<sup>th</sup> day of composting when compared to the controls (C).

In the case of vermicomposting (V) of tapioca solid waste, the urease activity was significantly ( $p < 0.05$ ) higher than those of the controls (C) on all the days of composting. However, unlike microbial composting (M), the activity of urease decreased with increase in the days of composting.

Microbial vermicomposting (M+V) of tapioca solid waste revealed significant ( $p < 0.05$ ) increase in urease activity when compared to the controls (C) upto the 25<sup>th</sup> of the composting. However, the activity was least on the 50<sup>th</sup> and 75<sup>th</sup> days of composting.

**TABLE 25**

**ACTIVITY OF UREASE\* IN TAPIOCA SOLID WASTE COMPOSTS AT VARIOUS STAGES OF COMPOSTING**

Days		C	M	V	M + V
Precompost		8.6±0.1	8.9±0.4	8.9±0.4	8.6±0.2
Composts	25	8.9 ±0.4	11.2±0.9	14.4±0.8	15.0±0.9
	50	9.6±0.8	11.9±0.9	13.3±0.4	10.6±0.8
	75	10.9±1.0	13.3±0.8	<b>12.8±0.9</b>	<b>10.6±0.8</b>
CD (P<0.05) = 1.5					

Values are expressed as mean ± SD for triplicates

\* - µg of ammonia nitrogen released g<sup>-1</sup> dry weight day<sup>-1</sup>

C : Control (Natural composting)      M : Microbial composting

V : Vermicomposting                      M+V : Microbial Vermicomposting

Hence from the results of urease activity, it can be concluded that the microbial composting (M) increased the enzyme activity upto the final day. Vermicomposting (V) and microbial vermicomposting (M+V) showed reduction in the urease activity, with the maintenance of the same level in the microbial vermicompost (M+V) on the final day.

The above results were on par with the reports of Ravikumar *et al.* (2008), who stated that the low urease activity in vermicompost may be due to its narrow C: N ratio, since release of ammonia by urease action inhibits urease activity and synthesis. This might have been responsible for the lower urease activity in the compost.

In the above study, it was confirmed that urease activity was low in the final compost. This might be due to the very low nitrogen in the tapioca solid waste. This was supported by the study of Cayuela *et al.* (2008), who stated that

the urease activity which catalyses the hydrolysis of urea to carbondioxide and ammonia was very low during the composting, probably because of low concentration of available substrates released during the mineralization in the vermicompost.

#### 4.2.2.5 Dehydrogenase

Dehydrogenase assay measures the intracellular catalysis and is more likely to be correlated with the activity of extant cells (Darke and Horn, 2007).

Table 26 expresses the dehydrogenase activity of the 3:1 ratio tapioca solid waste – cow dung composts at various stages.

**TABLE 26**  
**ACTIVITY OF DEHYDROGENASE\* IN TAPIOCA SOLID WASTE COMPOSTS AT VARIOUS STAGES OF COMPOSTING**

Days		C	M	V	M + V
Precompost		80.5±0.5	81.8±2.4	80.1±1.6	80.8±1.4
Composts	25	82.2±1.9	85.1±0.8	84.1±0.5	85.8± 0.8
	50	84.1±0.5	91.7±1.7	100.1±1.0	132.3±2.0
	75	88.1±2.0	97.8±1.4	120.3±0.6	<b>127.9±0.2</b>
CD (P<0.05) =3.5					

Values are expressed as mean ± SD for triplicates

\* - µg of 2,3,5- triphenylformazan released g<sup>-1</sup>dry weight h<sup>-1</sup>

C : Control (Natural composting)

M : Microbial composting

V : Vermicomposting

M+V : Microbial Vermicomposting

From the table, it is clear that the composts produced by the action of microbes (M) significantly (p<0.05) increased the dehydrogenase activity on the 50<sup>th</sup> and 75<sup>th</sup> day of composting on comparison with the controls (C). There was a

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gradual increase in the enzyme activity with increase in the number of days of composting.

The vermicomposts (V) revealed highly significant ( $p < 0.05$ ) increases in the dehydrogenase activity on the 50<sup>th</sup> and 75<sup>th</sup> days of composting. Here also, the enzyme levels increased with increase in the days of composting. The activity on the 50<sup>th</sup> and 75<sup>th</sup> days were significantly ( $p < 0.05$ ) higher than those of microbial composts (M).

In the case of microbial vermicomposts (M+V) though the dehydrogenase activity was significantly ( $p < 0.05$ ) higher than those of the controls (C) on all the days of the composting, the highest activity was recorded on the 50<sup>th</sup> day after which it was reduced on the 75<sup>th</sup> day.

Hence from the above findings it is clear that all types of composting increases the dehydrogenase activities. The combined activity of earthworms with microbes (M+V) in the degradation process gave higher enzyme activity than other types of composting.

The increased activity of dehydrogenase especially in microbial vermicomposting (M+V) is on par with a report of Aira and Dominguez (2009), who stated that increased dehydrogenase action in the vermicompost (V) shows the hydrolytic phase of the composting by which degradation of the easily available organic substrates is associated with the stimulation of the metabolic activity of the microbes (dehydrogenase). The end of this stage is represented as the maturation phase. This phase is characterized by a reduction in the dehydrogenase activity mainly due to the disappearance of easily decomposable organic compounds and the stabilization of the compost. So the reduced dehydrogenase level in the microbial vermicompost (M+V) confirms the maturation of the compost.

#### 4.2.2.6 Acid Phosphatase

The changes in phosphatase activity are helpful in providing information about the maturity of the composted product (Tiquia, 2005).

Table 27 depicts the acid phosphatase activities of the 3:1 ratio tapioca solid waste – cow dung composts at various stages.

**TABLE 27**  
**ACTIVITY OF ACID PHOSPHATASE\* IN TAPIOCA SOLID WASTE COMPOSTS AT VARIOUS STAGES OF COMPOSTING**

Days		C	M	V	M + V
Precompost		25.5±0.8	24.5±0.8	24.8±0.8	25.2±1.0
Composts	25	26.0±0.4	36.0±1.2	50.7±0.6	60.8±1.1
	50	26.5±1.2	50.0±0.8	73.8±1.0	81.0±0.4
	75	27.5±0.8	60.0±0.8	79.5±0.7	<b>85.2±1.0</b>
CD (P<0.05) =1.5					

Values are expressed as mean ± SD for triplicates

\* - µg of para nitrophenol released g<sup>-1</sup> dry weight h<sup>-1</sup>

C : Control (Natural composting)      M : Microbial composting  
V : Vermicomposting                      M+V : Microbial Vermicomposting

It is evident from the table that microbial composting (M) of tapioca solid waste –cow dung mixture significantly (p<0.05) increased the acid phosphatase activity on all the days of composting. The activity also increased with increase in number of days of the composting.

As regards, vermicomposting (V) and microbial vermicomposting (M+V) also, a similar trend was followed. The highest activity of alkaline phosphatase was exhibited by the microbial vermicompost (M+V) followed by the vermicompost (V) and microbial compost (M).

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It can thus be inferred from the above observations that acid phosphatase activity increased in all types of composting with the microbial vermicomposting (M+V) recording the highest activity. The observed results were supported by the information of Aira *et al.* (2003), who stated that the phosphatase activity has been shown to be greater in the casts of the earthworm species with different feeding habits such as *Lumbricus rubellus*, *Aporrectodea caliginosa* and *A. molleri*.

In the above research, the highest acid phosphatase activity in the microbial vermicompost (M+V) might be due to the combined action of the earthworms and microbes in the degradation of the substrate. These results correlate with the reports of Pramanik *et al.* (2009), who inferred that vermicompost (V) obtained from organic sources inoculated with fungi showed high phosphatase activity.

#### 4.2.2.7 Alkaline Phosphatase

Enzyme activity in organic waste degradation is considered to be a reliable indicator in response to microbial communities and compost maturation (Carreiro *et al.*, 2000).

Table 28 shows the alkaline phosphatase activity of the composts formed from various treatments of 3:1 ratio tapioca solid waste - cow dung mixture.

From the table, it is understood that microbial composting (M) significantly ( $p < 0.05$ ) enhanced the alkaline phosphatase activity upto the 75<sup>th</sup> day of composting as compared to the controls (C). As for other enzymes, the activity of alkaline phosphatase also increased with increase in the days of composting.

The composts produced by vermicomposting (V) depicted significant ( $p < 0.05$ ) increases in the alkaline phosphatase activity on all the days of

composting when compared to the controls (C) and microbial composts (M). The activity increased from the 25<sup>th</sup> upto the 75<sup>th</sup> day of composting.

**TABLE 28**  
**ACTIVITY OF ALKALINE PHOSPHATASE\* IN TAPIOCA SOLID WASTE COMPOSTS AT VARIOUS STAGES OF COMPOSTING**

Days		C	M	V	M + V
Precompost		23.2±0.6	23.0±0.7	22.7±0.2	23.3±0.98
Composts	25	24.7±0.5	31.2±0.5	40.8±0.6	50.0±1.2
	50	27.0±0.8	35.5±0.6	50.0±1.2	70.2±1.0
	75	28.2±1.0	40.8± 0.6	64.2±1.2	<b>80.8±1.0</b>
CD (P<0.05) = 1.4					

Values are expressed as mean ± SD for triplicates

\* - µg of para nitrophenol released g<sup>-1</sup> dry weight h<sup>-1</sup>

C : Control (Natural composting)      M : Microbial composting

V : Vermicomposting                      M+V : Microbial Vermicomposting

As usual, the highest activity of alkaline phosphatase was recorded by the microbial vermicomposts (M+V) which marked significantly (p<0.05) higher values than the controls (C), microbial composts (M) and vermicomposts (V).

It can therefore be concluded from the above results on enzyme activities that all the types of composting increased the alkaline phosphatase activity with the microbial vermicomposting (M+V) depicting higher values than the other composts. In the present study, the finding that there is an increased phosphatase activity in all types of composting upto the final day is on par with the reports of Benitez *et al.* (2005), who inferred that the phosphatases of the organic extracts formed by earthworm action either increased or remained the same after a nine month period of vermicomposting.

Thus, from the above results, it can be inferred that the extracellular enzymes (cellulase,  $\beta$ -glucosidase, protease and urease) decrease in vermicompost (V) and microbial vermicompost (M+V), but maximum reduction can be observed in the microbial vermicompost (M+V). With reference to the intracellular enzymes (dehydrogenase and phosphatases) the levels were found to increase in all types of composting. The microbial vermicomposts (M+V) were shown to exhibit optimum increase when compared to other composts.

#### 4.2.3 COMPOST MATURITY OF 3:1 RATIO TAPIOCA SOLID WASTE – COW DUNG MIXTURE

##### 4.2.3.1 Humic Acid

The amount and quality of the humic acid fraction in composts and vermicomposts are considered to be important indicators of their biological maturity, chemical stability and a warranty for safe impact and successful performance in soil.

**TABLE 29**  
**HUMIC ACID LEVELS (mg/g) IN TAPIOCA SOLID WASTE COMPOSTS AT VARIOUS STAGES OF COMPOSTING**

Days		C	M	V	M + V
Precompost		0.10 ± 0.01	0.12 ± 0.01	0.10 ± 0.01	0.09 ± 0.004
Composts	25	0.14 ± 0.01	0.20 ± 0.02	0.21 ± 0.02	0.40 ± 0.02
	50	0.14 ± 0.04	0.35 ± 0.03	0.46 ± 0.03	0.87 ± 0.04
	75	0.17 ± 0.01	0.46 ± 0.03	0.71 ± 0.04	<b>0.90 ± 0.03</b>
CD (P<0.05) = 0.03					

Values are expressed as mean ± SD for triplicates

C : Control (Natural composting)      M : Microbial composting  
V : Vermicomposting                      M+V : Microbial Vermicomposting

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Table 29 presents the humic acid levels of the composts obtained from 3:1 ratio tapioca solid waste - cow dung mixture at various stages.

From the table, it is evident that microbial composting (M) of tapioca solid waste significantly ( $p < 0.05$ ) increased the humic acid levels when compared to the controls (C). The humic acid levels were also found to increase with increase in the number of days of composting.

The degradation of tapioca solid waste by vermicomposting (V), expressed a significant ( $p < 0.05$ ) increase in the humic acid level on the 50<sup>th</sup> and 75<sup>th</sup> days of composting, when compared to the control (C) and microbial compost (M).

The composts obtained by microbial vermicomposting (M+V) revealed a significant ( $p < 0.05$ ) increase in the humic acid levels when compared to all other treatments.

Thus, from the above observations it can be concluded that composting of tapioca solid waste for 75 days using a combination of microbes and earthworms (M+V) maximally increased the content of humic acid when compared to the other types of composting.

The findings that humic acid increases on composting is in accordance with the report of Castaldi *et al.* (2005), who stated that vermicomposting and other types of compostings are characterized by the conversion of part of the organic material into humic substances. A report by Atiyeh *et al.* (2000) also supported the finding that the earthworms fragment the organic substrates and stimulate microbial activities that convert the waste into humic - like substances.

The findings that maximum humic acid level was in the microbial vermicompost (M+V) is supported by the study of Pramanik *et al.* (2007), who

mentioned that the increase in the humic acid content during this type of composting might be due to the increased organic matter degraded by the earthworms and cellulolytic action of microbial inoculants (*Trichoderma viridae*). Inoculation with *Bacillus polymyxa* was also found to be effective in increasing the humic acid content.

#### 4.2.3.2 Carbondioxide evolution

Compost maturity is related to suitability for plant growth. It refers to the resistance of compost organic matter to further rapid degradation, which can be directly measured by respiration rates (Eggen and Vethe, 2001).

Table 30 records the carbondioxide evolution of the composts obtained from various treatments of 3:1 ratio tapioca solid waste - cow dung mixtures at various stages.

**TABLE 30**  
**CARBONDIOXIDE EVOLUTION (mg/g/day) IN TAPIOCA SOLID WASTE COMPOSTS AT VARIOUS STAGES OF COMPOSTING**

Days		C	M	V	M + V
Precompost		4.1 ± 0.2	4.0 ± 0.2	4.0 ± 0.2	4.4 ± 0.3
Composts	25	4.3 ± 0.2	5.5 ± 0.5	4.7 ± 0.3	6.5 ± 0.5
	50	4.8 ± 0.3	7.0 ± 0.6	6.0 ± 0.4	9.3 ± 1.4
	75	5.3 ± 0.3	8.3 ± 0.4	9.0 ± 0.4	<b>3.2 ± 0.3</b>
CD (P<0.05) = 0.03					

Values are expressed as mean ± SD for triplicates

C : Control (Natural composting)      M : Microbial composting  
V : Vermicomposting                      M+V : Microbial Vermicomposting

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From the table, it is understood that the microbial composts (M) of tapioca solid waste significantly ( $p < 0.05$ ) increased the carbondioxide evolution upto the 75<sup>th</sup> day. The vermicompost (V) samples marked significant ( $p < 0.05$ ) increases only on the 50<sup>th</sup> and 75<sup>th</sup> days of composting. However, the microbial vermicomposts (M+V) showed significant ( $p < 0.05$ ) increase in the carbondioxide evolution from the 25<sup>th</sup> day onwards till the 50<sup>th</sup> day.

In general, it can be inferred from the table that carbondioxide evolution in tapioca solid waste composting increased with increase in the number of days of composting, with the microbial vermicompost (M+V) giving the maximum evolution on the 50<sup>th</sup> day.

The increase in carbondioxide evolution in the microbial vermicomposts (M+V) on the 50<sup>th</sup> day of composting followed by a decrease on the 75<sup>th</sup> day might be due to the combined effect of microbes and earthworms in the composting process such that the substrate is available only upto the 50<sup>th</sup> day and thereafter gets depleted towards the 75<sup>th</sup> day.

The observations that the microbial vermicompost (M+V) of tapioca solid waste expressed a highly significant ( $p < 0.05$ ) increase in carbondioxide evolution upto the 50<sup>th</sup> day of composting, whilst on the 75<sup>th</sup> day it was significantly ( $p < 0.05$ ) lower than the controls (C), microbial composts (M) and vermicomposts (M+V) was supported by the research work of Aira *et al.* (2007), who inferred that a sudden increase in carbondioxide release was observed on the 30<sup>th</sup> day of composting and this was maintained upto the 45<sup>th</sup> day, after which it was decreased drastically.

Another study by Khwairakpam and Bhargava (2009a) also reported that, the 75 percent reduction in carbondioxide release with polyculture worms on the 75<sup>th</sup> day of composting with the decrease starting from the 45<sup>th</sup> day of composting indicates the stability of the finished compost.

### 4.2.3.3 Earthworm biomass

The organic matter degradation by the earthworms can be determined by calculating the earthworm biomass. Addition of manure to the substrate supports the maintenance of biomass (Kostecka and Kaniuczak, 2008).

Table 31 presents the biomass of earthworms in the vermicomposts (V) and microbial vermicomposts (M+V) obtained from 3:1 ratio tapioca solid waste - cow dung mixture at various stages.

**TABLE 31**  
**GROSS BIOMASS (g) OF EARTHWORMS IN TAPIOCA SOLID WASTE COMPOSTS AT VARIOUS STAGES OF COMPOSTING**

Days		V	M + V
Precompost		107.2 ± 7.0	102 ± 9.5
Composts	25	169.3 ± 5.0	215 ± 9.0
	50	266.0 ± 13.4	321 ± 6.5
	75	303.3 ± 7.4	<b>291 ± 7.0</b>
CD (P<0.05) = 0.03			

Values are expressed as mean ± SD for triplicates

V : Vermicomposting

M+V : Microbial Vermicomposting

From the table it can be stated that vermicomposting (V) of tapioca solid waste gradually and significantly ( $p < 0.05$ ) increased the weight of the earthworms upto the 75<sup>th</sup> day of composting. A similar trend was observed in microbial vermicomposting (M+V) also where there was a significant ( $p < 0.05$ ) increase in the earthworm biomass from the 25<sup>th</sup> day upto the 50<sup>th</sup> day. However, on the 75<sup>th</sup> day, the value was slightly decreased. The increase in the earthworm biomass was more marked in the microbial vermicomposting (M+V) than only vermicomposting (V) though the value in microbial vermicomposting (M+V)

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decreased on the 75<sup>th</sup> day of composting unlike vermicomposting (V) alone where the value was maximum on the 75<sup>th</sup> day.

From the above results, it can be stated that vermicomposting (V) and microbial vermicomposting (M+V) showed increases in earthworm biomass.

In the above study, the increase in earthworm biomass in the vermicompost (V) and microbial vermicompost (M+V) indicates the availability of the substrate for the earthworms growth. The weight reduction in the microbial vermicompost (M+V) on the 75<sup>th</sup> day implies the exhaustion of the substrate. This finding is in accordance with a study which indicates that an increased biomass by the bioinoculants occurred during vermicomposting and after the 11<sup>th</sup> week, the biomass was decreased perhaps due to the exhaustion of food for the earthworms (Singh and Sharma, 2002).

#### **4.2.3.4 Number of earthworm cocoons**

The degradation of organic matter probably causes drastic changes in some of the environmental characteristics of the decomposing vermibeds. This changed condition modifies the rate of cocoon formation by the earthworms (Suthar and Singh 2008).

Table 32 presents the number of earthworm cocoons in the vermicomposts (V) and microbial vermicomposts (M+V) obtained from 3:1 ratio tapioca solid waste - cow dung mixture at various stages.

From the table, it can be said that in the vermicomposts (V) of tapioca solid waste, the total number of earthworm cocoons were significantly ( $p < 0.05$ ) increased on all the sampling days of the experimental period upto the 75<sup>th</sup> day. On the other hand, in the microbial vermicompost (M+V), the number of cocoons were significantly ( $p < 0.05$ ) increased upto the 50<sup>th</sup> day of composting after which the number was decreased on the 75<sup>th</sup> day.

**TABLE 32**  
**TOTAL NUMBER OF COCOONS\* IN TAPIOCA SOLID WASTE COMPOSTS AT VARIOUS STAGES OF COMPOSTING**

Days	V	M + V
25	$17.0 \pm 0.8^a$	$24.0 \pm 2.0^a$
50	$31.0 \pm 3.0^b$	$57.0 \pm 5.0^b$
75	$62.0 \pm 4.0^c$	<b><math>51.0 \pm 4.0^c</math></b>

Values are expressed as mean  $\pm$  SD for triplicates

Values in each column not sharing a common superscript letter differ significantly at  $p < 0.05$  (DMRT)

\* : Total number of cocoons / kilogram of substrate

V : Vermicomposting

M+V : Microbial Vermicomposting

The high rate of earthworm cocoon formation in the tapioca solid waste vermicompost (V) might be due to substrate availability for earthworm growth and reproduction. The low cocoon number on the final day of the microbial vermicomposting (M+V) might be due to the enhanced substrate depletion indicating the maturity of the compost.

The above findings depicting an increase in earthworm cocoon number on vermicomposting was supported by the fact that a pronounced increase in the number of earthworms as well as their cocoons occurs during vermicomposting as reported by Singh and Sharma (2002).

Another research work suggested that the rate of cocoon formation was high in the initial degradative phase and low in the final maturation phase and it was the best indicator to evaluate the vermicomposting process (Suthar, 2007a).

#### 4.2.3.5 Number of earthworms

The growth rate of earthworms has been considered as a good comparative index to determine the compost maturity. Addition of manure to the substrate alters the earthworm population. Table 33 reveals the number of earthworms in the vermicompost (V) and microbial vermicomposts (M+V) of 3:1 ratio tapioca solid waste - cow dung mixture on the 75<sup>th</sup> day of the composting period.

**TABLE 33**  
**TOTAL NUMBER OF EARTHWORMS AND YIELD OF THE COMPOSTS ON 75<sup>TH</sup> DAY OF COMPOSTING**

Days	C	M	V	M + V
Total number of earthworms	-	-	153±6.0 <sup>a</sup>	<b>202 ± 10.6<sup>b</sup></b>
Yield (g/kg substrate)	80±8.2 <sup>a</sup>	147±13.6 <sup>b</sup>	279±4.0 <sup>c</sup>	<b>330±13.0<sup>d</sup></b>
CD (P<0.05) = 0.03				

Values are expressed as mean ± SD for triplet

Values in each row not sharing a common superscript letter differ significantly at p<0.05 (DMRT)

C : Control (Natural composting)      M : Microbial composting  
V : Vermicomposting                      M+V : Microbial Vermicomposting

From the table, it can be reported that the number of earthworms in the final compost was significantly (p<0.05) high in microbial vermicompost (M+V) when compared to the vermicomposts (V) formed by the action of earthworms on the 50<sup>th</sup> day. On the 75<sup>th</sup> day, the microbial vermicompost (M+V) revealed significantly (p<0.05) lower number of earthworms than the vermicompost (V). The above results were in accordance with the reports of Kostecka and Kaniuczak (2008), who stated that after four months of duckweed vermicomposting, the initial number of

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earthworms had decreased by approximately 50 percent. This confirmed the maturity of the compost.

#### **4.2.3.6 Compost yield**

The compost yield mainly depends upon the activity of the earthworms and microbes. It is considered to be a good indicator for the selection of type and proportion of the wastes with bulking agent.

Table 33 presents the yield of vermicompost (V) and microbial vermicomposts (M+V) of the 3:1 ratio tapioca solid waste - cow dung mixture.

It can be observed from the table that the microbial composting (M+V) recorded high compost yield, which was significantly ( $p < 0.05$ ) higher than the control (C).

Vermicomposting also gave significantly ( $p < 0.05$ ) higher yield than the control (C). The same was the case with microbial vermicompost (M+V) also.

On comparing the various types of composts, it can be deduced that microbial vermicomposting (M+V) gave the maximum yield of the compost.

The yield of the final compost from microbial vermicompost (M+V) confirms that inoculation of selected microorganisms hastens the degradation of organic matter and promotes earthworms growth. The protozoa and fungi are assumed to form a substantial part of their diet (Brown, 1995).

From the results of compost maturity tests, it can be accomplished that the 3:1 ratio tapioca solid waste-cow dung composts obtained by microbial vermicomposting showed better compost maturity than other types of composts. So in the third phase, the experiment was carried out by using the 3:1 ratio tapioca solid waste - cow dung microbial vermicompost (M+V).

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## PHASE III

### 4.3 EFFECT OF THE 3:1 MICROBIAL VERMICOMPOST ON PLANT GROWTH

#### 4.3.1 SELECTION OF THE POT MIXTURE FOR PLANT GROWTH

The results of Phase II clearly revealed that among the three treatments of tapioca solid waste (microbial composting, vermicomposting and microbial vermicomposting), the microbial vermicomposting (M+V) was the most suitable method for obtaining good compost. Therefore, to study the effect of this compost on plant growth, the third phase involved growing two different types of plants - leguminous (Black gram -*Vigna mungo*) and green leafy vegetable (Fenugreek -*Trigonella foenum gracum*) in soil supplemented with different proportions (20 percent, 40 percent, 60 percent and 80 percent) of the 3:1 ratio microbial vermicompost (M+V) from tapioca solid waste - cow dung mixture. The growth of the plants on the 90<sup>th</sup> day of sowing (for Black gram -*Vigna mungo*) and on the 10<sup>th</sup> day of sowing (for Fenugreek -*Trigonella foenum gracum*) were recorded.

#### 4.3.2 BIOMETRIC ANALYSIS OF BLACK GRAM (*Vigna mungo*)

##### 4.3.2.1 Germination index

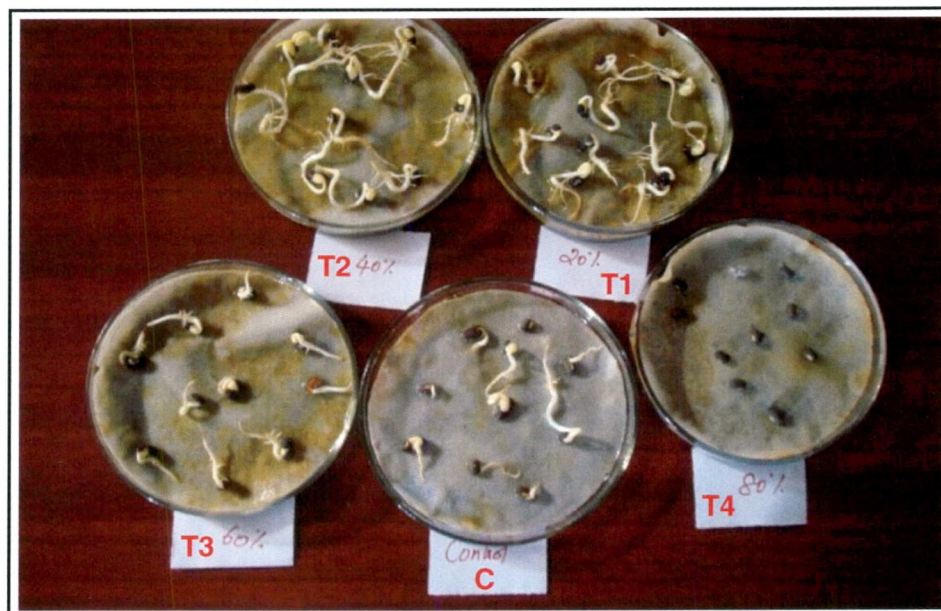
Application of vermicompost to soil promotes good emergence and growth of seedlings (Zaller, 2006). Analysis of germination indices in black gram plant is important to study the effect of microbial vermicomposts on plant growth.

Plate 4 and Figure 5 represent the germination indices of black gram in soil supplemented with various proportions (20 percent -T1, 40 percent-T2, 60 percent -T3 and 80 percent -T4) of 3:1 ratio tapioca solid waste – cow dung microbial vermicompost (M+V).

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## PLATE 4

### GERMINATION INDEX OF BLACK GRAM (*Vigna mungo*) GROWN IN 3:1 RATIO TAPIOCA SOLID WASTE – COW DUNG MICROBIAL VERMICOMPOST



**C** : Control (soil alone)

**T1** : 20% microbial Vermicompost, **T2** : 40% microbial Vermicompost

**T3** : 60% microbial Vermicompost **T4** : 80% microbial Vermicompost

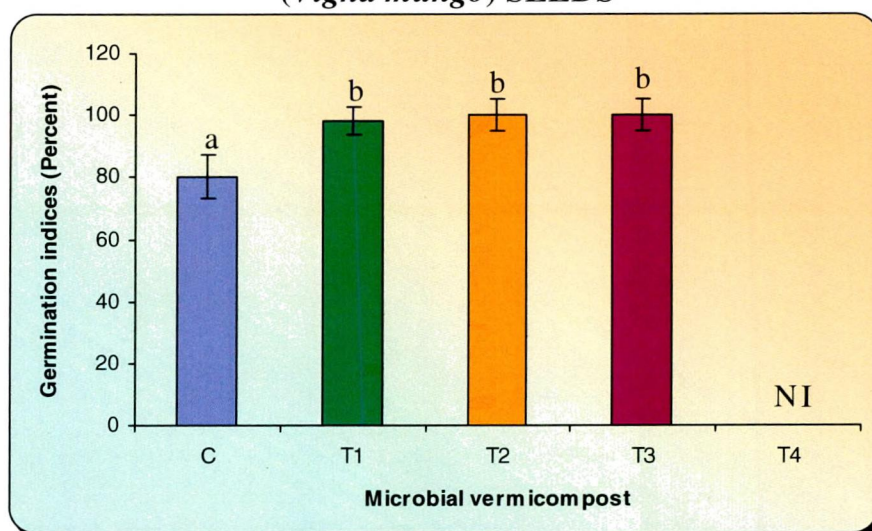
From Figure 5, it is understood that seeds of T1 T2 and T3 samples of black gram expressed significantly ( $p < 0.05$ ) high percentage of germination indices, when compared to the control (C). A complete absence of germination index was exhibited by the T4 sample.

The increase in germination indices in the above study was in agreement with the reports of Fernandez-Luqueno *et al.* (2009), who emphasized that addition of vermicompost to soil improved emergence of bean plants.

The maximum germination index shown by T1, T2 and T3 was supported by the observations of Arancon *et al.* (2005a), who stated that application of

vermicompost to soil improves its physical structure such as aeration and drainage. Studies also showed that supplementing soil with 70 to 100 percent vermicompost prevents the germination of the seeds which might be due to high salt content as a result of more proportion of vermicompost (Arancon, *et al.*, 2008).

**FIGURE 5**  
**GERMINATION INDEX (percent) OF BLACK GRAM**  
**(*Vigna mungo*) SEEDS**



Values are expressed as mean  $\pm$  SD for triplicates

Similar alphabets on vertical bars indicate that the respective groups do not differ significantly at  $p < 0.05$  (DMRT)

**C** : Control (soil alone)

**NI** : Not identified

**T1** : 20% microbial vermicompost, **T2** : 40% microbial vermicompost

**T3** : 60% microbial vermicompost **T4** : 80% microbial vermicompost

#### 4.3.2.2 Root length and shoot length

Determination of root and shoot lengths of black gram plant is considered effective, because, vermicompost promotes leguminous plant growth and this may be due to stimulation through nitrogen fixation (Han *et al.*, 2005).

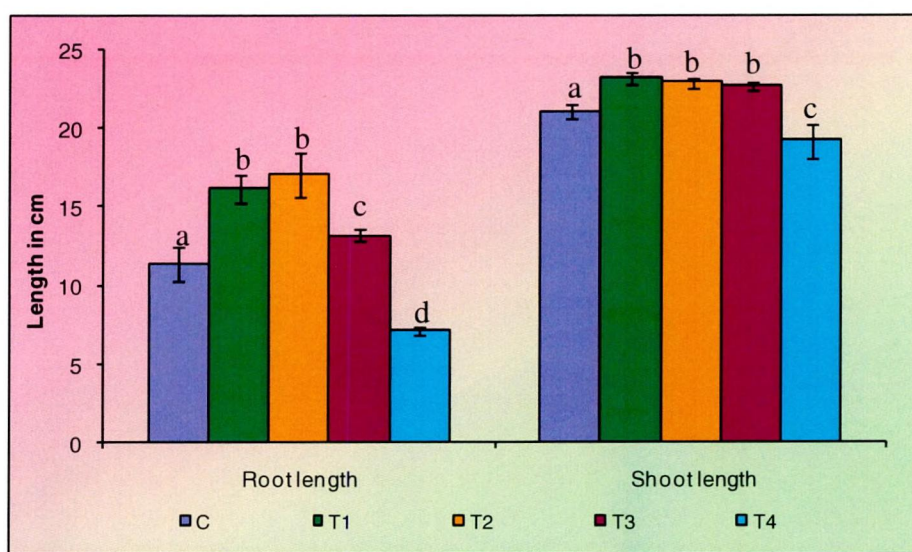
Figure 6 depicts the root and shoot lengths of the black gram plants grown in soil supplemented with various proportions (20 percent -T1, 40 percent-T2,

60 percent -T3 and 80 percent -T4) of the 3:1 ratio tapioca solid waste – cow dung microbial vermicompost (M+V).

### Root length

From Figure 6, it is clear that T1 and T2 samples of black gram plant expressed significantly ( $p < 0.05$ ) higher root lengths than the control (C), T3 and T4 treatments. Among all the treatments, maximum root length was expressed by the T2 sample.

**FIGURE 6**  
**ROOT LENGTH AND SHOOT LENGTH OF BLACK GRAM**  
**(*Vigna mungo*) PLANT**



Values are expressed as mean  $\pm$  SD for triplicates

Similar alphabets on vertical bars indicate that the respective groups do not differ significantly at  $p < 0.05$  (DMRT)

**C** : Control (soil alone)

**NI** : Not identified

**T1** : 20% microbial vermicompost, **T2** : 40% microbial vermicompost

**T3** : 60% microbial vermicompost **T4** : 80% microbial vermicompost

It can also be stated that T4 exhibited significantly ( $p < 0.05$ ) lower root length when compared to the control (C) and all other treatments.

The above results agree with the study of Padmavathiamma *et al.* (2008), who inferred that the addition of vermicompost to soil improved the soil

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environment, encouraging the proliferation of roots which in turn draws more water and nutrients from large areas.

The present study records the highest root length for the T2 sample. This might be due to the lower content of vermicompost in the soil as mentioned by Arancon *et al.* (2008). The lowest root length in T4 might be due to the presence of high concentrations of substances which were toxic to the tender roots and shoots emerging from the germinated seeds (Gopal *et al.*, 2010).

### **Shoot length**

As regards the shoot lengths, it is clear from Figure - 6 that T1, T2 and T3 samples revealed significant ( $p < 0.05$ ) increases in the shoot lengths of the black gram plant when compared to the control (C) and T4. However, among the T1, T2 and T3 samples, the maximum increase in shoot length was exhibited by the T1 sample.

The above results correlated with the observation of Atiyeh *et al.*, (2001), who reported that supplementing soil with 5 percent, 10 percent, 25 percent and 50 percent pig manure vermicompost increased the shoot lengths of tomato seedlings with no fertilizer treatment when compared to those grown in soil without any supplementation.

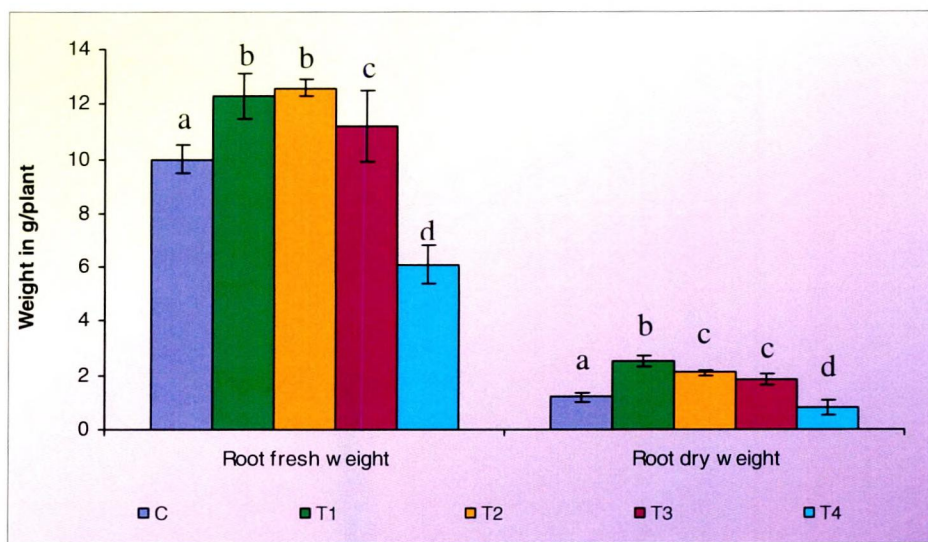
The maximum shoot length in T1 is also supported by the work of Bachmen and Metzger (2008), who stated that 20 percent vermicompost supplemented soil had positive effects on plant growth. A decreased shoot length was observed in T4 as compared to the control (C). This finding is also on par with the observations of Arancon *et al.* (2004), who mentioned that decreased shoot length in T4 might be due to high soluble salt concentrations, poor aeration, heavy metal toxicity and/or plant phytotoxicity in the concentrated vermicompost.

### 4.3.2.3 Root fresh and dry weights

Vermicompost application builds up water retention capacity of soil because of its high organic matter content and promotes better root growth and nutrient absorption (Nourbakhsh, 2007). Evaluation of root fresh and dry weights of the black gram plant is considered as an important parameter to study the effect of vermicompost on its growth.

Figure 7 depicts the root fresh weights and dry weights of black gram plants grown in soil supplemented with various proportions (20 percent -T1, 40 percent-T2, 60 percent -T3 and 80 percent -T4) of the 3:1 ratio tapioca solid waste - cow dung microbial vermicompost (M+V).

**FIGURE 7**  
**ROOT FRESH WEIGHT AND ROOT DRY WEIGHT OF BLACK GRAM (*Vigna mungo*) PLANT**



Values are expressed as mean  $\pm$  SD for triplicates

Similar alphabets on vertical bars indicate that the respective groups do not differ significantly at  $p < 0.05$  (DMRT)

**C** : Control (soil alone)

**T1** : 20% microbial vermicompost, **T2** : 40% microbial vermicompost

**T3** : 60% microbial vermicompost **T4** : 80% microbial vermicompost

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### **Root fresh weight**

From Figure 7, it is obvious that the root fresh weight of the T1 and T2 samples of the black gram were significantly ( $p < 0.05$ ) higher than those of the control (C), T3 and T4 plants. On comparing the values found in the T1 and T2 samples, the maximum root fresh weight was exhibited by the T2 sample.

The above observations were supported by the work of Atiyeh *et al.* (2002), who stated that supplementation of soil with 20 percent pig manure vermicompost resulted in the roots of flowering plants being larger than plants grown in soil without any supplementation. In the above research, the maximum root fresh weight was shown by the T2 samples. As quoted by Gopal *et al.* (2010), this may be due to the beneficial effects of the vermicompost on plant growth. According to him, diluted vermivash had a positive effect on the percentage of seed germination and growth of the cowpea and paddy seedlings.

### **Root dry weight**

From Figure 7, it is clear that dry weight of the black gram root was significantly ( $p < 0.05$ ) higher in the T1 sample when compared to all other treatments and control. The results also showed that T4 treatment revealed significantly ( $p < 0.05$ ) lowest level of root dry weight than control and all other treatments.

The above findings are supported by the observations of Bachmen and Metzger (2008), who deduced that the dry root weights were similar in black gram plants grown in the 10 percent and 20 percent vermicompost with values which are 44 percent greater when compared to the control.

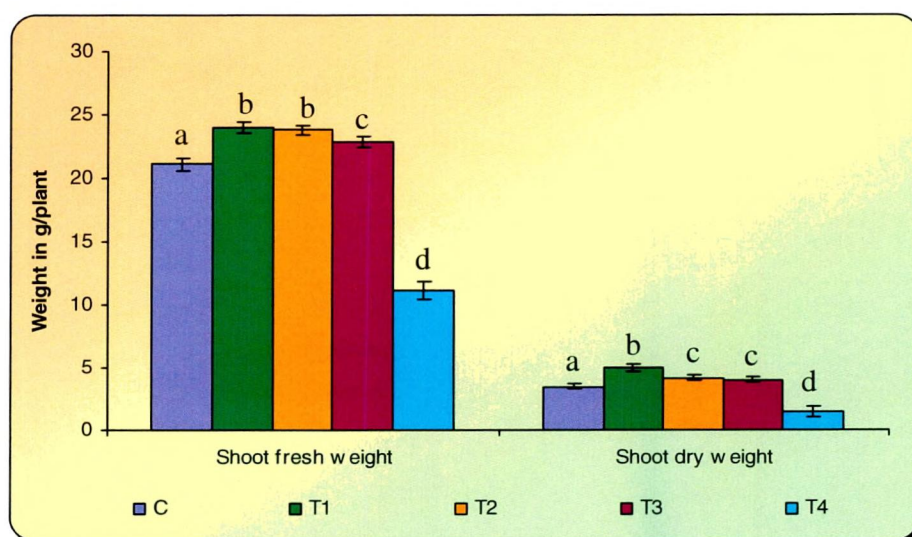
The maximum root dry weight in T1 sample as mentioned above is supported by the findings of Atiyeh *et al.* (2001), who stated that the presence of growth enhancing factors such as plant growth regulators provided by pig manure vermicompost is more effective at low concentration. The lowest root dry weight

in T4 sample confirms that high salt concentration, poor porosity or poor aeration in the medium with high percent of vermicompost inhibits plant growth (Atiyeh *et al.*, 2002).

#### 4.3.2.4 Shoot fresh and dry weights

Application of compost and vermicompost in traditional agriculture and horticulture has been found to have beneficial effects on soil structure or soil biota (Carpenter-Boggs *et al.*, 2000). It may be responsible for alteration in the shoot fresh weight and dry weight of the black gram plant.

**FIGURE 8**  
**SHOOT FRESH WEIGHT AND SHOOT DRY WEIGHT**  
**OF BLACK GRAM (*Vigna mungo*) PLANT**



Values are expressed as mean  $\pm$  SD for triplicates

Similar alphabets on vertical bars indicate that the respective groups do not differ significantly at  $p < 0.05$  (DMRT)

**C** : Control (soil alone)

**T1** : 20% microbial vermicompost,

**T2** : 40% microbial vermicompost

**T3** : 60% microbial vermicompost

**T4** : 80% microbial vermicompost

Figure 8 presents the shoot fresh and dry weights of black gram plant grown in soil supplemented with various proportions (20 percent -T1, 40 percent-

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T2, 60 percent -T3 and 80 percent -T4) of the 3:1 ratio tapioca solid waste – cow dung microbial vermicompost (M+V).

### **Shoot fresh weight**

From Figure 8, it is clear that the shoot fresh weights of T1 and T2 black gram samples were significantly ( $p<0.05$ ) higher than those of the control (C), T3 and T4 plants. It can be said that T4 represents significantly ( $p<0.05$ ) low value, when compared to control (C) and all other treatments.

The above results are in accordance with the reports of Chamani *et al.* (2008), who stated that soil incorporated with 20 percent and 40 percent vermicompost significantly ( $p<0.05$ ) increased the fresh weights of Petunia shoots compared to the control and peat - amended soil.

In the above experiment, the maximum shoot fresh weight in T1 sample might be due to the presence of appropriate amounts of certain metabolites and vitamins in the vermicompost which helped to enhance plant growth (Ansari and Ismail, 2008).

It can also be said that decrease in shoot fresh weight in T4 might be due to high-moisture and possible phytotoxic effects exhibited by high percentage of the vermicompost (Atiyeh *et al.*, 2000a).

### **Shoot dry weight**

From Figure 8, it is clearly understood that shoot dry weights were significantly ( $p<0.05$ ) higher in T1 black gram plant sample on comparison with the control (C), T2, T3 and T4 samples.

However, the T4 sample showed a decrease in the shoot dry weight which was much lower than those of the control (C) and also T1, T2 and T3 treatments.

These findings are on par with the reports of Bachmen and Metzger (2008), who mentioned that soil amended with 20 percent vermicompost

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produced greater dry shoot weights of plants than those grown in soil without compost.

The maximum shoot dry weight was exhibited by the T1 sample. The increase in shoot dry weight in T1, T2 and T3 samples might be due to the enhanced available nutrient status of soil by the application of vermicompost as an organic source (Prabha *et al.*, 2007).

In the above study the finding that low shoot dry weight is exhibited by the T4 sample is on par with the reports of Jordao *et al.* (2006), who mentioned that supplementation of soil with high proportion of vermicompost inhibits the growth of plants.

#### **4.3.2.5 Nodule number and seed number**

The number of nodules was found to be altered in plants grown in vermicompost amended soil, because, vermicompost acts as a cheap source of nitrogen and other essential elements for better nodulation (Parthasarathi and Ranganathan, 2002).

Figure 9 presents the number of nodules and the number of seeds of the black gram plant grown in soil supplemented with various proportions (20 percent -T1, 40 percent-T2, 60 percent -T3 and 80 percent -T4) of the 3:1 ratio tapioca solid waste - cow dung microbial vermicompost (M+V).

#### **Nodule number**

From Figure 9, it is obvious that the number of nodules in T1 was significantly ( $p < 0.05$ ) higher than those of the control (C) and all other treatments. In contrast, the T4 plants represented the lowest number of nodules, the value of which was significant ( $p < 0.05$ ).

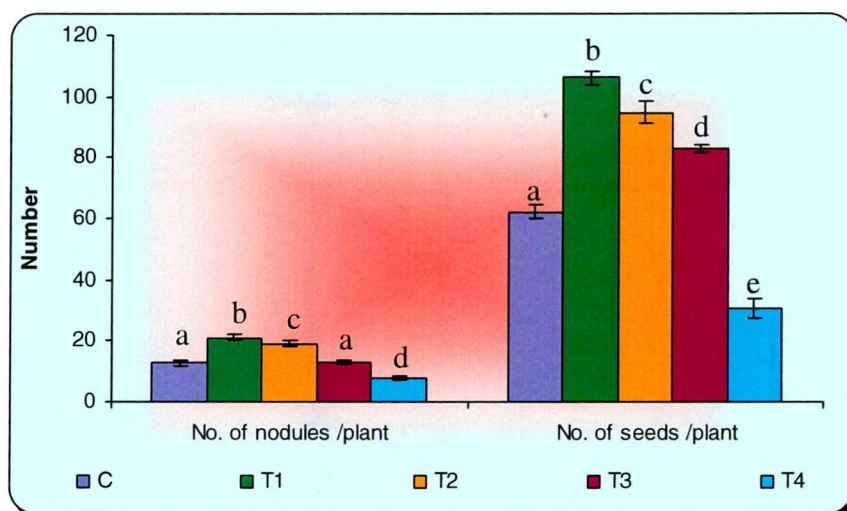
These results were supportive to the observations of Benik and Bejbaruah (2004), who stated that application of vermicompost has a positive effect on

growth and productivity of legumes. Suthar *et al.* (2005) also reported that a hormone – like effect of earthworm body fluid may have stimulatory effect on the seedling growth of some legumes.

In the above experiment, a marked increase in the nodule number of plants grown in T1 sample might have been due to the presence of soil organic matter, total nitrogen, phosphorus, potassium, calcium and magnesium in favourable amounts for production of nodules (Nascimento *et al.*, 2004).

The decrease in nodule number in T2, T3 and T4 plants might be due to the presence of nitrogen in the form of nitrates as supported by the report that the presence of high nitrate reduces root nodulation in common bean plants (Bruck and Guo, 2006).

**FIGURE 9**  
**NUMBER OF NODULES AND SEEDS OF BLACK GRAM**  
**(*Vigna mungo*) PLANT**



Values are expressed as mean  $\pm$  SD for triplicates

Similar alphabets on vertical bars indicate that the respective groups do not differ significantly at  $p < 0.05$  (DMRT)

**C** : Control (soil alone)

**T1** : 20% microbial vermicompost, **T2** : 40% microbial vermicompost

**T3** : 60% microbial vermicompost **T4** : 80% microbial vermicompost

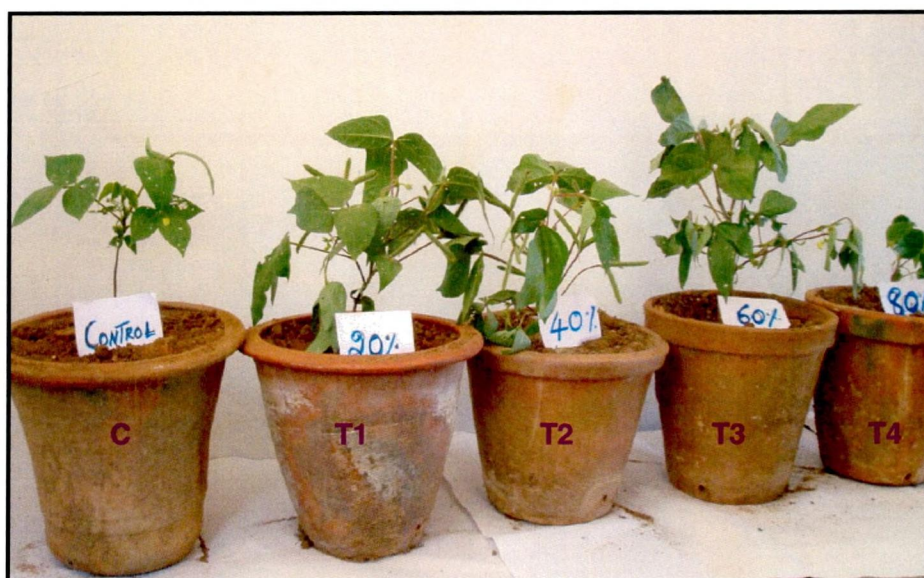
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## Seed Number

From Figure 5, it can be mentioned that the number of seeds in the T1 black gram plants was significantly ( $p < 0.05$ ) higher than the number of seeds from other plants and control. Similarly, the value for T4 plants was significantly ( $p < 0.05$ ) very low as compared to the control (C).

### PLATE 5

#### GROWTH OF BLACK GRAM (*Vigna mungo*) PLANT IN 3:1 RATIO TAPIOCA SOLID WASTE - COW DUNG MICROBIAL VERMICOMPOST ON THE 90<sup>TH</sup> DAY



C : Control (soil alone)

T1 : 20% microbial vermicompost,

T2 : 40% microbial vermicompost

T3 : 60% microbial vermicompost

T4 : 80% microbial vermicompost

The maximum number of seeds in the T1 sample might be due to the improvement in the physicochemical characteristics of the soil and increase in nutrient availability by the application of low proportion of vermicompost. These results are supported by the reports of Cordovil *et al.* (2007), who stated that vermicompost from waste water sludge increases crop yield.

The reduction in the yield of plants grown in T4 might be due to excess salinity, which may have caused an osmotic imbalance. The above findings were

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supported by the reports of Garcia and Gamez *et al.* (2002), who inferred that the electrical conductivity is the main factor which can limit the supplementation of high proportion of vermicompost in the soil especially the presence of anions like chloride which should be minimized to avoid phytotoxic effects.

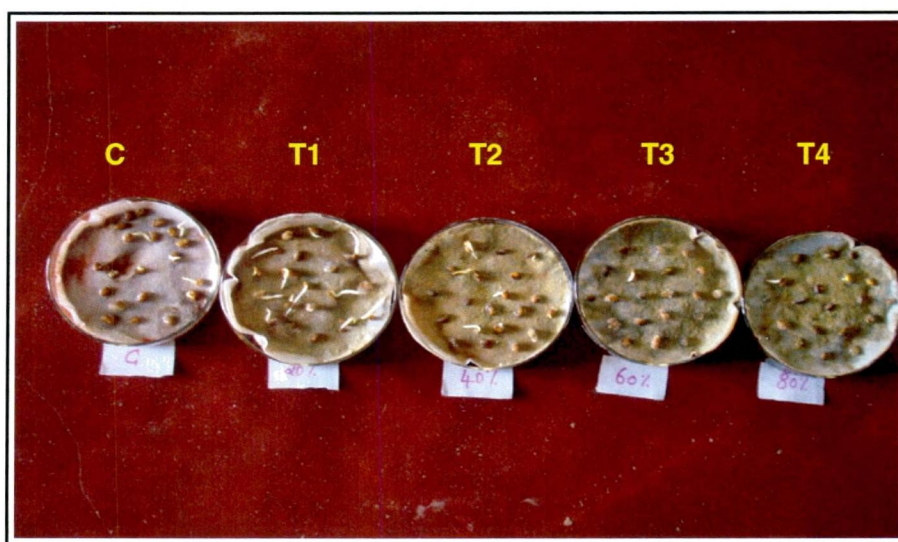
### 4.3.3 BIOMETRIC AND BIOCHEMICAL ANALYSIS OF GREEN LEAFY VEGETABLE (*Fenugreek -Trigonella foenum gracum*)

#### 4.3.3.1 Germination Index

Application of composts like vermicompost could contribute to increase in the availability of nutrients to plants (Ouedraogo *et al.*, 2001). It may also alter the germination of the seeds in vermicompost applied soil.

#### PLATE 6

#### GERMINATION INDEX OF FENUGREEK (*Trigonella foenum gracum*) GROWN IN 3:1 RATIO TAPIOCA SOLID WASTE-COW DUNG MICROBIAL VERMICOMPOST



C : Control (soil alone)

T1 : 20% microbial vermicompost,

T2 : 40% microbial vermicompost

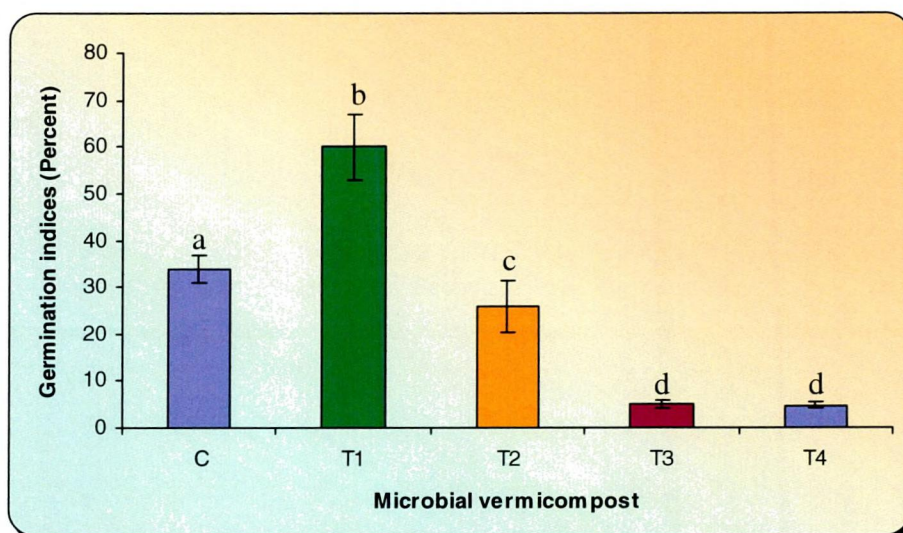
T3 : 60% microbial vermicompost

T4 : 80% microbial vermicompost

Plate 6 and Figure 10 present the germination indices of fenugreek plants grown in soil supplemented with various proportions (20 percent -T1, 40 percent-

T2, 60 percent -T3 and 80 percent -T4) of the 3:1 ratio tapioca solid waste - cow dung microbial vermicompost (M+V).

**FIGURE 10**  
**GERMINATION INDEX (percent) OF FENUGREEK**  
**(*Trigonella foenum gracum*) SEEDS**



Values are expressed as mean  $\pm$  SD for triplicates

Similar alphabets on vertical bars indicate that the respective groups do not differ significantly at  $p < 0.05$  (DMRT)

**C** : Control (soil alone)

**T1** : 20% microbial vermicompost,    **T2** : 40% microbial vermicompost

**T3** : 60% microbial vermicompost    **T4** : 80% microbial vermicompost

It is clear from Plate 6 and Figure 10, that the germination indices of T1 and T2 plants were significantly ( $p < 0.05$ ) higher than the control (C), T3 and T4 plants with T1 plants giving the highest value. Similarly, the T3 and T4 samples recorded significantly ( $p < 0.05$ ) a lower germination indices, when compared to the control (C).

The results of the present study can be correlated with the reports of Joshi and Pal vig (2010), who inferred that the germination rate of white clover grown in

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20 percent cow manure vermicompost was significantly ( $p < 0.05$ ) more than that grown in control.

The highest value in T<sub>1</sub> sample might be due to the production of plant growth regulators in optimum amounts such as indole acetic acid, kinetin or gibberellins associated with humic and fulvic acid as suggested by Arancon *et al.* (2005a). On the other hand, the lowest value for T<sub>3</sub> and T<sub>4</sub> as stated by Gopal *et al.* (2010) might be due to the higher concentration of vermicompost which would have been phytotoxic to the seeds (cowpea and paddy) as it significantly ( $p < 0.05$ ) reduced the percentage of germination.

#### **4.3.3.2 Root length and Shoot length**

Alteration in root and shoot lengths of the plants grown in vermicompost applied soil might be due to the inhibition of root pathogens/soil-borne plant diseases (Perner *et al.*, 2006).

Figure 11 represents the root lengths and shoot lengths of the fenugreek plants grown in soil supplemented with various proportions (20 percent -T<sub>1</sub>, 40 percent-T<sub>2</sub>, 60 percent -T<sub>3</sub> and 80 percent -T<sub>4</sub>) of the 3:1 ratio tapioca solid waste - cow dung microbial vermicompost (M+V).

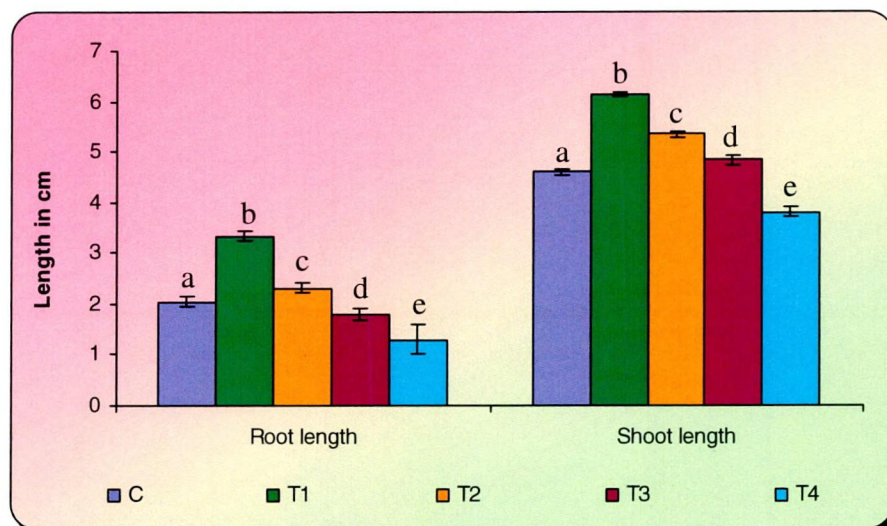
##### **Root length**

It is obvious from Figure 11 that the root lengths of the T<sub>1</sub> fenugreek plants exhibited significantly ( $p < 0.05$ ) higher values than the control (C), T<sub>2</sub>, T<sub>3</sub> and T<sub>4</sub> with the T<sub>1</sub> giving the highest value. Similarly, the values in T<sub>3</sub> and T<sub>4</sub> were significantly ( $p < 0.05$ ) lower than those of the control (C).

The above results are in accordance with the reports of Sahni *et al.* (2008) who stated that substituting of soil with 25 percent vermicompost increased the root lengths of the plants progressively when compared with those grown in soil alone. Another study justified that increase in root lengths of plants grown in T<sub>1</sub>

might be due to the supply of nutrients mainly as minerals through the application of small proportion (10-20 percent) of vermicompost (Atiyeh *et al.*, 2000a).

**FIGURE 11**  
**ROOT LENGTH AND SHOOT LENGTH OF FENUGREEK**  
**(*Trigonella foenum gracum*) PLANT**



Values are expressed as mean  $\pm$  SD for triplicates

Similar alphabets on vertical bars indicate that the respective groups do not differ significantly at  $p < 0.05$  (DMRT)

**C** : Control (soil alone)

**T1** : 20% microbial vermicompost,

**T2** : 40% microbial vermicompost

**T3** : 60% microbial vermicompost

**T4** : 80% microbial vermicompost

In the present study, the lowest values in T3 and T4 samples when compared to the control (C) and other treatments is supported by the reports of Chamani *et al.* (2008), who stated that a high proportion of pig manure vermicompost application reduces the growth of plants.

### Shoot length

From Figure 11, it can be observed that the fenugreek plants grown in T1, T2 and T3 represents significantly ( $p < 0.05$ ) higher shoot lengths than those grown in control (C) and T4, with the T1 exhibiting the highest value.

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The present study showing the maximum shoot lengths in T1 plants was supported by the report of Arancon *et al.* (2008), who stated that increase in shoot length in response to vermicompost supplementation was much greater at lower concentration.

The findings that, T4 gave the lowest shoot length is on par with the study of Atiyeh, *et al.* (2001b), who stated that high concentration of soluble salts, poor porosity and poor aeration in the vermicompost inhibits plant growth.

#### **4.3.3.3 Root fresh and root dry weights**

Vermicompost application enhances the physical and chemical characteristics of soil. This leads to an excellent increase in different morphological parameters of plants (Alam *et al.*, 2007). So determination of fresh and dry weights of plant roots helps in assessing the effect of compost on plant morphological parameters.

Figure 12 expresses the root fresh and dry weights of fenugreek plants grown in soil supplemented with various proportions (20 percent -T1, 40 percent-T2, 60 percent -T3 and 80 percent -T4) of the 3:1 ratio tapioca solid waste-cow dung microbial vermicompost (M+V).

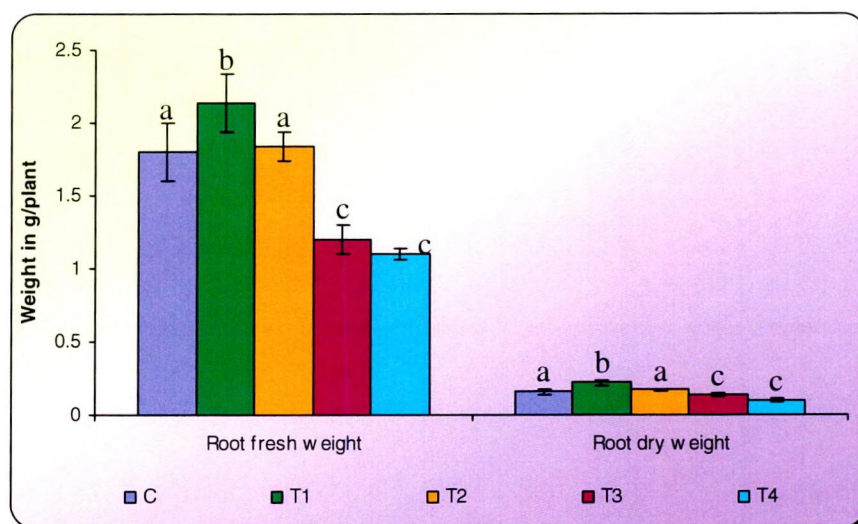
#### **Root fresh weight**

It is clearly understood From Figure 12, that the root fresh weights of T1 plants were significantly ( $p < 0.05$ ) higher than those of the control (C) and all other plants. However, the values of T3 and T4 were significantly ( $p < 0.05$ ) lower than the values of the control (C) with the T4 expressing the lowest root fresh weight.

In the above study, the highest value for root fresh weights of T1 plants is supported by the findings of Quaggiotti *et al.* (2004), who emphasized that in the

vermicompost, the association of bioactive substances with low molecular weight fraction of humic acid changes the morphology and physiology of the plants.

**FIGURE 12**  
**ROOT FRESH WEIGHT AND ROOT DRY WEIGHT OF FENUGREEK (*Trigonella foenum gracum*) PLANT**



Values are expressed as mean  $\pm$  SD for triplicates

Similar alphabets on vertical bars indicate that the respective groups do not differ significantly at  $p < 0.05$  (DMRT)

**C** : Control (soil alone)

**T1** : 20% microbial vermicompost, **T2** : 40% microbial vermicompost

**T3** : 60% microbial vermicompost **T4** : 80% microbial vermicompost

### Root dry weight

From Figure 12, it is clear that the root dry weights of T1 fenugreek plants were significantly ( $p < 0.05$ ) higher than those of the control (C) and all other treatments. The values in T3 and T4 were significantly lower than that of the control (C). Among all the treatments and the control (C), the plants grown in T4 revealed the lowest value.

The finding that maximum root dry weight was revealed by the T1 sample is in accordance with the results of Marinari *et al.* (2000), who reported

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that the use of organic amendments like vermicompost is effective in improving aggregation, structure, fertility, moisture-holding capacity and cation exchange capacity of the soils that promote crop yields.

The reduction in dry shoot weights of plants grown in T4 is supported by the findings of Jordao *et al.* (2006), who mentioned that application of 60 percent and 80 percent vermicompost to plants results in high metal concentration which may pose problems.

#### **4.3.3.4 Shoot fresh and dry weights**

Vermicompost application enhances physical and chemical characteristics of soil (Edwards *et al.*, 2000). It leads to changes in the fresh weight and dry weight of plant shoots.

Figure 13 depicts the shoot fresh and dry weights of the fenugreek plants grown in soil supplemented with various proportions (20 percent -T1, 40 percent-T2, 60 percent -T3 and 80 percent -T4) of the 3:1 ratio tapioca solid waste - cow dung microbial vermicompost (M+V).

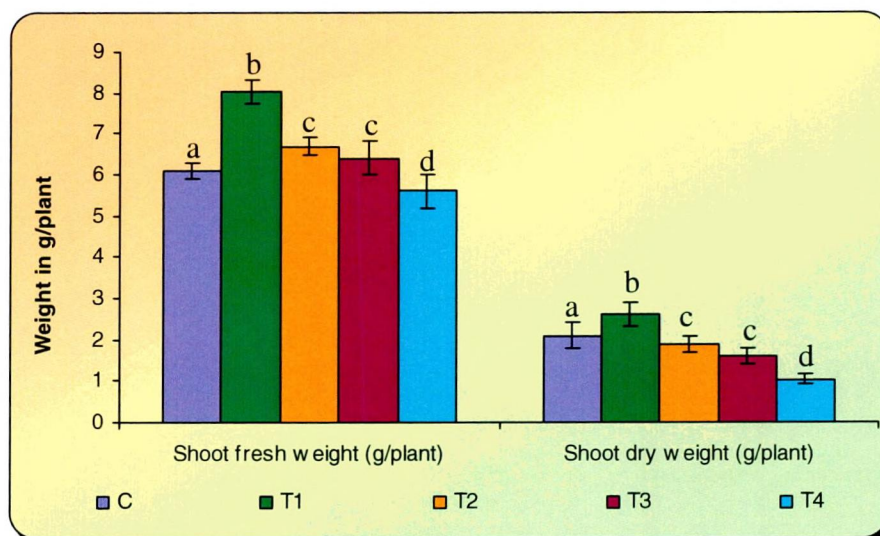
#### **Shoot fresh weight**

From Figure 13, it is clearly understood that the plants grown in T1, T2 and T3 plants exhibited significantly ( $p < 0.05$ ) higher fresh weights when compared to control (C) and T4. On comparing T1, T2 and T3, the T1 samples expressed the highest value. Similarly, the T4 plants expressed significantly ( $p < 0.05$ ) lower fresh weights than the control (C) and other plants.

The finding that maximum fresh weight is shown by T<sub>1</sub> plants is in agreement with the reports of Zaller (2007), who concluded that application of vermicompost consisting of an amalgamate of humified earthworm faeces and organic matter can stimulate plant growth.

FIGURE 13

SHOOT FRESH WEIGHT AND SHOOT DRY WEIGHT OF FENUGREEK (*Trigonella foenum gracum*) PLANT



Values are expressed as mean  $\pm$  SD for triplicates

Similar alphabets on vertical bars indicate that the respective groups do not differ significantly at  $p < 0.05$  (DMRT)

C : Control (soil alone)

T1 : 20% microbial vermicompost,

T2 : 40% microbial vermicompost

T3 : 60% microbial vermicompost

T4 : 80% microbial vermicompost

However, the lowest fresh weight in the T4 sample in the above observation is in accordance with the work of Arancon *et al.* (2005b), who stated that the lower growth rates in response to large substitution of vermicomposts could be attributed to higher electrical conductivity.

### Shoot dry weight

It is clearly understood from Figure 13 that the shoot dry weight was significantly ( $p < 0.05$ ) high in T1, when compared to control and all other treatments. The values in T2, T3 and T4 were significantly lower than those in control (C) and T1 with the T4 revealing significantly ( $p < 0.05$ ) the lowest shoot dry weight.

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## PLATE 7

### GROWTH OF FENUGREEK (*Trigonella foenum gracum*) PLANT IN 3:1 RATIO TSW-CD MICROBIAL VERMICOMPOST ON THE 10<sup>TH</sup> DAY



C : Control (soil alone)

T1 : 20% microbial vermicompost,

T2 : 40% microbial vermicompost

T3 : 60% microbial vermicompost

T4 : 80% microbial vermicompost

The above results showing maximum dry weight of shoots in T1 treatment might be due to the impressive effects of vermicompost on germination, growth, flowering, fruiting and yield of the crops. These results are supported by the finding of Shukla and Singh (2010), who stated that the shoot dry weight of white clover supplemented with low concentration of vermicompost was significantly ( $p < 0.05$ ) greater than that of the control (C).

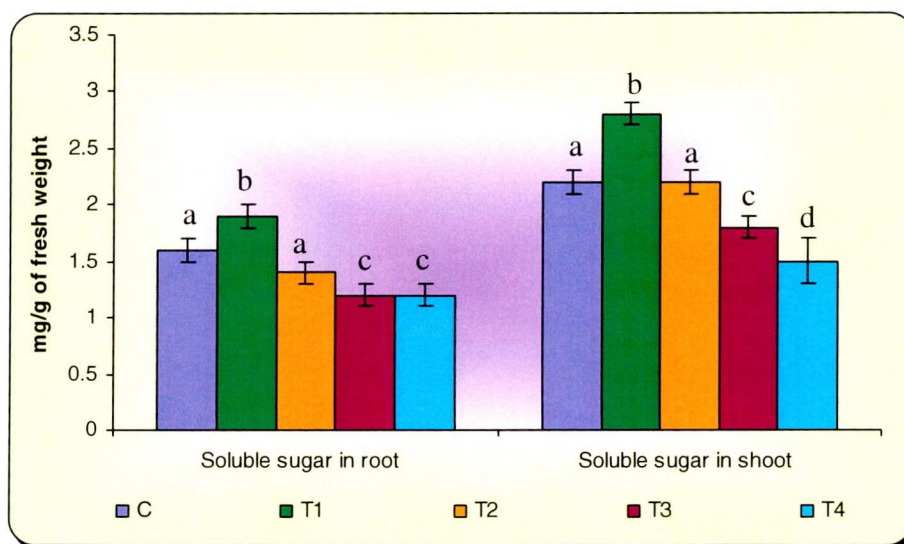
The above finding of decreased shoot dry weights in T2, T3 and T4 treatments is similar to the findings of Scheuerell and Mahaffee (2004), who inferred that low plant growth might have been due to the undesirable effects of high doses of vermicompost.

#### 4.3.3.5 Soluble sugar content of root and shoot

Application of vermicompost improves soil fertility and physical properties. It causes an alteration in the sugar contents of both roots and shoots of plant (Zheljazkov and Warman, 2004).

Figure 14 shows the soluble sugar levels in the roots and shoots of fenugreek plants grown in soil supplemented with various proportions (20 percent -T1, 40 percent-T2, 60 percent -T3 and 80 percent -T4) of 3:1 ratio tapioca solid waste –cow dung microbial vermicompost (M+V).

**FIGURE 14**  
**SOLUBLE SUGAR CONTENTS OF ROOT AND SHOOT OF FENUGREEK (*Trigonella foenum gracum*) PLANT**



Values are expressed as mean  $\pm$  SD for triplicates

Similar alphabets on vertical bars indicate that the respective groups do not differ significantly at  $p < 0.05$  (DMRT)

**C** : Control (soil alone)

**T1** : 20% microbial vermicompost,

**T2** : 40% microbial vermicompost

**T3** : 60% microbial vermicompost

**T4** : 80% microbial vermicompost

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From the results of Figure 14, it is clear that the soluble sugar levels in the shoots and roots of fenugreek plants were significantly ( $p < 0.05$ ) high in the T1 sample. Likewise, the value in T2 sample was significantly higher than in the T3 and T4 samples. On the contrary, the soluble sugar contents of the plants grown in T3 and T4 were significantly lower than those grown in control (C), T1 and T2.

The finding that the soluble sugar levels in the shoots and roots of fenugreek plants grown in T1 sample increased is in agreement with the reports of Deshpande and Devasenapathy (2010), who stated that application of green manure along with poultry manure significantly increased the grain and straw yield of rice and also the total carbohydrate content.

The low soluble sugar levels in the T2, T3 and T4 revealed the undesirable effect of compost on plant growth. This finding was supported by Hendawy (2008), who mentioned that application of high amounts of vermicomposted tea significantly decreased the total carbohydrate content of *Plantago arenaria* (Bhumichakkarai kilangu in Tamil) plant.

#### **4.3.3.6 Protein content of root and shoot**

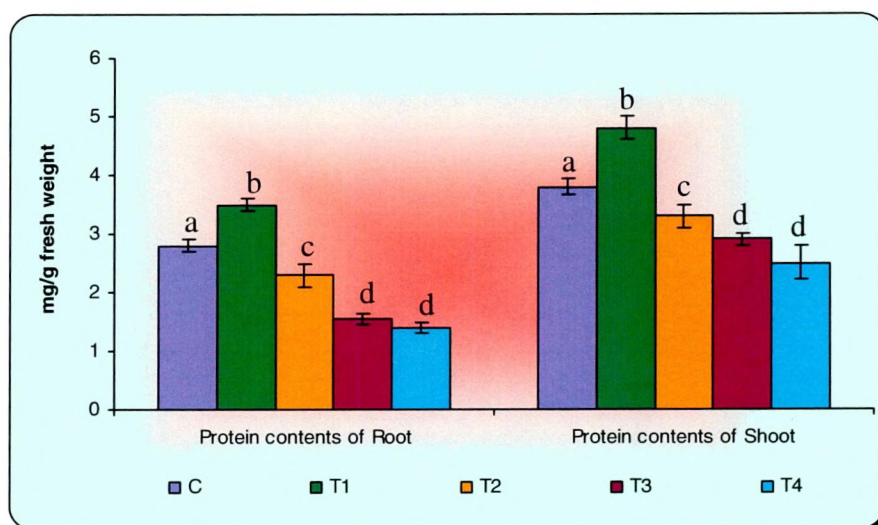
Application of vermicompost to soil enhances crop yield, protein content and other nutrient contents, and nutrient uptake by plants (Roberts *et al.*, 2007).

Figure 15 presents the protein contents of the fenugreek plants grown in soil supplemented with various proportions (20 percent -T1, 40 percent-T2, 60 percent -T3 and 80 percent -T4) of the 3:1 ratio tapioca solid waste – cow dung microbial vermicompost (M+V).

From Figure-15, it is clear that the protein contents in both the shoots and roots were significantly ( $p < 0.05$ ) higher in T1 when compared to the control (C) and other treatments. The values in T2, T3 and T4 samples were significantly lower than in the control (C).

**FIGURE 15**

**PROTEIN CONTENT OF ROOT AND SHOOT OF FENUGREEK  
(*Trigonella foenum gracum*) PLANT**



Values are expressed as mean  $\pm$  SD for triplicates

Similar alphabets on vertical bars indicate that the respective groups do not differ significantly at  $p < 0.05$  (DMRT)

C : Control (soil alone)

T1 : 20% microbial vermicompost, T2 : 40% microbial vermicompost

T3 : 60% microbial vermicompost T4 : 80% microbial vermicompost

Thus, the results of the present study agrees with the reports of Quaggiotti *et al.* (2004), who inferred that the highest protein content in both shoots and roots might be due to the presence of bioactive substances associated with the low molecular weight fraction of humic acids capable of inducing changes in plant morphology and physiology.

Similarly, the low protein content in T2, T3 and T4 might be due to the phytotoxic effects of the high concentration of vermicompost. These results are in accordance with the reports of Lazcano *et al.* (2010), who inferred that application of high doses of vermicompost in soil decreases the biomass of both roots and shoots.

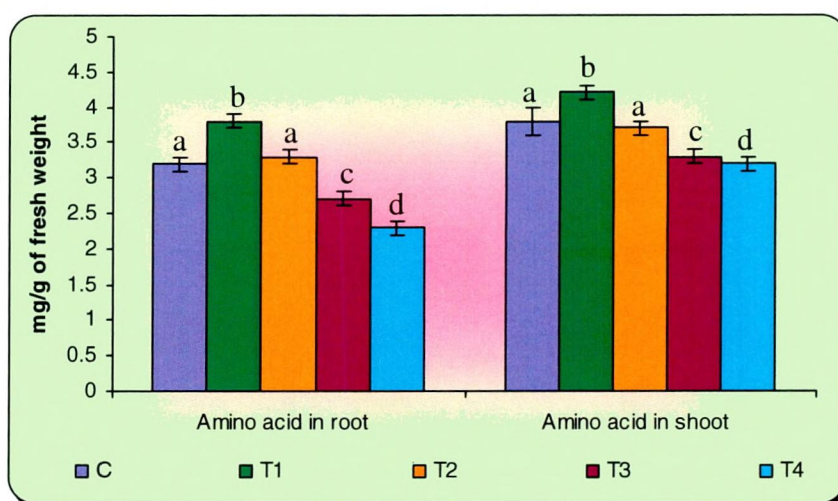
#### 4.3.3.7 Amino acid content of root and shoot

Vermicomposting is known to change the amino acid contents of plants, Hence analysis of amino acid content was done.

Figure 16 displays the amino acid levels in the roots and shoots of the fenugreek plants grown in the soil supplemented with various proportions (20 percent -T1, 40 percent-T2, 60 percent -T3 and 80 percent -T4) of the 3:1 ratio microbial vermicompost (M+V).

**FIGURE 16**

#### **AMINO ACID CONTENT OF ROOT AND SHOOT OF FENUGREEK (*Trigonella foenum gracum*) PLANT**



Values are expressed as mean  $\pm$  SD for triplicates

Similar alphabets on vertical bars indicate that the respective groups do not differ significantly at  $p < 0.05$  (DMRT)

**C** : Control (soil alone)

**T1** : 20% microbial vermicompost, **T2** : 40% microbial vermicompost

**T3** : 60% microbial vermicompost **T4** : 80% microbial vermicompost

It is obvious from Figure 16 that the shoots and roots of T1 fenugreek plants expressed significantly ( $p < 0.05$ ) higher levels of amino acids when compared to the control (C) and other treatment plants. The values of T2, T3 and

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T4 samples were significantly ( $p < 0.05$ ) lower than those of the control (C) with the T4 expressing the lowest value.

The high amino acid content in plants grown in T1 as observed in the present study may be due the presence of high plant available nutrients that perform best in promoting plant growth and yields at relatively low application rates as reported by Zaller (2007). The results were also supported by the findings of Wang *et al.* (2010), who stated that vermicompost application significantly ( $p < 0.05$ ) increased the amino acid contents of plants.

The observation that, low amino acid contents in T2, T3 and T4 plants were due to the high proportion of vermicompost in the soil. These results are in agreement with the reports of Canellas *et al.* (2002), who mentioned that application of high dosage of vermicompost leads to detrimental effects on seedling growth, probably due to the creation of adverse physical conditions in the growing media.

**Thus from the results of Phase III**, it can be concluded that application of 20%, 40%, and 60% of the 3:1 ratio tapioca solid waste: cow dung microbial vermicompost (M+V) to soil influenced the growth of black gram plants. Among the three, the 20% microbial vermicompost - supplemented soil exhibited significantly favourable levels in some of the parameters when compared to the other treatments. In the case of fenugreek plants, the growth was best in 20% microbial vermicompost supplemented soil with all the parameters recording significantly higher values.

Thus the findings of **Phase I** showed that microorganisms, earthworms and a combination of both were able to degrade efficiently the tapioca solid waste alongwith cow dung upto 3:1 ratio. It was also found that among the three treatments, utilization of microbes alongwith earthworms gave better result.

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The results of **Phase II** confirmed that a combination of microorganisms with earthworms were able to compost 3:1 ratio tapioca solid waste - cow dung mixture more efficiently than microorganisms alone and earthworms alone and forms a better way to attain compost maturity within the experimental period (75<sup>th</sup> day).

From the results of **Phase III**, it can be concluded that application of low proportion (20% 3:1 ratio tapioca solid waste - cow dung mixture) of microbial vermicompost promotes better growth of selected plants.

An outline of the findings of the present study and conclusions drawn thereof are presented in the following chapter.