INFLUENCE OF COMPOSTING METHODS ON COMPOST MATURITY AND QUALITY

By

HARSHA NARAYANAN

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Department of Agronomy

COLLEGE OF HORTICULTURE

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DECLARATION

I hereby declare that the thesis entitled **"Influence of composting methods on compost maturity and quality"** is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara

Date: 26.10.15

Harsha Narayanan

(2012-11-129)

CERTIFICATE

Certified that thesis entitled **"Influence of composting methods on compost maturity and quality"** is a bonafide record of research work done independently by Harsha Narayanan **(2012-11-129)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to her.

Vellanikkara

Date: 26-10-15

Dr. S. Anitha 26/10/15
Chairman (Advisory Committee)
Associate Professor (Agronomy)
Water Management Research Unit
Vellanikkara, Thrissur

CERTIFICATE

We, the undersigned members of the advisory committee of Harsha Narayanan (2012-11-129), a candidate for the degree of **Master of Science in Agriculture**, with major field in **Agronomy**, agree that the thesis entitled **"Influence of composting methods on compost maturity and quality"** may be submitted by Harsha Narayanan **(2012-11-129)**, in partial fulfillment of the requirement for the degree.

Dr. S. Anitha 28/10/15
(Chairman, Advisory committee)
Associate Professor (Agronomy)
Water Management Research Unit
Vellanikkara, Thrissur

Dr. P. Sreedevi 26/10/15
(Member, Advisory committee)
Professor and Head
Department of Agronomy
College of Horticulture, Vellanikkara

Dr. P. S. John 26/10/15
(Member, Advisory committee)
Professor
Department of Agronomy
College of Horticulture, Vellanikkara

Dr. P. K. Sushama 26/10/15
(Member, Advisory committee)
Professor and Head
Department of Soil Science and Agricultural Chemistry
College of Horticulture, Vellanikkara

Dr. D. Girija 26-10-15
(Member, Advisory committee)
Professor and Head
Department of Agricultural Microbiology
College of Horticulture, Vellanikkara

EXTERNAL EXAMINER
Dr. S. P. Halagalimath.
Agronomist, IWMRC,
University of Agril. Sciences.
Dharwad.

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To My Parents

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Introduction

1. INTRODUCTION

Compost can be defined as a humified organic matter produced via biologically-mediated oxidative processes, and is one of the most commonly used organic amendments in agriculture. Composting has been recognized not only as a promising attempt for processing and disposal for biodegradable solid waste but an absolute imperative for nutrient recycling and soil improvement in an agricultural economy. Composting has capacity of reducing the volume and weight of crop residual waste by approximately five percent and resulting in a stable product called 'compost' which can be used as a nutrient source for crop production (He *et al.*, 2009). Recently new methods have been developed for speedy composting and also utilize certain microbes as a substitute for cowdung for initiating the microbial decomposition. Effective microorganisms, trichoderma and microbial culture are utilized for substituting cowdung owing to its decreased availability. Vermicomposting is a well established method for composting but need more efforts from the part of composter.

Though different methods of composting have been developed, none of the methods have been tested frequently for its maturity and stability at frequent intervals. Iqbal *et al.* (2012) reported that composting methods differ in duration of decomposition and potency of stability and maturity and the compost prepared by different methods yield chemically different products. One of the important factors affecting the successful use of compost for agricultural purpose is compost maturity. The application of immature compost to the soil causes severe damage to plant growth (Wu *et al.*, 2000).

Maturity is assessed by measuring various physico-chemical parameters, seedling emergence, root elongation and phytotoxicity (Mathur *et al.*, 1993). Seal *et al.* (2012) opined that presence of a very large and diverse population of self-generated microorganisms in the end product of compost indicated its potential in terms of fast and effective soil application.

Although the practical applicability and benefits of composting methods are widely known, there has been very limited effort towards scientific documentation and evaluation of the biodegradation process, along with quality evaluation of its end product and soil application efficiency. Compost obtained from many of the rapid methods is found to be coarser and need to be evaluated for maturity and quality prior to its agricultural use. Hence it is highly essential to study the influence of various composting methods on its end product quality, particularly in terms of its stability and maturity status and to evaluate whether the compost obtained from these methods can be directly used as manure. Comparative evaluation of various composting methods will be helpful for the farmers to select the best and cost effective method for composting.

The present study is proposed against this backdrop with the following objectives.

- To assess the influence of composting methods on compost maturity and quality.
- The effect of compost obtained from different composting methods on crop performance.
- Economics of composting methods.

Review of Literature

2. REVIEW OF LITERATURE

Composting methods differ in duration of decomposition and potency of stability and maturity and compost obtained from different methods differ in physical and chemical parameters. Research results available on parameters of compost maturity and quality, influence of composting methods on physical, chemical and biological parameters of compost and effect of compost on crop productivity are reviewed in this chapter.

2.1. Enrichment of compost

In order to prepare speedy and quality compost, certain enrichment materials need to be added to the compost. According to Gaur (1987), the best systematic approach of composting procedure is when crop residue and animal dung are layered in the pit and turned twice during decomposition. Enrichment of cattle dung compost with rock phosphate, micronutrient, *Bacillus* spp. *Azotobacter*, composting culture, effective microorganisms and earthworms resulted in significant decrease in organic carbon and C:N ratio at both 60 and 120 days of composting (Battikopad *et al.*, 2009). The authors also reported that inoculation with *Azotobacter* at 30 and 60 days of composting increased NH_4^+, NO_3^- and total nitrogen content and decreased water soluble phosphorus and C:N ratio, whereas the inoculation done at the start of composting had no effect. Rock phosphate enrichment accelerated decomposition, conserved nitrogen and improved nitrogen mineralization. Thakur *et al.* (1998) observed that phosphorus from rock phosphate was solubilized during composting and transformed into available forms. Though different enrichment increased the activity of certain organisms, certain abiotic parameters slowed down the composting process. Immature cattle manure harbored high number of active bacteria (El-Shinnawi *et al.*, 1988).

2.2. Compost stability and maturity

Compost stability and compost maturity are important factors affecting the successful use of compost as organic manure. Iannotti *et al.* (1993) reported compost stability as the degree or rate of decomposition of organic matter. It was also reported that the stability of compost could be expressed as a function of microbiological activity, and was determined by O_2 uptake rate, CO_2 production rate or by the heat released as a result of microbial activity (Chen and Inbar, 1993).

Hoitink *et al.* (1997) reported that compost stability is crucial for disease suppressive applications. According to Lasaridi and Stentiford (1998) compost stability increased with age for all composts. They also reported that a single test is inadequate for assessing compost maturity. Zucconi *et al.* (1981) and Iannotti *et al.* (1993) reported that maturity of compost referred to the degree of decomposition of phytotoxic organic substances produced during the active composting stage and could be assessed by plant or seed testing. Furthermore, Wu *et al.* (2000) reported that compost stability and maturity depended on the chemical constituents present in the compost feed stock as well as those present in different stages of composting. According to Forster *et al.* (1993), immature compost inhibited germination. They found that root length is reduced with the application of immature compost due to the production of water-soluble phytotoxic compounds into the growth medium. According to Barker (1997), plant growth is promoted due to the application of mature compost, because a part of its nitrogen is available to plants as NO_3^-. Hue and Liu (1995) reported strong demand for oxygen and high carbondioxide production rates in immature compost due to the intense development of microorganisms. They found that it was as a consequence of the abundance of easily biodegradable compounds in the raw material.

2.3. Compost maturity and stability parameters

The principal requirement of compost for it to be safely added to soil is compost stability and compost maturity. Iannotti *et al.*, (1993) related compost stability with microbial activity and maturity with plant growth potential. Zucconi *et al.* (1981) reported that both stability and maturity go hand in hand since phytotoxic compounds are produced by microorganisms in unstable compost. Physical parameters such as colour, odour and temperature give general information on decomposition stage, but little information on degree of maturation. As a result of this, chemical parameters such as cation exchange capacity, C:N ratio, total volatile solids etc are widely used.

2.3.1. Physical parameters of compost maturity and stability

Temperature

Temperature is one of the key indicator in composting. It depends primarily on heat produced by microorganisms and its loss by aeration and surface cooling.

Joshua *et al.* (1998) reported temperature as an important environmental variable in composting efficiency. Compost temperature is a key parameter controlling degradation rate. The temperature in the compost heap was found to increase during the first few days, remain between 60°C and 70°C and then decreased gradually to a constant temperature (Golueke, 1992). Decomposition was completed when temperature in the pile drops to the temperature of the surroundings (Abu Zahra *et al.*, 2014). Compost is matured even when the temperature remains more or less constant and does not vary with turning over of the pile (Stickelberger, 1975). Finstein *et al.* (1986) reported the importance of achievement of minimum temperature levels for composting process. Minimum temperature contributed substantially to high rates of decomposition. According to Taiwo and Oso (2003), small heaps generate low temperature and large heaps lead to high temperature.

Moisture

Moisture content and aeration are two interdependent factors in composting. If the composting material is too dry, biological activity will be slow. Compost organisms need water to live. Some microorganisms use the film of water to move slipping and sliding to another section of the pile. An initial moisture content of around 75 percent under 0.6 bar can be considered as being suitable for efficient composting of organic fraction of municipal solid waste (Makan *et al.*, 2013). It has been noted that biological activity stopped as the pile dries out. If adequately aerated, composting material with moisture content between 30 percent and 100 percent will be aerobic. In practical aerobic composting, high moisture content must be avoided because water displaces air from the interstices between the particles causing anaerobic conditions. However, too low moisture content deprives organisms of water needed for their metabolism and inhibits their activity. Bertoldi *et al.* (1983) reported very low moisture content values caused early dehydration during composting and arrested the biological process and resulted in physically stable but biologically unstable compost. If anaerobic composting is practiced, the maximum moisture content is not as important since oxygen maintenance is not a factor. According to Tiquia *et al.* (1998), 50-60 percent moisture content is suitable for efficient composting. The upper limit of moisture, which may be from 80 percent to over 90 percent is the amount of which excessive drainage from the compost will be produced.

For composting organic waste, relatively high moisture contents are better at achieving higher temperature and retaining them for longer period. Moisture content affected the pattern of temperature change and microbial activities during composting of spent litter (Tiquia *et al.,* 1996). Optimum moisture content varies for different compost mixtures ranging from 50 to 70 percent on wet basis. The biodegradation rate was found to reduce whenever operated outside the optimum range.

Aeration

According to Van der Werf and Ormseth (1997) aeration is one of the most important factor in composting, as it is basically an aerobic transformation of organic matter where O_2 is consumed, and gaseous H_2O and CO_2 are produced. Forced aeration increased decomposition rate by removal of heat and promoted maximum microbial activity (Stentiford *et al.*, 1985; Bernal *et al.*, 1998). Lopez *et al.* (2002) reported wide increase in humification ratio due to high aeration rates after 60 days in biotransformation of lignocellulosic wastes by white rot fungi (*Phanerochaete chrysosporium).* According to De Bertoldi *et al.* (1983), all materials must be rotated into the interior and exposed to higher temperatures within the compost pile. Tiquia and Tam (2002) reported that oxygen transformation was necessary for the growth of aerobic organisms.

Colour and Odour

Odour and colour are too subjective to provide accurate assessment of stability. Garcia *et al.* (1992) reported that the colour in solid samples of compost cannot be considered sufficiently reliable for determining the degree of maturity in composts. According to Sugahara *et al.* (1979), it is possible to monitor visually the gradual process of compost darkening. Colour changed from dark to grayish black on maturity (Sughara et al., 1981). Jimenez and Garcia (1989) reported that in determining the degree of darkness, it is necessary to ensure a good homogenization of the material in the compost pile since there was evidence that a variation in colour occured at different depths during composting in windrows or piles. Furthermore the problem was minimized in piles with aeration by turning. The production of lower volatile fatty acids was one of the major components causing obnoxious odour of domestic refuse (Chanyasak *et al.*, 1982).

However at the later stage, these acids show a decreasing trend. Henry and Harrison (1996) reported obnoxious odour in instable compost.

Bulk density

Bulk density affects the transportation and storage of compost. Schaub-Szabo and Leonard (1999) reported that the bulk density of compressible materials depended on the compressive load to which they were subjected. This resulted in bulk density variation within piles of such materials. Bazzoffi *et al.* (1998) reported that compost addition caused a significant increase of bulk density due to more porosity.

Volume reduction

Volume reduction is an important factor in composting. The reduction in volume depended on the type of waste and the method of composting adopted (Iyengar *et al.*, 2006). According to Dominguez *et al.* (1997), microbial activity is altered by earthworms in organic matter.

2.3.2. Chemical parameters of compost maturity and stability

pH

Compost microorganisms operate best under neutral to acidic conditions with pH in the range of 5.5 to 8.0. Beck-Friis *et al.* (2003) has reported rise in pH from 8.0 to 9.0 during successful and fully developed composting. During the initial stages of decomposition, organic acids are formed. Acidic conditions are favorable for growth of fungi and breakdown of lignin and cellulose. Anqi *et al.* (2014) reported final pH value less than 8 for composting materials of all layers in composting reactor system. As composting proceeds, the organic acids become neutralized and mature compost generally had a pH between 6.0 and 8.0. pH becomes neutral when organic acids are converted to CO_2 by microorganisms during composting (Iqbal *et al.*, 2012).

Carbon nitrogen ratio

C:N ratio is an important factor used to determine compost maturity. As decomposition progresses due to loss of carbon as carbon dioxide, the carbon content of compostable material decrease with time and nitrogen content per unit material increases. This result in decrease in C:N ratio.

Crop residues containing high C: N ratio, lignin, cellulose, and hemicellulose compounds were resistant to decompose with increase in temperature and as a result have undergone slow decomposition and mineralization (Hassan, 2013). Organic residues entering to the soil contain large amounts of carbon and comparatively small amounts of total nitrogen. The C: N ratio of organic residues added to soil depended upon the maturity of plants turned under. The older the plants, the larger will be the C: N ratio and longer will be the period of nitrate suppression (Brady, 1995). Benito *et al.* (2003) reported that C: N ratio decreased mainly during the bio oxidative phase (before day 81) due to the high decomposition of organic matter in pruning waste compost. Ndegwa and Thompson (2000) reported that a C: N ratio of 25 resulted in highest stability of the product, the best fertilizer-value of the product, and also a product with the lowest potential for environmental pollution. Bhasme *et al.* (2006) evaluated five decomposers [viz. EM Solution, Maple Orgtech, India Pvt. Ltd), EM 2 Solution, Bio decomposers (APDRC, Dr. PDKV, Akola), biodecomposers (AC, Nagpur) and biodecomposers (Bio-era technologies Pvt. Ltd) for decomposition of agricultural wastes (Wheat straw, paddy straw, pigeon pea stalks and sorghum stubbles) in laboratory and found that all treatments were effective, but EM solution was superior over all treatments and it bought down C: N ratio of crop waste from 53.86:1 to 6.17:1. and EM solution contained *Lactobacillus sp. Sterptococcus sp. Rhodopseudomonas sp. Sacharomyces sp and Propionibacterium sp.* According to Bernal *et al.* (2009), C: N ratio less than 20 is the maturity index for composts of all origin. Bustamante *et al.* (2008) reported strong degradation of organic carbon compounds at early stage of composting. Giusquiani *et al.* (1995) reported that rate of decomposition of organic matter in soil is not proportional to the amount of organic carbon added with soil. More the organic matter added, the more rapidly it disappears.

Cation Exchange Capacity

Harada and Inoko (1975) reported cation exchange capacity (CEC) as an important chemical parameter used for assessing the degree of compost maturity. He also found close correlation of cation exchange capacity with degree of decomposition of organic matter in soil as well as the degree of decomposition of plant residues and manures. Lax *et al.* (1986) reported that cation exchange capacity in organic material increased as a function of humification. This was due to the formation of carboxylic and phenolic functional groups. Garcia *et al.* (1992) revealed that numerical value of CEC is influenced by nature of initial material and found the values ranging between 41.1 and 123 cmol (p+) per kg. Bernal *et al.* (1996) reported that cation exchange capacity increased during composting. Epstein *et al.* (1976) reported that compost affect the release of nutrients to plants directly through the nutrients present in them and indirectly by their effect on cation exchange capacity. Higher cation exchange capacity in aerobic sample during active composting stage is an indication of rapid decomposition of organic matter (Iqbal *et al.*, 2012). Harada *et al.* (1981) reported CEC value greater than 60 C mol kg $^{-1}$ (on an ash-free material basis) as the minimum value needed to ensure an acceptable degree of maturity. Cation exchange capacity greater than or approximately 60 was considered as sufficiently matured for application to crops (Baca *et al.*, 1992).

Total Volatile Solids

Composting exhaust gases are characterized by high flow rates and normally low pollutant concentration, in which volatile organic compounds can be found as the major pollutants. According to Eitzer (1995), volatile organic compounds are emitted at early stage of composting. Moreover the emissions are concentrated at the tipping floors where the waste is dropped off at the shredder and at the initial active composting region where the temperature rise to normal conditions (>55°C). Kilikowska and Klimiuk (2011) reported that volatile organic compounds are significantly correlated with organic matter degradation. Muller *et al.* (2004) reported excessive aeration speed up the process of emission of volatile organic compounds. Volatile organic compounds are produced at a higher rate in early stage of composting than in the later stage (Kumar *et al.*, 2011). Pierucci *et al.* (2005) reported that most of the substances in the gaseous effluent had a hydrocarbon-like structure, mainly terpenoids.

According to Wu *et al.* (2000), total volatile solids and C: N ratio failed to follow a consistence trend in biosolid compost.

2.3.3. Biological Parameters

Microbial activity

The key parameters that can be used to elucidate the dynamics of composting process are microbial activities, numbers and biomass (Tiquia et. *al.,* 2001). Mesophilic bacteria are the dominant degraders of fresh organic waste at an early phase of composting process (Hassen *et al.*, 2001). They also reported that during the thermogenic stage (40-60°C), mesophilic organisms are partially killed or inactivated and the species diversity of thermophilic/thermotolerant bacteria, actinimycetes and fungi got dominated. Petkova and Kostov (1996) revealed that during the second month of vine twig composting, CO_2 produced, biomass carbon and the number of ammonifiers, microscopic fungi, and cellulose decomposing microorganisms were reduced indicating that the microbial indices used for assessing the compost stability are early and reliable indicators of compost maturity.

Fungal count increased in later stages of composting when substrate was predominantly cellulose and lignin, which normally occurs during the later stages of composting (De Bertoldi *et al.* 1983). Golueke (1992) reported the role of fungi which were involved in the decomposition of cellulose and lignocellulosic compounds of the compost and they provided more readily available carbon to the bacteria.

Dehydrogenase

Dehydrogenase activity has been used as a measure of overall heterotrophic microbial inhabitants in soil and compost (Tiquia *et al.*, 1996; Scheafer *et al.*, 1963). According to Shinnawi *et al.* (1988) the activity of dehydrogenase enzyme decreased during anaerobic digestion of cattle manure. They have also reported that immature cattle manure contain high count of bacteria and as the digestion preceded the bacterial number tend to decrease. Forster *et al.* (1993) reported dehydrogenase activity as an index of microbiological activity and catalyzed the oxidation of soil organic matter.

2.4. Elemental composition of compost

Adediran *et al.* (2003) reported that the nutrient concentrations varied slightly depending on type of material and to a lesser extent the method of composting. Moreover the type of organic material and the method of compost preparation are important factors that can lead to making successful compost. Vermicomposting involves bio-oxidation and stabilization of organic material by joint action of microorganisms and earthworms (Gandhi and Sundari, 2012). According to Tiquia (2003), maturation of spent pig litter compost was accompanied by a decline in total carbon, water-extractable metals, NH_4^+-N, increase in ash, (NO_3^-+NO_2^-)-N, humic acid, cation exchange capacity and elimination of phytotoxicity. Raj and Antil (2011) opined that compost maturity should be assessed by measuring two or more compost parameters, and that parameters of compost maturity need to satisfy the following threshold values: OM loss>42 percent, C:N ratio <15, GI>70 percent, CEC/TOC>1.7 and HI>30 percent. Biswas and Narayanaswamy (2006) reported that rock phosphate enriched compost had significantly higher content of total phosphorus (2.20 percent) compared to straw compost (0.37 percent) where no rock phosphate was added. Iqbal *et al.* (2012) reported lesser utilization of nitrogen in anaerobic composting. According to Atiyeh *et al.* (2002), earthworms fragment organic waste and convert the wastes into humus-like substances with a finer structure than compost with more diverse microbial activity. The authors have also reported enhanced seedling growth, fruiting and productivity by the application of vermicompost. Rao *et al.* (1996) reported increased potassium in vermicompost due to enzymatic activity in worm's gut. Joseph *et al.* (1995) reported enhanced mineralization of native phosphorus on application of organic manure at higher dose. He *et al.* (2009) observed lower amounts of Cu, Zn and Pb in compost prepared from aerobic composting of sewage sludge. Hsu and Lo (2001) reported that during composting of swine manure, the major portions of Cu, Mn, and Zn were in the organically-bound, solid particulate and organically complexed fractions respectively. Moreover metal distributions in different chemical fractions were generally independent of composting age and thus independent of respective total metal concentrations in the composts. Hsu and Lo (1998) reported that the major portions of Cu, Mn, and Zn were found in the organic, oxide and carbonate fractions respectively, regardless of their content in swine manure composts. The study also revealed that Cu in swine manure compost is primarily bound to organics.

Heavy metals

Contamination by Cd led to a much lower degree of nitrification during composting on sewage sludge contaminated with heavy metals (Garcia *et al.*, 1995). Furthermore the study revealed that contamination negatively affected phosphatase, although not β-glucosidase, which increased with the level of contamination.

2.5. Relative seed germination (%)

A positive influence on crop production is noted on application of animal manure compost due to its ability to supply nutrients to the plants. (Mc Connell *et al.,* 1993; Tam and Wong, 1995; Chen *et al.,* 1996). According to Zucconi *et al.* (1981), without stabilization, the decomposition in immature compost continues, foul odour develop and metabolites are produced which are toxic to the plants. He also reported that degree of maturity can be revealed by biological methods involving seed germination and root length. He also reported that germination index is a sensitive parameter to evaluate phytotoxicity of composts.

2.6. Soil properties and compost

According to Eghball (2002), twenty five percent of applied manure carbon and thirty six percent of applied compost carbon remained in the soil after four year of application indicating greater carbon sequestration with composted than non composted manure. According to Ouedraogo *et al.* (2001), no significant difference was observed in soil organic matter content between treatments receiving compost and no-compost. According to Mays *et al.* (1993), incorporation of compost over a two year period significantly increased moisture-holding capacity and decreased bulk density and compression strength of the soil. Moreover pH, organic matter, potassium, calcium, magnesium and zinc levels were increased by application of municipal compost. They also observed that soil and plant tissue analyses indicated potentially toxic amounts of Zn accumulated in the soil when compost were applied at rates totaling several hundred tons/ha over a few years. Scanlon *et al.* (1973) reported that addition of municipal solid waste compost increases soil pH form 2.8 to 5.8.

Terman *et al.* (1973) reported that application of large quantity of compost may contaminate the soil with heavy metals or other toxic elements and only some of these elements appeared to be absorbed by plants in larger quantity. Addition of compost to top layer of soil favour penetration of water and air significantly.

2.7. Effect of compost on crop productivity

Saviozzi *et al.* (1988) reported that organic wastes have to be transformed into a humus-like material and be sufficiently stabilized so as to avoid the adverse effects on plant growth. The combined uses of ground rock phosphate applied together with poutry manure significantly improved growth and yield of *Abelmoschus esculentus* L. Moench (Akande *et al.*, 2003). Pradeepkumar *et al.* (2011) reported that sludge compost induced earliness in flowering and improved okra yield. Compost amendment is a management option likely to enhance soil quality and crop yield as indicated by a considerable body of research (Arthur *et al.*, 2010). According to Lal (2006), decomposing organic amendments slowly release nutrients which may be taken up by plants and thus result in improved agro ecosystem productivity. Vermicompost amendments lead to increased plant growth compared to the application of compost and chemical fertilization and that this effect is constant over time (Edwards *et al.*, 2004).

Earthworm development is higher with vermicompost due to the chemical stabilization of vermicompost (Lazcano *et al.*, 2008). Earthworm activity will improve plant growth and yield (Laossi *et al.*, 2010). Vermicompost improve germination, growth, and yield of plants due to faster release of nutrients than traditional compost and production of plant growth hormones (Arancon *et al.*, 2008). The efficiency of compost-originated nitrogen uptake by plants is very low at less than 7 percent of applied nitrogen which indicated only a limited amount of the released nitrogen being transformed into a soluble form that can be taken up by plants while considerable amounts are probably emitted into the atmosphere (Jerzy *et al.*, 2014). Compost levels had a promoting influence on most of the vegetative growth parameters and accelerated essential oil accumulation and chemical constituents including total carbohydrate and photosynthetic pigments content. Addition of compost enriched with rock phosphate and microbial cultures increased the nodulation and yield of green gram (Tiwari *et al.*, 1988).

Krishnamoorthy and Vajranabhiah (1986) reported drastic increase in microbial activity in organic matter by earthworms resulting in production of significant quantities of plant growth regulators such as IAA, gibberellins and cytokinins by microorganisms. El-Ghadban *et al.* (2002) reported increased carbohydrate percentage by the application of compost.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation entitled "Influence of composting methods on compost maturity and quality" was carried out to study the effect of different composting methods on compost maturity and quality and to evaluate the suitability of compost obtained from various composting methods as organic manure. The materials and methods adopted for the study are briefly described below.

3.1. Location

The experiment was conducted at Plant Propagation and Nursery Management Unit (PPNMU), Vellanikkara, Thrissur. The station is geographically located at 10° 31' N latitude and 76°13' E longitude. The experimental site lies at an altitude of 40m above MSL. It is located 10km away from Thrissur on the northern side of NH-47.

3.1.1. Weather condition during the experimental period

The area enjoys a typical humid tropical climate. The meteorological data prevailed during the period of investigation are given in Fig. 1 and Appendix 1. The weather prevailed during the cropping period were normal. The maximum and minimum temperature recorded during the cropping period were 35.2°C and 21.0°C respectively. Relative humidity of 75.93 percent was recorded. Rainfall of about 84.8mm was distributed over 5 rainy days over the cropping growth.

3.1.2. Period of study

Different methods of composting were carried out from June 2013 to September 2013. Suitability of compost as organic manure was assessed from November 2013 to February 2014.

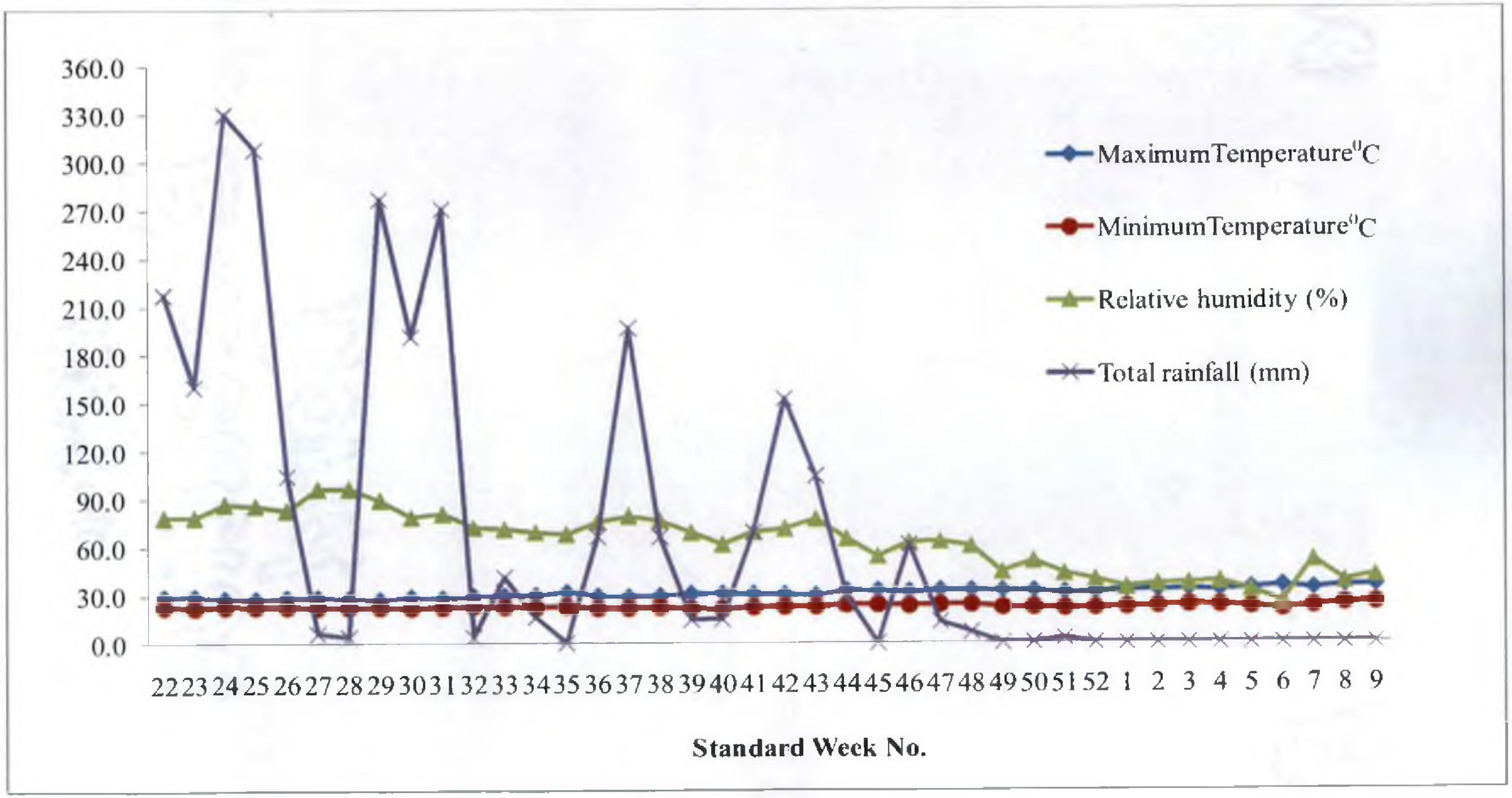


Fig. 1. Weather data during the experiment

3.2. Materials used

Experiment 1

3.2.1. Influence of different composting methods on compost maturity

Substrate for composting

Banana pseudostem both fresh and 2-5 week old and green leaves of glyricidia (2kg leaves along with 100kg pseudostem) was used as common substrates for all the methods of composting. Banana crop residues and pseudostem were collected from banana field of PPNMU and was transported to the experiment site. The pseudostem was cut into small pieces so as to facilitate faster decomposition. Glyricidia leaves were collected from the Coconut Development Farm.

Inoculum used for composting

Cowdung

Cowdung containing NPK in the range of 0.8:0.5:0.6 (%) and microbial content of 16.1 X 10^5 cfu/g were used as inoculum in aerobic composting with cowdung, vermicomposting, varariasi composting as well as heap and pit methods of composting.

Bacillus subtilis

Microbial culture of *Bacillus subtilis* developed in the Department of Agricultural Microbiology, College of Horticulture was used as inoculum in aerobic composting using *Bacillus subtilis.* The inoulum used has an initial microbial count of 13 X 10^6 cfu/ml.

ENVIRON

An EM preparation containing microbial count of 83 X 10^4cfu/g was used in composting using effective microorganisms.

The product known as ENVIRON was developed at the University of Ryukyus, Okinawa, Japan in the early 1980s. The EM product of Maple Company commonly known as MAPLE E.M.1™ ENVIRON was used for the study.

Earthworm

A composite culuture of *Eudrillus euginae* and *Isenia foetidae* was used in vermicomposting and composting using trichoderma and worms.

Trichoderma

Trichoderma containing microbial count of 2 X 10^4 cfu/g was used in composting with trichoderma and worms.

Rock phosphate

Rock phosphate containing phosphorus to the tune of 20 percewnt was used in varanasi composting method.

Varanasi composter

Varanasi composter containing microbial count of 12.5 X 10^5 cfu/g was used as inoculum in varanasi composting.

Experiment 2

3.2.2. Suitability of compost as organic manure

Seed

Bhindi variety Arka Anamika was used for the experiment. The variety is known for green fruits, 110 days duration and tolerant to BMV (Bhindi Mosaic Virus).

Potting mixture

Ordinary potting mixture for control treatment was prepared in the ratio of 1:1:1 using sand, soil and cowdung. The quantity of compost added in treatments was decided based on nitrogen content of farm yard manure.

Fertilizers

Fertilizers with following nutrient contents were used to supply NPK recommendation as per package of practice recommendation of Kerala Agriculture University (KAU).

Urea	-	46.1% N
Mussorie Rock Phosphate	-	20% P_2O_5
Muriate of Potash	-	60% K_2O

Plant protection chemicals

Rogor spray (1.5ml/L) was given to control aphids and ants as and when required.

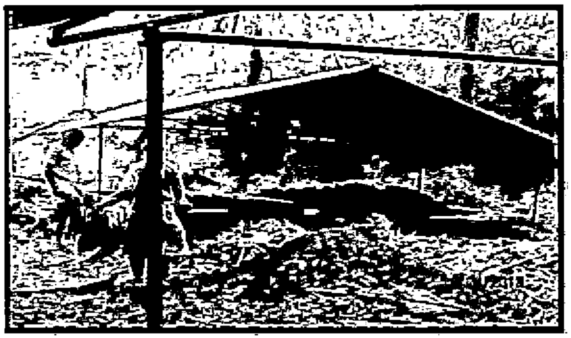
3.3. Methods

Experiment 1

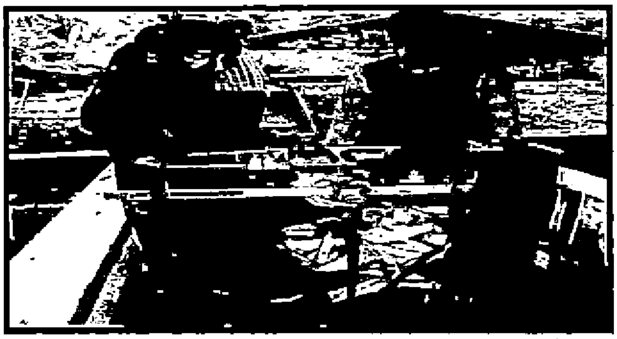
3.3.1. Influence of composting methods on compost maturity

Composting was carried out in tanks constructed in the compost sheds available at Coconut Development Farm of PPNMU (Plate No. 1 and 2). The tanks were partitioned internally using bricks. The size of the tank for each treatment was 156cm X 75cm width and 50cm height. About 100kg waste including fresh and 2-5 weeks old banana pseudostem and glyricidia leaves were added uniformly. The height of the heap was 15cm. For the development of temperature, gunny sacks were placed over the composting materials in all the composting methods except varanasi composting. The layout of experimental site is given in Fig. 2.

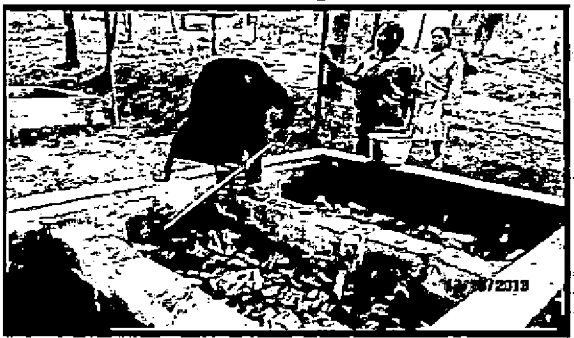
Plate 1: General view of composting site



Collection of crop residues



Weighing



Addition of residues to tanks

Harvesting

Plate 1: General view of composting site

Collection of crop residues

Weighing

Addition of residues to tanks

Harvesting

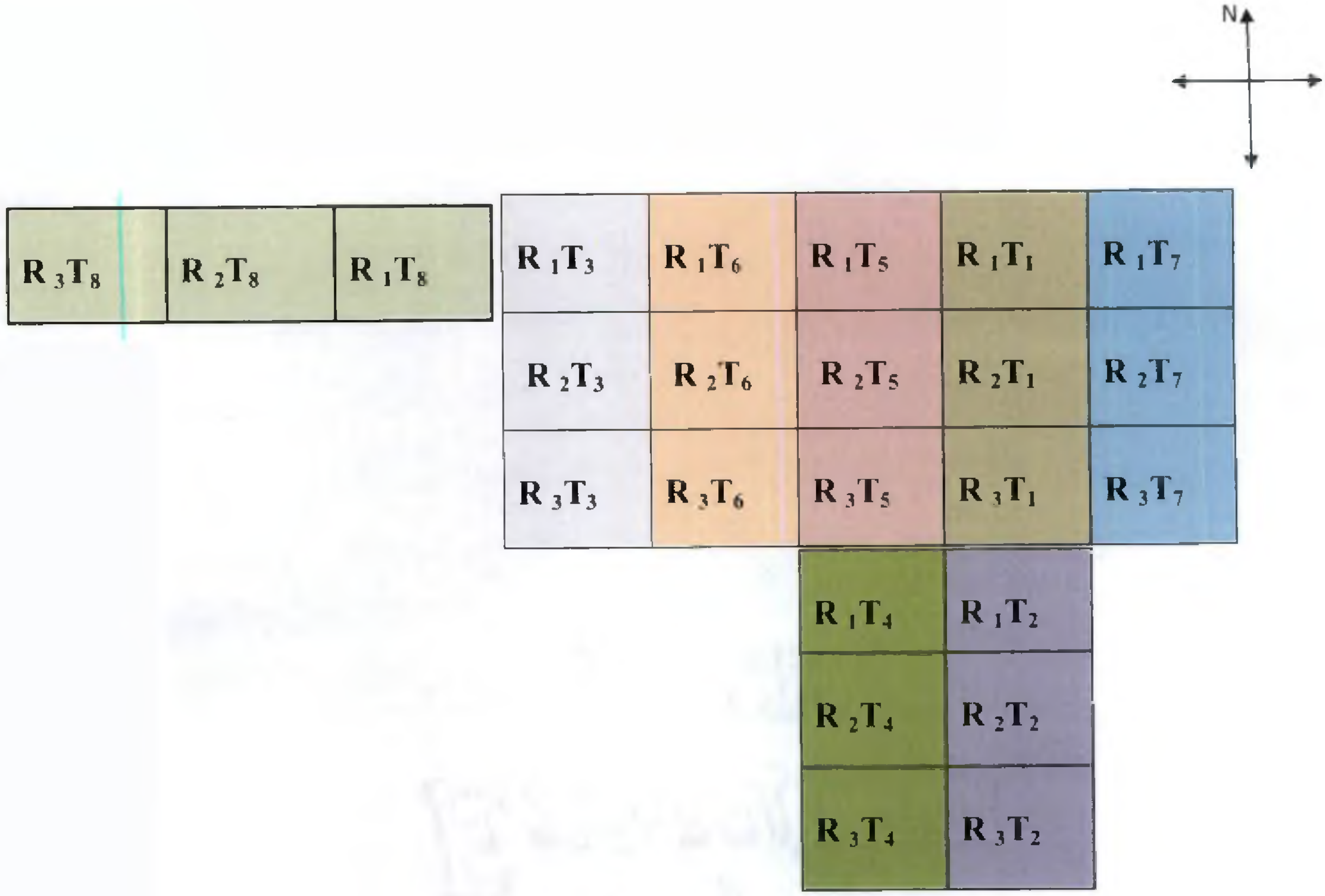


Fig. 2 Layout of experiment on different composting methods

Treatments- 8 Nos

T_1 - Aerobic composting with cowdung

T_2 - Aerobic composting with *Bacillus subtilis*

T_3 - Composting using effective microorganisms

T_4 - Composting with Trichoderma & worms

T_5 - Vermicomposting

T_6 – Varanasi composting

T_7 - Heap method

T_8 - Pit method

3.3.1.1. Aerobic composting with cowdung

Aerobic composting was carried out in tanks provided with sufficient holes for aeration. About 10kg of cowdung was added as inoculum in alternate layer with 100kg substrate. Turning was given at every two weeks interval.

3.3.1.2. Aerobic composting with *Bacillus subtilis*

Aerobic composting with *Bacillus subtilis* was carried out in tanks provided with sufficient holes for aeration and the inoculum used for composting was microbial culture of *Bacillus subtilis.* The culture of 200ml was diluted to 1litre and 300ml was sprinkled as alternate layer above the crop residues. Turning was given at two weeks interval.

3.3.1.3. Composting using effective microorganisms

Composting using effective microorganisms was carried out in tanks provided with sufficient holes for air circulation. The inoculum used was ENVIRON and 50ml was diluted to 1000ml and 300ml of which was added as alternate layers to the substrate. Turning was given at two weeks interval.

3.3.1.4. Composting using trichoderma and worms

The inoculum used in the experiment was trichoderma and composite culture of *Eudrillus euginae* and *Isenia foetidae* earthworms. Trichoderma was added at the rate of 100gm per 100kg of substrate and applied as alternate layers .The worms were introduced at the rate of 100 worms per 100kg substrate each during the first week and one month after composting. Turning was given at two weeks interval for the entire period.

3.3.1.5. Vermicomposting

The inoculum used were cowdung and culture of *Eudrillus euginae* and *Isenia foetidae* earthworms. Cowdung at the rate of 10kg per 100kg of substrate was added as alternate layers over the substrate. The worms were introduced at the rate of 100 worms per 100kg of substrate each during the first week and one month after composting. Turning was given at two weeks interval for the entire period.

3.3.1.6. Varanasi composting

UV stabilized plastic sheet obtained with varanasi compost kit was used for composting. The sheet was spread on a levelled area under compost shed. The composter at the rate of 100gm and 30kg of cowdung was added as alternate layers with 100kg substrate. Rock phosphate was sprinkled over the layer at the rate of 500gm. In this manner the heap was built upto a height of 15cm. The heap was covered fully with UV stabilized plastic sheet till the end of composting. As the heap was prepared under thatched shed, additional covering to protect the heap from direct sunlight was not required.

3.3.1.7. Heap method

Substrate (100kg) was heaped at a length of 156cm and breadth of 75cm and 15cm height over the levelled land to get the same volume as in the above treatments. About 10kg of cowdung was added as inoculum in alternate layers. No turning was given.

3.3.1.8. Pit method

The pits were taken at a dimension of 156cm X 75cm under open condition. Pits were covered with a tarpaulin sheet to protect it from direct sunlight and rainfall.

Plate 2: General view of compost tanks used for composting

The substrate (100kg) was added in the pit to a height of 15cm along with cowdung at the rate of 10kg as inoculum in alternate layer. Turning was given at two weeks interval for the entire period.

3.3.2. Phytotoxicity studies

3.3.2.1. Seed germination test using compost extract

A modified Phytotoxicity test employing seed germination was used (Zucconi *et. al.*, 1981). Tomato seeds (*Lycopersicon esculentum* L.) were used for seed germination test in compost extract. Whatman (No.2) filter paper was placed inside 90mm UV sterilized, disposable petridish. The filter paper was wetted with 9ml of 1:10 compost: water extract and 30 tomato seeds were placed on the paper. Distilled water was used as control and all the treatments were run in triplicate. The petridishes were sealed with parafilm to minimize water loss while allowing air penetration and the same were kept in the dark for four days at room temperature. At the end of fourth day, the percentage of seed germination in compost extract was noted and compared with control.

3.3.2.2. Seed germination test using potting mixture

The potting mixture was prepared in the ratio of 1:1 compost: soil and was taken in UV sterilized petridishes and 30 tomato seeds were placed in it. Soil alone was used as control. It was placed under dark and germination was noted on the fourth day and compared with that of the control (Plate No.3).

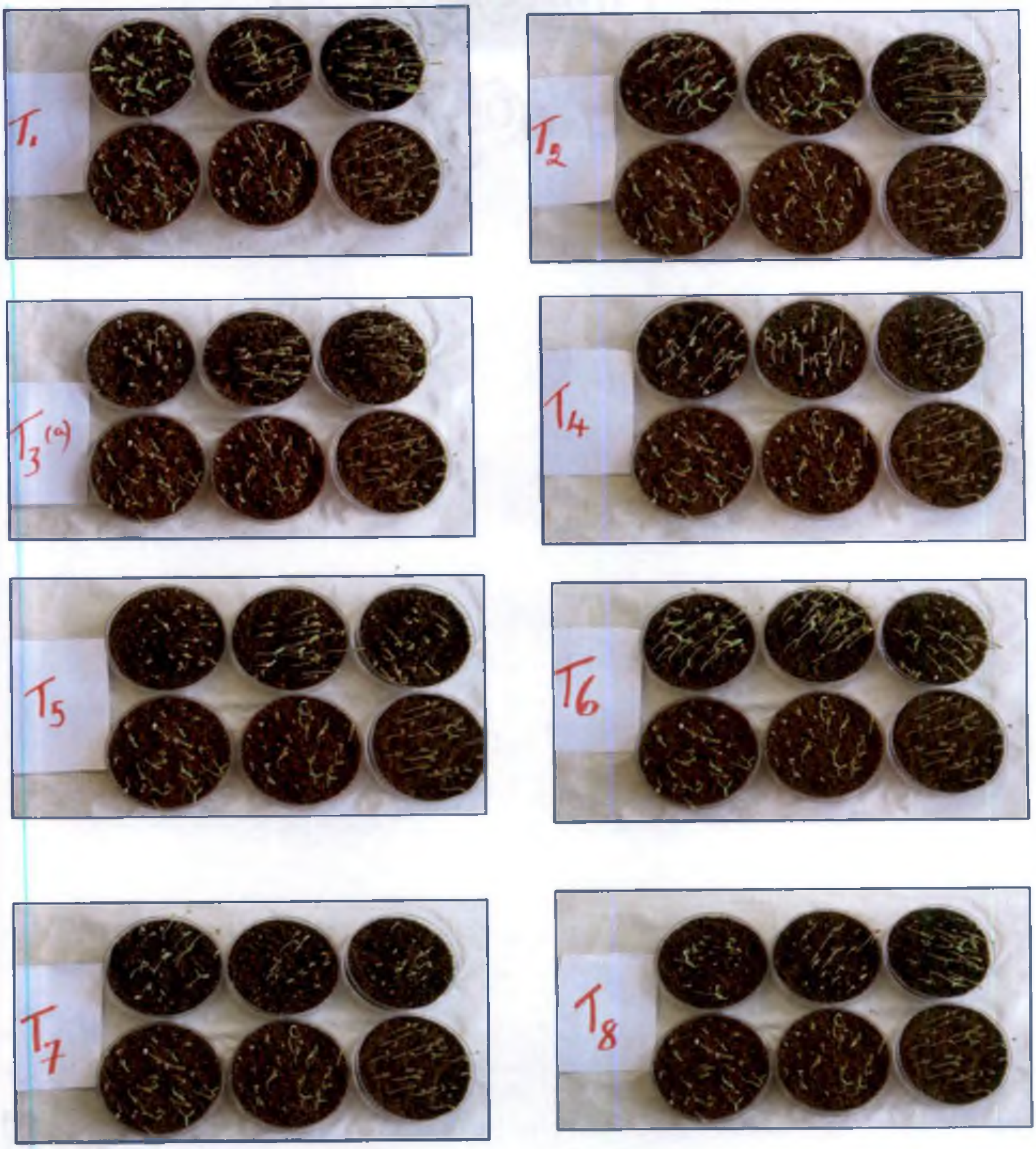
Experiment 2

3.3.3. Suitability of compost as organic manure

3.3.3.1. Design and layout

The experiment was conducted in pot culture technique. The layout of the experiment is given in Fig. 3.

Plate 3: Seed germination test using compost as potting mixture



Treatments- 9 Nos

Compost obtained from the above composting methods were tested as organic manure and the quantity of compost was decided in comparison to nitrogen content of farm yard manure and it was compared with ordinary potting mixture containing cowdung as control. The treatments are as follows.

T_1 – Ordinary potting mixture (Sand, soil and cowdung in the ratio 1:1:1)

T_2 -Aerobic composting with cow dung

T_3 - Aerobic composting with *Bacillus subtilis*

T_4 - Composting using effective microorganisms

T_5 - Composting with Trichoderma & worms

T_6 - Vermicomposting

T_7 – Varanasi composting

T_8 - Heap method

T_9 - Pit method

Design : CRD

Treatments : 9

Replications : 3

Pots/replication : 3

Crop : Bhindi

Variety : Arka Anamika

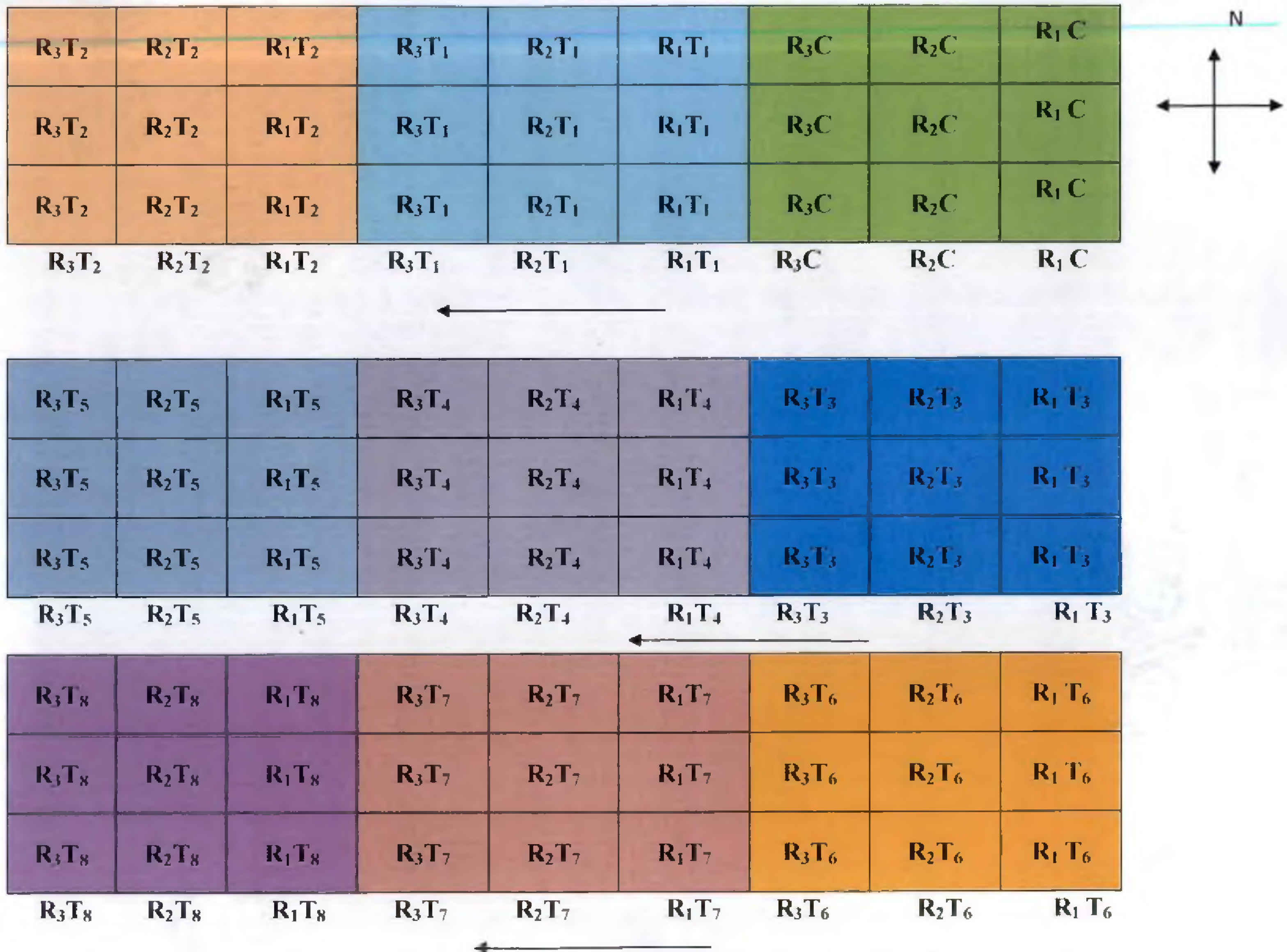


Fig. 3 Layout of pot culture experiment to study the suitability of compost as organic manure

3.3.3.2. Sowing

Sowing was done on 11th November 2013.The seeds were soaked in luke warm water for 15 minutes before sowing for uniform germination. One seed per polybag was placed in the centre of the polybag. General view of the pot culture experiment is given in plate No. 4.

3.3.3.3. Manure and fertilizer application

Recommended dose and schedule of fertilizer application are given in table 3.1

Table 3.1. Recommended dose of fertilizer and schedule of fertilizer application

Crop	Recommended dose of fertilizer (kg/ha)			Schedule of fertilizer application (g/plant)
	N	P	K	
Bhindi	50	8	25	½ N, Full P, Full K ½ N one month after planting

3.3.3.4. Compost application

The organic manure requirement of the crop was substituted by compost and the quantity was decided in comparison to nitrogen content of FYM (farm yard manure) requirement of Bhindi (12t/ha). Quantity of compost added as organic manure is given in table 3.2

Plate 4: General view of the pot culture experiment

Table 3.2. Quantity of compost added based on nitrogen equivalent basis

Treatments		Organic manure(kg/ha)
T_1	Aerobic composting with cowdung	4507
T_2	Aerobic composting with *Bacillus subtilis*	5333
T_3	Composting using EM	4120
T_4	Composting using Trichoderma and worms	5303
T_5	Vermicomposting	5818
T_6	Varanasi composting	6666
T_7	Heap method	4974
T_8	Pit method	6193
C	Farm Yard Manure	12000

3.3.3.5. Weeding

Hand weeding was performed as and when weeds were observed in the pot.

3.3.3.6. Irrigation

Pre-sowing irrigation was given. Daily irrigation was provided uniformly to all the treatments using micro sprinkler.

3.3.3.7. Harvesting

Harvesting was started from the 24th day onwards and subsequent harvest was done at 2-3 days interval depending on the fruit maturity. A total of twenty four harvests were obtained.

3.4. Observations

3.4.1. Collection of compost samples

The samples were collected from different stages of composting depending upon the temperature recorded during the stages. The nutrient content of the substrates and microbial count of inoculum were calculated as per standard procedures which are tabulated in Table. 3.3.

3.4.2. Physical parameters

Daily temperature

The temperature was recorded from three different parts of compost tank using digital thermometer in morning hours and the average of the three was taken. The data were recorded in degree centigrade.

Moisture content

Moisture was measured from three different parts of the respective method of composting and the average value was taken. Measurements were recorded using digital moisture meter during morning hours. Whenever the moisture content was found to be lower than the optimum (50%), water was sprinkled over the layers to bring back the moisture content to the required level. The moisture content was recorded in percentage.

Particle size

The matured compost samples were allowed to pass through different sieves of mesh size 5mm and 2mm. The percentage of the compost obtained was expressed as percentage.

Colour

The colour of the mature compost was recorded visually (Plate No. 5).

Volume reduction

The volume of the substrate added for composting was measured by multiplying length, breadth and height. The volume was recorded at frequent intervals of composting and the final reduction in volume was recorded as percentage with respect to the initial volume. Change of volume from the initial volume was recorded as volume reduction.

Harvest of compost

First harvesting was done on 100^{th} day when more than 90 percent of the substrate was found to be composted.

Plate 5: Mature compost obtained from different composting methods

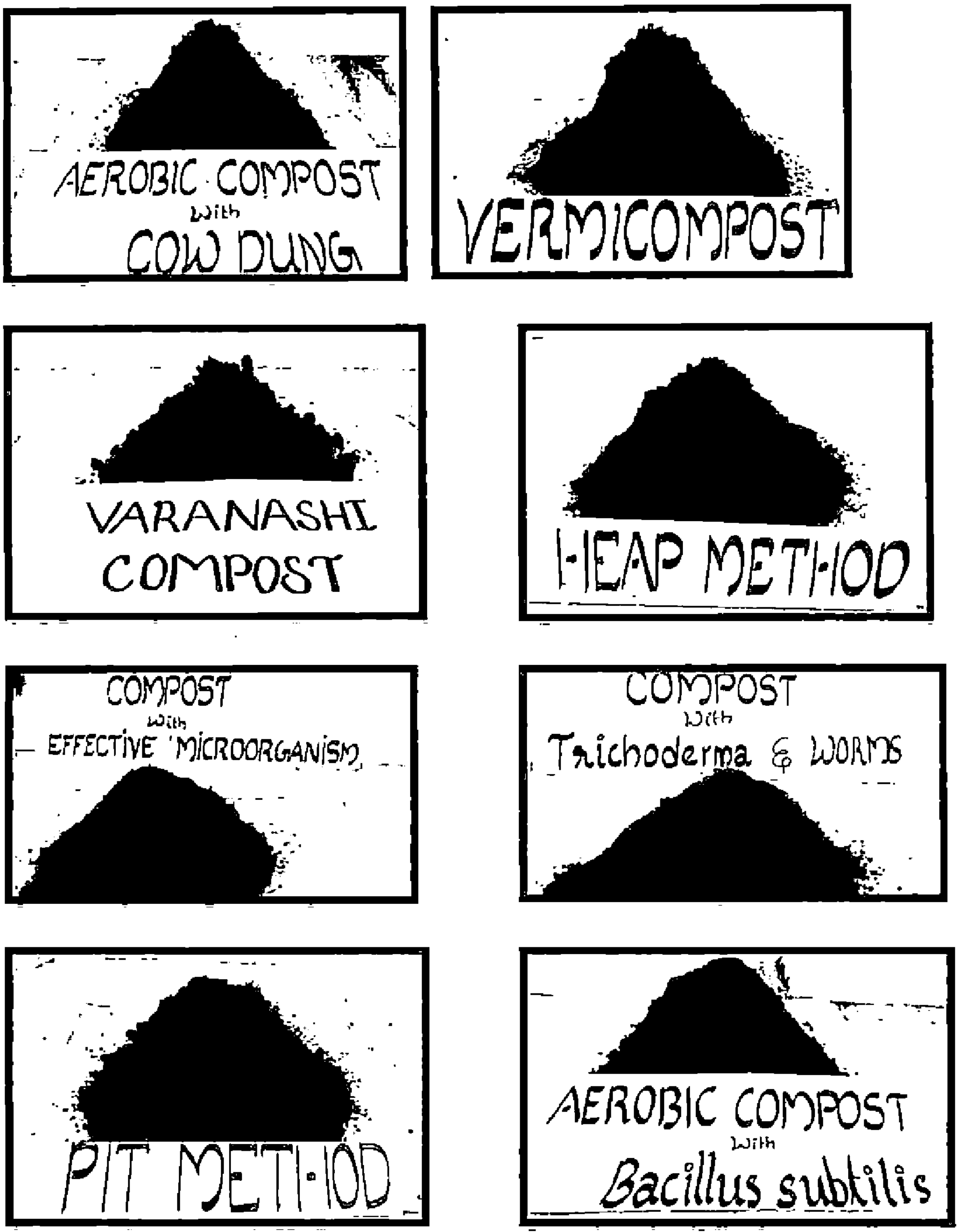
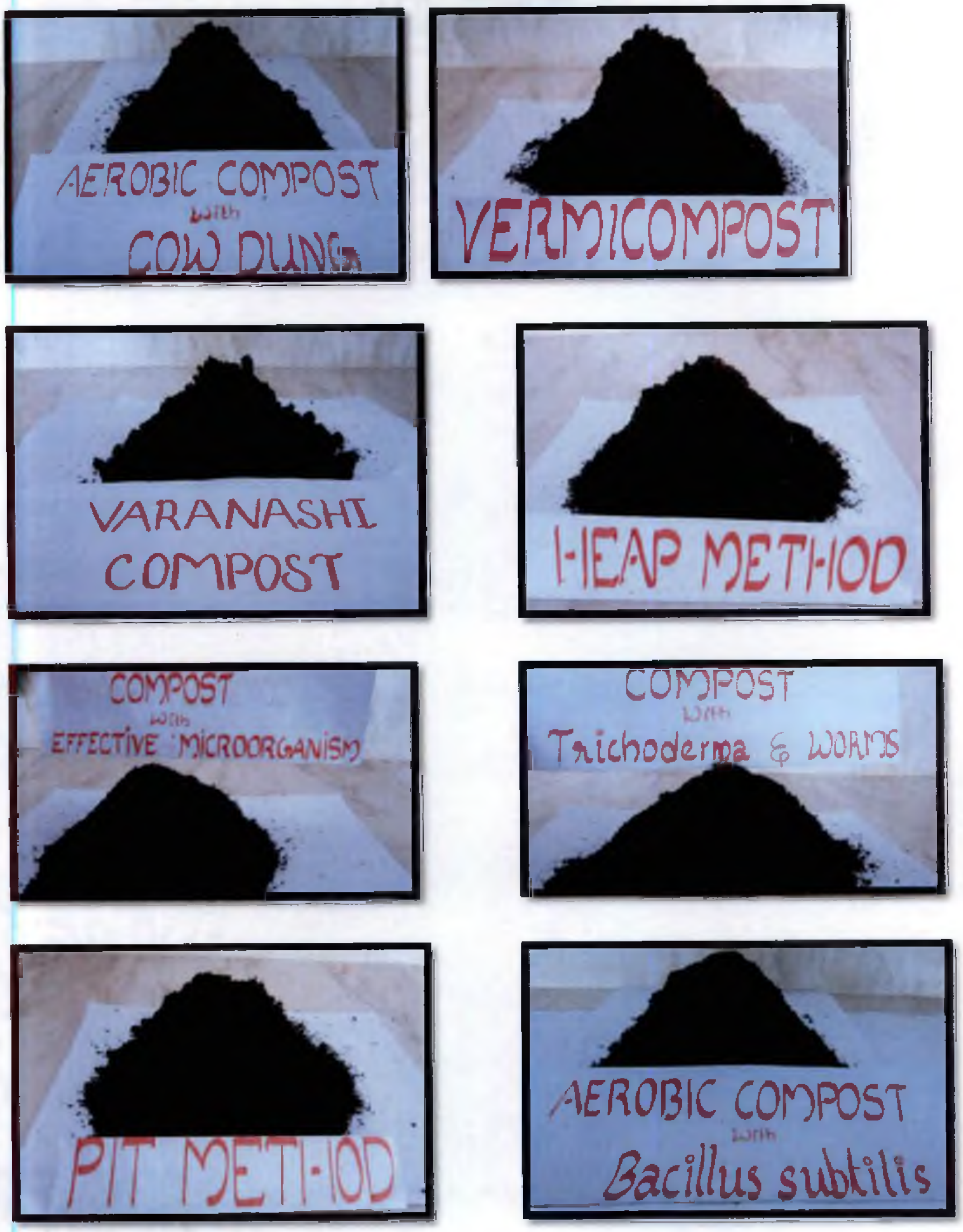


Plate 5: Mature compost obtained from different composting methods



The undecomposed residue after sieving was again heaped and covered with gunny sacks. The moisture was maintained at 60 percent of its water holding capacity and the final harvesting was done on the 114th day.

3.4.3. Chemical and biological parameters

Compost samples collected during different stages of composting were analyzed for chemical and biological parameters according to the standard procedure, the details of which are depicted in Table.3.3.

Table 3.3 Methods of compost analysis

Sl.No.	Particulars	Method	Reference
1	Temperature	Digital thermometer	FCO, 1985
2	Moisture content	Moisture meter	
3	Particle size	Sieving	
4	Odour	Visual	
5	Colour	Visual	
6	Bulk density	Using measuring cylinder	
8	Organic carbon	Ashing	
9	Total Nitrogen	Microkjeldahl digestion and distillation	(Jackson, 1958)
10	Total Phosphorus	Ashing- 25% HCL extract- Bray 1 extractant-spectrophotometry	FCO, 1985
11	Total Potasium	Ashing- 25% HCL extract- Bray 1 extractant-spectrophotometry	
12	Available Cu and Zn	Ashing- 25% HCL	

	(Micronutrients)	extract- Bray 1 extractant- spectrophotometry	
13	pH	pH meter 1:10 suspension (Organic waste :water)	
14	Cation Exchange Capacity	Extraction of cations by $BaCl_2$ and filtration. Reading of cations in Atomic absorption spectrophotometer and Flame Photometer	Hendershot and Duquette (1986)
15	Total Volatile Solids	Ashing	FCO, 1985
16	Microbial Count	Serial Dilution	(Martin, 1950)
17	Volume reduction	By measuring the volume	
18	Dehydrogenase enzyme activity	Colorimetrically using spectrophotometer based on the reduction of 2, 3, 5-triphenyltetrazolium chloride (TTC) to the creaming red-colored tri phenyl formazan (TPF)	(Benito *et al.*, 2003)
19	Heavy metals (As, Cr, Pd, Cd, Hg, Ni)	Ashing- 25% HCL extract- Bray 1 extractant- spectrophotometry	FCO, 1985

3.5. Biometric observations and yield

Biometric observations were recorded at important growth stages, viz. vegetative, reproductive and harvest stages from three plants /replication.

Plant height

Plant height was measured from the base of the plant to the tip of the growing point and expressed in cm.

Number of leaves per plant

Number of fully opened leaves produced per plant was taken at different stages of plant growth. (Vegetative, reproductive and harvest stage).

Number of branches per plant

Number of branches per plant was taken during different stages of plant growth.

Fruits per plant

The number of fruits per plant was taken at each harvest and the total number was recorded.

Fruit weight

The weight of four fruits was taken during different periods of harvest and the mean was taken and was expressed in gram. In total, twenty four harvests were taken.

Yield per plant

Fruit per plant was taken at different intervals. Total fruit yield obtained from all the harvests were summed up to get the yield of the crop.

Dry matter production

Three plants were taken from each replication and the mean was taken and was oven dried and the dry weight was recorded in grams.

3.6. Plant analysis

The plant samples were collected from each pot at harvest and was sun dried and thereafter oven dried at 70 ± 5°C, powdered and estimated the contents of total NPK of crop at harvest as per standard procedure given in Table 3.4

Table 3.4. Methods of plant analysis

Sl.No.	Particulars	Method
1	Nitrogen (%)	Modified Kjeldhal's digestion method (Jackson, 1958)
2	Phosphorus (%)	Diacid digestion of plant sample (2:1 HNO_3 : $HClO_4$) followed by filtration. Vanadomolybdate phosphoric yellow colour in nitric acid system (Piper, 1966)
3	Potassium (%)	Diacid digestion of plant sample (2:1 HNO_3:$HClO_4$) followed by filtration. Flame photometry determination (Jackson, 1958)

3.6.1. Uptake of major nutrients

Uptake of N, P and K were calculated by multiplying the respective values of N, P and K with total dry weight of the plant at harvest. The values were expressed in kg/ha.

3.7. Soil analysis

Soil samples were collected from experimental site before and after the experiment and were dried under shade. The samples were sieved through 2mm sieve and were used for analysis of available NPK and pH. The samples sieved through 0.5mm sieve were used for the estimation of organic carbon. The procedures adopted are given below in Table 3.5.

Table 3.5. Methods of soil analysis

Sl.No.	Particulars	Method
1	Soil pH	Jackson, 1958
2	Organic carbon	Walkley and Black method (Walkley and Black, 1934).
3	Available Nitrogen (kg/ha)	Subbiah and Asija, 1958
4	Available Phosphorus (kg/ha)	Soil samples were extracted using Bray No.1 reagent (Bray and Kurtz, 1945) and estimated colorimetrically by reduced molybdate ascorbic blue colour method (Watanabe and Olsen, 1965)
5	Available Potassium (kg/ha)	Jackson, 1958

3.8. Economics

The expenditure incurred for the production of various composting methods and benefit cost ratio of compost production was worked out.

3.9. Statistical analysis

Data relating to different characters were compiled, tabulated and analyzed statistically by applying the technique of analysis of variance (Gomez and Gomez, 1984) and significance was tested by Duncan's Multiple Range Test (Duncan, 1955).

Results

4. RESULT

The investigation entitled "Influence of composting methods on compost maturity and quality" was conducted at Plant Propogation and Nursery Management Unit (PPNMU), Vellanikkara with the objectives to study the effect of different composting methods on compost maturity and quality and to assess the suitability of compost as organic manure. The experimental data collected were statistically analyzed and the results obtained are presented under the following sections.

4.1. Influence of different composting methods on compost maturity:

4.1.1. Initial chemical composition of substrate and microbial count of Inoculum

The data on initial chemical composition of the substrate and microbial count of the inoculum used for composting are shown in Table 4.1. and 4.2. respectively. The substrates used for composting had an initial carbon content of 44.90 percent. N, P and K content of the substrate was in the ratio of 0.87:0.95:3.65 respectively. The pH of fresh banana pseudostem was 6.1. Cowdung had the highest total microbial count of 16.1 X 10^5 cfu/g. Effective microorganisms had total microbial count of 8.3 X 10^5 cfu/ml and the microbial count of *Bacillus subtilis* culture was 13 X 10^5 cfu/g and in trichoderma the total count was 0.2 X 10^5 cfu/g. The microbial count of varanasi composter was 12.5 X 10^5 cfu/g.

Table 4.1. Chemical composition of the substrates used for composting

Properties	Content
Carbon (%) of psedustem	44.90
pH (Banana pseudostem)	6.1
pH (Cowdung)	6.6
Rock Phosphate (P %)	20
Cowdung (N:P:K)	0.8:0.5:0.6
Substrate (N:P:K)	0.87:0.95:3.65

Table 4.2. Initial microbial count of inoculum

Inoculum	Microbial count (cfu/ml/g x 10^5)
Effective microorganisms	8.3
Bacillus subtilis	13
Varanasi composter	12.5
Cowdung	16.1
Trichoderma	0.2

4.1.2. Physical parameters

4.1.2.1. Compost yield (kg)

The data on compost yield is presented in table 4.3. When yield from 100kg substrate along with inoculum was taken into account, highest compost yield was obtained from varanasi composting which were on par with vermicomposting followed by aerobic composting with cowdung and pit method. The lowest compost yield was noticed in composting using effective microorganisms. Percent recovery from compost was highest in aerobic composting using cowdung which were on par with composting with Trichoderma and worms, Vermicomposting and Varanasi composting.

Table 4.3. Influence of composting methods on compost yield (kg)

Treatments	**Compost yield**	**% recovery from compost**	**Undecomposed material (Kg)**
Aerobic composting with cowdung (T_1)	15.12[a]	13.75[a]	3.64[b]
Aerobic composting with *Bacillus subtilis* (T_2)	8.30[de]	8.30[cd]	4.03[b]
Composting using effective microorganisms (T_3)	6.76[e]	6.76[d]	4.34[b]
Composting using Trichoderma and worms (T_4)	11.32[bc]	11.32[ab]	3.56[b]
Vermicomposting (T_5)	13.42[ab]	12.20[ab]	3.23[b]
Varanasi composting (T_6)	15.47[a]	11.90[ab]	6.65[a]
Heap method (T_7)	10.72[bc]	9.74[bc]	4.34[b]
Pit method (T_8)	12.58[abc]	11.02[bcd]	4.08[b]

*The data followed by same superscript do not vary significantly

4.1.2.2. Daily temperature (°C)

The initial temperature of the substrate used for composting was 28.5°C. The daily temperature data is presented in appendix 2. Change in temperature from 27°C to 34.29°C was observed in all the methods of composting during the initial few weeks of composting. The highest temperature of 34.29°C was observed in heap method of composting followed by pit method of composting (30.26°C). Varanasi composting and vermicomposting showed a temperature of 30.38°C and 32.26°C respectively. In all the other methods of composting, the temperature was maintained in the range of 27 to 29°C after one month of composting.

The temperature decreased slowly after two months of composting. The highest temperature was observed in varanasi method (29.92°C) followed by pit (29.85°C) and heap method (29.20°C) of composting.

4.1.2.3. Moisture content (%)

The initial moisture content of the substrate used for composting was 86.78 percent. Moisture content of 40-50 percent was maintained throughout the period in all the methods of composting.

4.1.2.4. Particle size (%)

The data on particle size of the compost is presented in Table 4.4. More than 98 percent of the compost obtained from all the methods of composting had a particle size less than 5mm. Particle size reduction was found maximum in vermicomposting wherein almost 81.90 percent of the final compost passed through less than 2mm sieve followed by composting by trichoderma and worms (79.9%). Particle size reduction was found to be the least in compost obtained from heap method (68.60%) and varanasi method (70.70%).

4.1.2.5. Bulk Density (mg/m^3)

The data on bulk density of mature compost is presented in Table 4.4. The lowest bulk density was observed in varanasi composting (0.58 mg/m^{-3}). However there was no significant difference in bulk density of compost obtained from heap and pit method.

4.1.2.6. Odour

Compost obtained from various composting methods had an earthy smell and there was no foul odour in none of the composting methods. Composting methods had no significant influence in the odour of the final compost.

4.1.2.7. Colour

A dark brown to black colour was noticed for almost all the compost samples. No variations were observed in the colour of the final compost due to the different composting methods.

Table 4.4. Influence of composting methods on particle size (%) and bulk density (mg/m^3) of the mature compost

Treatments	Particle size		Bulk density
	< 5 mm	<2mm	
Aerobic composting with cowdung (T_1)	100.00	77.50	0.61^{ab}
Aerobic composting with *Bacillus subtilis* (T_2)	100.00	79.60	0.61^{ab}
Composting using effective microorganisms (T_3)	98.90	71.30	0.68^{ab}
Composting using trichoderma and worms (T_4)	100.00	79.90	0.66^{ab}
Vermicomposting (T_5)	100.00	81.90	0.65^{ab}
Varanasi composting (T_6)	98.80	70.70	0.58^{b}
Heap method (T_7)	99.70	68.60	0.70^{a}
Pit method (T_8)	100.00	79.60	0.70^{a}

*The data followed by same superscript do not vary significantly

4.1.2.8. Volume reduction (%)

The volume reduction at different monthly interval is presented in Table 4.5. Before composting, volume was kept at 0.18m^3 in all the methods. Varanasi method of composting and pit method recorded the lowest reduction in volume after one month of composting. During the second month of composting, volume reduction for heap method as well as pit method was significantly less compared to other methods of composting.

For all the other methods of composting, volume reduction was similar during second month of composting. At maturity, varanasi method of composting and pit method showed significantly less reduction in volume compared to other composting methods.

Table 4.5. Influence of composting methods on volume reduction (%) of compost at different intervals of composting

Treatments	Volume reduction		
	1 month	2 month	At maturity
Aerobic composting with cowdung (T_1)	32.58[a]	55.06[a]	83.15[a]
Aerobic composting with *Bacillus subtilis* (T_2)	32.58[a]	66.29[a]	83.15[a]
Composting using effective microorganisms (T_3)	38.20[a]	60.67[a]	88.76[a]
Composting using Trichoderma and worms (T_4)	32.58[a]	60.67[a]	88.76[a]
Vermicomposting (T_5)	32.58[a]	60.67[a]	83.15[a]
Varanasi composting (T_6)	21.35[b]	55.06[a]	66.29[b]
Heap method (T_7)	32.58[a]	43.82[b]	83.15[a]
Pit method (T_8)	21.35[b]	43.82[b]	71.91[b]

*The data followed by same superscript do not vary significantly

4.1.3. Chemical parameters of maturity

4.1.3.1. pH

The data on pH is presented in Table 4.6. Composting methods showed no significant difference in pH content of the compost. Vermicomposting (T_5) indicated slightly alkaline pH among the treatments (8.00).

4.1.3.2. Cation Exchange Capacity (CEC) (cmol/kg of compost)

The data on CEC is presented in Table 4.6. Composting methods showed significant variation in CEC of mature compost. The highest CEC was observed in aerobic composting with cowdung and the lowest CEC was recorded in pit method followed by heap method. Except heap and pit method, the CEC of compost obtained from all the other composting methods showed a similar value.

Table.4.6. Influence of composting methods on CEC (cmol/kg of compost) and pH of mature compost

Treatments	CEC	pH
Aerobic composting with cowdung (T_1)	24.17[a]	7.07[a]
Aerobic composting with *Bacillus subtilis* (T_2)	22.57[a]	7.67[a]
Composting using effective microorganisms (T_3)	20.26[abc]	7.67[a]
Composting using Trichoderma and worms (T_4)	21.97[ab]	7.97[a]
Vermicomposting (T_5)	20.62[abc]	8.00[a]
Varanasi composting (T_6)	22.80[a]	7.43[a]
Heap method (T_7)	17.41[bc]	7.90[a]
Pit method (T_8)	16.50[c]	7.83[a]

*The data followed by same superscript do not vary significantly

4.1.3.3. Total volatile solids (TVS)

The data on total volatile solids obtained during different month is presented in Table 4.7. Total volatile solids showed a decreasing trend in all the methods of composting. Total volatile solids of mature compost were significantly higher in varanasi composting and total volatile solids of mature compost were significantly less in pit method. There was not much variation in total volatile solids of mature compost obtained from all the other methods of composting.

Table. 4.7. Influence of composting methods on total volatile solids (%) during different intervals of composting

Treatments	Total Volatile Solids		
	30 days	60 days	100 days
Aerobic composting with cowdung(T_1)	72.82^{a}	42.00^{b}	38.00^{ab}
Aerobic composting with *Bacillus subtilis* (T_2)	71.50^{a}	34.00^{c}	32.00^{bc}
Composting using effective microorganisms (T_3)	74.66^{a}	31.33^{c}	26.00^{cd}
Composting using Trichoderma and worms (T_4)	71.33^{a}	35.33^{c}	31.33^{bc}
Vermicomposting (T_5)	60.00^{b}	42.66^{b}	32.00^{bc}
Varanasi composting (T_6)	62.00^{b}	50.66^{a}	40.66^{a}
Heap method (T_7)	62.49^{b}	41.33^{b}	25.33^{cd}
Pit method (T_8)	73.33^{a}	44.66^{b}	20.66^{d}

*The data followed by same superscript do not vary significantly

4.1.3.4. Total Organic Carbon (%)

The result of organic carbon obtained during different monthly interval is presented in Table 4.8. During the initial stages of composting, maximum reduction in organic carbon was recorded in vermicomposting which were on par with varanasi and heap method of composting. During the second and third month of composting, significant reduction in carbon was recorded in composting using effective microorganisms.

Table.4.8 Influence of composting methods on organic carbon reduction (%) at different interval of composting

Treatments	Total Organic Carbon		
	1 month	2 month	At maturity
Aerobic composting with cowdung(T_1)	41.37[a]	23.86[b]	21.59[a]
Aerobic composting with *Bacillus subtilis* (T_2)	40.62[a]	19.32[c]	18.18[b]
Composting using effective microorganisms (T_3)	42.53[a]	17.80[c]	14.77[cde]
Composting using Trichoderma and worms (T_4)	40.67[a]	20.07[c]	17.80[bc]
Vermicomposting (T_5)	34.08[b]	24.24[b]	18.18[b]
Varanasi composting (T_6)	35.23[b]	28.78[a]	23.11[a]
Heap method (T_7)	35.51[b]	23.48[b]	14.39[de]
Pit method (T_8)	41.66[a]	25.38[b]	11.74[e]

*The data followed by same superscript do not vary significantly

4.1.3.4. C: N ratio

The data on C: N ratio during different interval is presented in Table 4.9. C: N ratio showed a decreasing trend during the process of composting irrespective of the method of composting. At harvest, C: N ratio was significantly higher in varanasi composting and lowest in composting using effective microorganisms. Other methods of composting showed no significant variation in C: N ratio.

Table 4.9. Influence of composting methods on C: N ratio of compost during different intervals of composting

Treatments	C:N ratio		
	1 month	2 month	At maturity
Aerobic composting with cowdung(T_1)	39.68^{ab}	15.82^{cd}	10.14^{bc}
Aerobic composting with *Bacillus subtilis* (T_2)	38.98^{abc}	18.23^{bc}	10.17^{bc}
Composting using effective microorganisms (T_3)	32.28^{bcd}	7.42^{e}	6.34^{c}
Composting using Trichoderma and worms (T_4)	39.19^{ab}	15.67^{cd}	9.83^{bc}
Vermicomposting (T_5)	30.04^{de}	16.97^{cd}	11.02^{b}
Varanasi composting (T_6)	31.39^{cd}	22.99^{ab}	16.05^{a}
Heap method (T_7)	22.83^{e}	14.90^{cd}	7.46^{bc}
Pit method (T_8)	40.05^{a}	24.16^{a}	7.57^{bc}

*The data followed by same superscript do not vary significantly

4.1.4. Biological parameters

4.1.4.1. Microbial count (cfu/gm)

The data obtained by microbial enumeration on mature compost is presented in Table 4.10. The maximum bacterial count was observed in varanasi composting followed by composting with trichoderma and worms, pit and aerobic composting with cowdung, Moreover the lowest count was noted in heap method which was on par with aerobic composting with *Bacillus subtilis* and composting using effective microorganisms. Fungal count was significantly higher in composting using trichoderma and worms which was on par with aerobic composting with cowdung, aerobic composting using *Bacillus subtilis* and composting using effective microorganisms. The least fungal colony was observed in heap and pit method. Actinomycetes count was significantly higher in both vermicomposting and varanasi composting and was significantly less in aerobic composting with *Bacillus subtilis*.

Table 4.10. Influence of composting methods on microbial count of the mature compost (cfu/g)

Treatments	Bacteria (10^6)	Fungi (10^4)	Actinomycetes (10^5)
Aerobic composting with cowdung(T_1)	7.6^{abc}	7.47^{abc}	6.47^{c}
Aerobic composting with *Bacillus subtilis* (T_2)	5.23^{c}	9.00^{ab}	2.73^{d}
Composting using effective microorganisms (T_3)	5.43^{c}	7.47^{abc}	7.00^{c}
Composting using Trichoderma and worms (T_4)	10.03^{ab}	9.37^{a}	11.10^{b}
Vermicomposting (T_5)	5.63^{bc}	4.00^{de}	24.13^{a}
Varanasi composting (T_6)	11.67^{a}	6.57^{bcd}	24.60^{a}
Heap method (T_7)	4.17^{c}	1.83^{e}	10.17^{b}
Pit method (T_8)	7.47^{abc}	1.77^{e}	10.13^{b}

*The data followed by same superscript do not vary significantly

4.1.4.2. Earthworm count

Presence of earthworms were noticed in composting methods were earthworms were introduced. The earthworm count in vermicomposting at harvesting stage was 206 and composting with trichoderma and worms had an earthworm count of 182.

4.1.4.3. Dehydrogenase activity (ug g^{-1} compost day^{-1})

The data on dehydrogenase enzyme activity is presented in Table 4.11. Dehydrogenase activity of compost varied with composting methods. The dehydrogenase activity was found to be maximum in aerobic composting using cowdung followed by varanasi method of composting and vermicomposting. The enzyme activity was significantly less in pit method of composting.

Table 4.11. Influence of composting methods on dehydrogenase activity ($\mu g\ g^{-1}$ compost day^{-1})

Treatments	Dehydrogensae activity
Aerobic composting with cowdung(T_1)	626.76^{a}
Aerobic composting with *Bacillus subtilis* (T_2)	302.13^{d}
Composting using effective microorganisms (T_3)	322.83^{c}
Composting using Trichoderma and worms (T_4)	344.72^{cd}
Vermicomposting (T_5)	407.80^{bc}
Varanasi composting (T_6)	484.59^{b}
Heap method (T_7)	292.73^{d}
Pit method (T_8)	130.60^{e}

*The data followed by same superscript do not vary significantly.

4.1.5. Nutrients and heavy metal content in compost

4.1.5.1. Nitrogen (%)

The data on the content of nitrogen (%) is presented in table 4.12. Composting methods have significant influence on the nitrogen content of compost. The nitrogen content was significantly higher in composting using effective microorganisms followed by aerobic composting using cowdung. The nitrogen content was found to be lowest in varanasi method of composting.

4.1.5.2. Phosphorus (%)

The data on phosphorus content in mature compost is presented in table 4.12. Phosphorus content of compost varied with the method of composting. The phosphorus content in varanasi method of composting recorded significantly higher phosphorus content compared to other methods of composting followed by vermicomposting and aerobic composting with cowdung which were on par with each other. The lowest content of phosphorus was recorded in composting using effective microorganisms.

Table 4.12. Influence of composting methods on major nutrients (%) and micronutrient (mg litre^{-1}) of mature compost

Treatments	Nitrogen	Phosphorus	Potassium	Copper	Zinc
Aerobic composting with cowdung (T_1)	2.13^{a}	0.21^{bc}	1.36^{c}	24.37^{c}	20.68^{a}
Aerobic composting with *Bacillus subtilis* (T_2)	1.80^{cd}	0.17^{cd}	1.56^{abc}	25.30^{c}	14.24^{bc}
Composting using effective microorganisms (T_3)	2.33^{a}	0.10^{f}	1.41^{bc}	23.35^{c}	7.33^{d}
Composting using Trichoderma and worms (T_4)	1.81^{cd}	0.15^{de}	1.66^{ab}	31.46^{ab}	10.60^{bcd}
Vermicomposting (T_5)	1.65^{de}	0.24^{b}	1.700^{a}	34.05^{a}	14.91^{b}
Varanasi composting (T_6)	1.44^{e}	0.33^{a}	1.68^{ab}	28.60^{bc}	22.86^{a}
Heap method (T_7)	1.93^{bc}	0.18^{cd}	1.59^{abc}	24.84^{c}	14.57^{b}
Pit method (T_8)	1.55^{de}	0.11^{ef}	1.45^{abc}	16.34^{d}	9.33^{cd}

*The data followed by same superscript do not vary significantly

4.1.5.3. Potassium (%)

The data on potassium content is presented in table 4.12. Method of composting had significant influence on potassium content of compost. The highest content of potassium was observed in vermicomposting. The potassium content of compost obtained from other methods was on par with each other. The potassium content was the least in aerobic composting with cowdung.

4.1.5.4. Micronutrients (mg/litre)

The data on micronutrient is presented in table 4.12. Copper content of compost was found higher in methods of composting using earthworms.

Compost obtained from vermicomposting had the highest content of copper which was on par with compost obtained using trichoderma and worms. Copper content of compost obtained from heap method, aerobic composting using cowdung, composting using *Bacillus subtilis* and compost prepared using effective microorganisms showed a similar trend. Zinc content was found to be more in compost obtained from varanasi method followed by aerobic composting using cowdung. The lowest zinc content was noticed in composting using effective microorganisms.

4.1.5.5. Heavy metals (ppm)

The data on heavy metal content is presented in Table 4.13. Presence of heavy metals such as arsenic, mercury, lead, chromium and nickel content were analyzed. Mercury and Arsenic were found negligible. Heavy metal content varied with method of composting but none of the composting methods showed a heavy metal content more than permissible limit. Lead content was least in compost obtained from pit method and aerobic composting using cowdung. Chromium content was significantly higher in composting with trichoderma and worms and in vermicomposting compared to other methods. Nickel content was observed higher in varanasi composting which was on par with composting using trichoderma and worms and effective microorganisms. Arsenic and mercury were present in trace amounts in all the methods. All the heavy metals were found to be significantly less in pit method.

Table 4.13 Influence of composting methods on heavy metal content of mature compost (ppm)

Treatments	Lead	Chromium	Nickel
Aerobic composting with cowdung (T_1)	39.40^{d}	9.38^{bc}	1.27^{c}
Aerobic composting with *Bacillus subtilis* (T_2)	58.90^{ab}	9.11^{bc}	1.19^{c}
Composting using effective microorganisms (T_3)	65.90^{ab}	9.27^{bc}	2.21^{ab}
Composting using Trichoderma and worms (T_4)	98.23^{a}	13.19^{a}	2.31^{ab}
Vermicomposting (T_5)	73.70^{a}	12.75^{a}	1.30^{c}
Varanasi composting (T_6)	94.80^{a}	9.34^{bc}	2.62^{a}
Heap method (T_7)	88.30^{a}	10.86^{ab}	1.55^{bc}
Pit method (T_8)	17.97^{d}	5.92^{d}	0.79^{c}
Permissible limit	100.00	50.00	50.00

*The data followed by same superscript do not vary significantly

4.1.6. Phytotoxicity studies

4.1.6.1. Seed germination using compost extract (%)

The data on seed germination in compost extract using tomato seeds is given in Table 4.14. Seed germination in compost extract prepared from composting using *Bacillus subtilis* recorded highest germination percentage on the first day. Seed germination using compost extracts of different methods of composting showed no significant difference on fourth day.

Table 4.14. Effect of composting methods on seed germination (%) in compost extract

Treatments	First day	Fourth day
Distilled water (Control)	80.00^{ab}	98.89^{a}
Aerobic composting with cowdung (T_1)	69.99^{bc}	98.89^{a}
Aerobic composting with *Bacillus subtilis* (T_2)	83.33^{a}	95.55^{a}
Composting using effective microorganisms (T_3)	79.99^{ab}	93.33^{ab}
Composting using Trichoderma and worms (T_4)	55.56^{d}	93.33^{a}
Vermicomposting (T_5)	68.89^{c}	95.56^{a}
Varanasi composting (T_6)	71.11^{bc}	94.44^{a}
Heap method (T_7)	74.44^{abc}	98.89^{a}
Pit method (T_8)	77.78^{abc}	93.37^{a}

*The data followed by same superscript do not vary significantly

4.1.6.2. Seed germination in compost as potting mixture (%)

The data on seed germination percentage using tomato seeds in compost as potting mixture is presented in Table 4.15. More than 75 percent seed germination was noticed in all the composts obtained from different method of composting. The data indicated that none of the composting methods had any phytotoxicity. The seed germination was recorded as the highest in control on the first day which was significantly different from other method of composting. Varanasi compost recorded the highest seed germination percentage on the fourth day which was on par with control, aerobic composting using cowdung, *Bacillus subtilis* and pit method. Seed germination was significantly less in pit method.

Table 4.15. Effect of composting methods on seed germination (%) using compost as potting mixture

Treatments	First day	Fourth day
Soil (Control)	64.44^{a}	88.89^{ab}
Aerobic composting with cowdung(T_1)	41.11^{bc}	91.11^{ab}
Aerobic composting with *Bacillus subtilis* (T_2)	31.11^{cd}	91.11^{ab}
Composting using effective microorganisms (T_3)	32.22^{cd}	79.99^{bc}
Composting using Trichoderma and worms (T_4)	16.67^{e}	78.88^{bc}
Vermicomposting (T_5)	14.44^{e}	82.22^{b}
Varanasi composting (T_6)	48.88^{b}	96.67^{a}
Heap method (T_7)	16.66^{e}	67.77^{c}
Pit method (T_8)	24.45^{de}	84.44^{ab}

*The data followed by same superscript do not vary significantly

4.2. Suitability of compost as organic manure

4.2.1. Biometric and yield attributes

4.2.1.1. Plant height (cm)

The data on plant height at different growth stages is presented in Table 4.16. Compost obtained from different composting methods showed significant difference in plant height at different growth stage. With the application of compost obtained from trichoderma and worms, the plant height was significantly higher in all the growth stages except harvest. During harvest, the highest plant height was noticed in aerobic composting with *Bacillus subtilis*. The lowest plant height was obtained on application of compost obtained from pit method.

4.16. Effect of application of compost obtained from different methods on plant height (cm) at different growth stages

Treatments	Stages of plant growth			
	Vegetative	Reproductive	Fruiting	Harvest
Aerobic composting with cowdung(T_1)	21.56^{cd}	59.91^{ab}	87.13^{a}	97.00^{bcd}
Aerobic composting with *Bacillus subtilis* (T_2)	22.00^{cd}	59.28^{ab}	94.50^{a}	116.00^{a}
Composting using effective microorganisms (T_3)	22.61^{abc}	62.00^{ab}	84.89^{a}	98.33^{bcd}
Composting using Trichoderma and worms (T_4)	25.37^{a}	64.03^{a}	88.21^{a}	92.22^{bcd}
Vermicomposting (T_5)	21.56^{cd}	56.55^{ab}	91.09^{a}	104.33^{b}
Varanasi composting (T_6)	22.67^{abc}	58.89^{ab}	91.33^{a}	101.44^{bc}
Heap method (T_7)	22.67^{abc}	56.70^{ab}	92.04^{a}	101.00^{bc}
Pit method (T_8)	24.89^{ab}	55.22^{ab}	73.35^{b}	85.89^{d}
Farm Yard Manure (control)	19.62^{d}	53.00^{b}	85.10^{ab}	96.22^{bcd}

*The data followed by same superscript do not vary significantly

4.2.1.2. Number of leaves

The data on the number of leaves produced during different stages of plant growth is represented in Table 4.17. Leaf production showed variation with different composts. With the application of compost obtained from aerobic composting using cowdung, number of leaves was significantly higher during vegetative stage. No significant difference was observed during reproductive stage. During harvest stage, number of leaves on application of compost obtained from heap method produced more number of leaves.

Table 4.17. Effect of application of compost obtained from different methods on number of leaves at different growth stages

Treatments	Stages of plant growth		
	Vegetative	Reproductive	Harvest
Aerobic composting with cowdung(T_1)	6.22^{a}	12.00^{a}	11.89^{cd}
Aerobic composting with *Bacillus subtilis* (T_2)	6.11^{ab}	12.56^{a}	13.00^{bc}
Composting using effective microorganisms (T_3)	5.44^{abc}	11.56^{a}	15.89^{abc}
Composting using Trichoderma and worms (T_4)	5.554^{abc}	10.56^{a}	11.77^{cd}
Vermicomposting (T_5)	5.22^{bc}	11.33^{a}	14.22^{bcb}
Varanasi composting (T_6)	5.33^{abc}	10.11^{a}	17.22^{ab}
Heap method (T_7)	5.22^{bc}	12.44^{a}	19.33^{a}
Pit method (T_8)	5.00^{c}	12.67^{a}	17.77^{ab}
Farm Yard Manure (Control)	5.33^{abc}	11.77^{a}	11.66^{cd}

*The data followed by same superscript do not vary significantly

4.2.1.3. Number of branches

The results on the number of branches at different growth stages of the plant are presented in Table 4.18. No significant difference was observed in the number of branches during vegetative stage. Composting with effective microorganisms recorded the highest number of branches during reproductive and harvest stage which were on par with aerobic composting using cowdung, composting with trichoderma and worms and heap method.

Table 4.18. Effect of application of compost obtained from different methods on number of branches at different growth stages

Treatments	Stages of plant growth		
	Reproductive	**Fruiting**	**Harvest**
Aerobic composting with cowdung (T_1)	1.72^a	2.22^{ab}	2.88^{ab}
Aerobic composting with *Bacillus subtilis* (T_2)	1.77^a	2.00^b	2.67^{ab}
Composting using effective microorganisms (T_3)	1.33^a	3.06^a	3.78^a
Composting using Trichoderma and worms (T_4)	1.44^a	2.06^{ab}	2.89^{ab}
Vermicomposting (T_5)	2.00^a	2.00^b	2.33^b
Varanasi composting (T_6)	1.77^a	2.00^b	3.22^{ab}
Heap method (T_7)	2.11^a	2.67^{ab}	2.61^{ab}
Pit method (T_8)	2.17^a	2.11^{ab}	2.45^b
Farm Yard Manure (Control)	1.77^a	1.77^b	2.28^b

*The data followed by same superscript do not vary significantly

4.2.1.4. Fruits/Plant

The data on the total number of fruits produced per plant is presented in Table 4.19. Production of fruits per plant was significantly affected by the application of different compost. The number of fruits/plant was the highest in varanasi composting which was on par with other treatments. Pit method recorded significantly lower number of fruits/plant.

Table 4.19. Effect of application of compost obtained from different methods on number of fruits/plant, fruit weight (g) and yield/plant (g) of bhindi

Treatments	Fruits/Plant	Fruit weight	Yield/Plant
Aerobic composting with cowdung(T_1)	26.56[ab]	23.95[bc]	554.79[de]
Aerobic composting with *Bacillus subtilis* (T_2)	27.26[ab]	26.62[a]	557.77[cd]
Composting using effective microorganisms (T_3)	26.55[ab]	23.70[cd]	631.98[abc]
Composting using Trichoderma and worms (T_4)	27.33[ab]	24.17[bc]	574.17[cd]
Vermicomposting (T_5)	28.00[ab]	24.12[bc]	669.34[ab]
Varanasi composting (T_6)	29.33[a]	23.16[cd]	694.84[a]
Heap method (T_7)	24.33[ab]	25.29[ab]	532.04[de]
Pit method (T_8)	22.33[b]	19.90[e]	493.60[e]
Farm Yard Manure (Control)	26.00[ab]	20.18[e]	558.43[de]

*The data followed by same superscript do not vary significantly

4.2.1.5. Fruit weight (g)

The result on the fruit weight is given in table 4.19. Fruit weight of bhindi significantly varied with the application of composts. The highest fruit weight was recorded in crop treated with compost obtained from aerobic composting with *Bacillus subtilis* followed by heap method. Fruit weight was least in crop which received compost obtained from pit method.

4.2.1.6. Yield/Plant (g)

The total yield of the plant is presented in Table 4.19. Application of different compost had significant influence on the yield of bhindi. The highest yield was recorded in varanasi treated crop followed by vermicompost. The lowest yield was recorded in crop treated with compost obtained from pit method.

4.2.1.7. Dry matter production (g)

Dry matter production of the plant is presented in Table 4.20. Dry matter production was found to be maximum in vermicompost applied crop and least in crop applied with compost from pit method.

Table 4.20.Effect of application of compost obtained from different methods on dry matter production (g)

Treatments	Dry matter production
Aerobic composting with cowdung (T_1)	137.13
Aerobic composting with *Bacillus subtilis* (T_2)	107.50
Composting using effective microorganisms (T_3)	141.23
Composting using Trichoderma and worms (T_4)	102.60
Vermicomposting (T_5)	148.13
Varanasi composting (T_6)	137.23
Heap method (T_7)	134.10
Pit method (T_8)	71.17
Farm Yard Manure (Control)	115.47

*Values are not statistically analyzed

4.2.2. Plant analysis

4.2.2.1. Nitrogen % (N) and N uptake

The data on nitrogen content and nitrogen uptake is presented in table 4.21. Application of different compost significantly affected the N (%) and N uptake. Nitrogen content (%) was higher in crop treated with compost obtained from composting using effective microorganisms. Nitrogen uptake was also found highest in this treatment. The lowest nitrogen content was observed in crops treated with compost obtained from pit method.

Table 4.21. Effect of application of compost obtained from different methods on macronutrients (%) and their uptake (g/plant)

Treatments	**N**	**N uptake**	**P**	**P uptake**	**K**	**K uptake**
Aerobic composting with cowdung(T_1)	1.50^{cde}	2.06^{cd}	0.73^{a}	1.00^{a}	1.81^{bc}	2.49^{bc}
Aerobic composting with *Bacillus subtilis* (T_2)	1.77^{abcd}	1.90^{cde}	0.07^{b}	0.08^{b}	1.63^{c}	1.75^{d}
Composting using effective microorganisms (T_3)	1.97^{ab}	2.77^{a}	0.06^{b}	0.09^{b}	2.04^{ab}	2.87^{a}
Composting using Trichoderma and worms (T_4)	1.40^{de}	1.43^{ef}	0.07^{b}	0.07^{b}	1.94^{ab}	1.99^{d}
Vermicomposting (T_5)	1.33^{e}	1.97^{cd}	0.06^{b}	0.09^{b}	1.99^{ab}	2.95^{a}
Varanasi composting (T_6)	1.60^{bcde}	2.19^{bc}	0.71^{a}	0.97^{a}	1.99^{ab}	2.73^{ab}
Heap method (T_7)	1.200^{e}	1.61^{de}	0.08^{b}	0.11^{b}	2.06^{ab}	2.76^{ab}
Pit method (T_8)	1.83^{abc}	1.30^{f}	0.08^{b}	0.06^{b}	1.82^{bc}	1.30^{e}
Farm Yard Manure	1.47^{cde}	1.69^{cdef}	0.09^{b}	0.11^{b}	2.07^{ab}	2.39^{c}

*The data followed by same superscript do not vary significantly

4.2.2.2. *Phosphorus % (P) and P uptake*

The data on plant P content and plant uptake is given in table 4.21. The phosphorus content and phosphorus uptake varied with the application of composts. Significantly higher content of phosphorus and P uptake was noticed in aerobic composting with cowdung followed by varanasi composting. All the other treatments did not show significant difference with regard to P content and uptake.

4.2.2.3. Potassium % (K) and K uptake

The data on potassium content and K uptake is presented in table 4.21. Compost application has significant influence on K content and uptake. The K (%) was found to be the lowest in aerobic composting with *Bacillus subtilis*. Other treatments showed a similar pattern in potassium content. Potassium uptake was significantly higher in vermicompost applied crop and in crop receiving compost produced using effective microorganisms.

4.2.3. Soil analysis

4.2.3.1. Initial soil nutrient status

The data on initial soil status is presented in Table 4.22.

Table 4.22. Initial nutrient status of soil

Particulars	**Contents**
Organic carbon (%)	0.90
pH	6.2
N (kg/ha)	87.16
P (kg/ha)	7.62
K(kg/ha)	214.58

4.2.3.2. Soil pH

The data on pH of soil is presented in Table 4.23. There was a slight increase in pH in all treatments compared to initial pH. Compost application has significant influence on soil pH. The highest pH was noticed in treatments receiving compost produced using trichoderma and worms. The lowest pH was noticed in compost obtained from pit method.

Table 4.23 Effect of application of compost obtained from different methods on pH, organic carbon (%) and nutrient status (kg/ha) of soil after experiment

Treatments	pH	Organic carbon	Available Nitrogen	Available Phosphorus	Available Potassium
Aerobic composting with cowdung (T_1)	6.45[ab]	1.45[a]	132.95[cd]	13.17[abc]	1243.32[a]
Aerobic composting with *Bacillus subtilis* (T_2)	6.40[b]	1.45[a]	179.80[a]	14.08[a]	281.86[ab]
Composting using effective microorganisms (T_3)	6.33[b]	1.43[a]	128.25[cd]	10.88[cde]	228.77[b]
Composting using Trichoderma and worms (T_4)	6.77[a]	1.34[a]	146.35[bc]	12.10[abcd]	373.71[ab]
Vermicomposting (T_5)	6.40[b]	1.24[a]	122.82[d]	11.11[bcde]	265.82[b]
Varanasi composting (T_6)	6.47[ab]	1.44[a]	158.89[b]	10.05[def]	246.95[b]
Heap method (T_7)	6.50[ab]	1.28[a]	113.92[d]	9.01[ef]	242.67[ab]
Pit method (T_8)	5.67[c]	1.22[a]	122.05[d]	7.69[f]	259.47[ab]
Farm Yard Manure	6.57[ab]	1.51[a]	146.94[bc]	14.392[a]	1371.45[ab]

*The data followed by same superscript do not vary significantly

4.2.3.3. Soil organic carbon

The data on soil organic carbon is presented in Table 4.23. The initial organic carbon content was 0.9 percent. Application of different compost did not show significant difference in soil organic carbon.

4.2.3.4. Available Nitrogen

The data on available soil nitrogen is presented in Table 4.23. Compost application had significant influence on soil available nitrogen. The available nitrogen was found to be maximum in soil treated with compost obtained from aerobic composting with *Bacillus subtilis* and the least content was recorded in compost obtained from heap method.

4.2.3.5. Available Phosphorus

The data on soil available phosphorus is presented in Table 4.23. Compost application showed significant variation in available soil phosphorus status. Soil available phosphorus was found to be more in control (FYM) which was on par with aerobic composting using *Bacillus subtilis*. Application of compost obtained from pit method recorded lowest soil phosphorus.

4.2.3.6. Available Potassium

The data on soil available potassium is presented in Table 4.23. Application of compost had significant influence on soil available potassium. Available potassium was recorded higher in soil treated with compost obtained using trichoderma and worms followed by farm yard manure (control). Other treatments did not show significant difference in terms of available soil potassium.

4.3. Economics of composting methods

The data on economics of composting methods is presented in Table 4.24 and appendix 3. Among the different methods of composting, BC ratio was found favorable for vermicomposting and lower BC ratio was recorded in pit method.

Table 4.24 Economics of composting methods

Treatments	**Total Cost (Rs)**	**Total Returns* (Rs)**	**BC ratio**
Aerobic composting with cowdung (T_1)	2463	1512	0.62
Aerobic composting with *Bacillus subtilis* (T_2)	2494	830	0.34
Composting using effective microorganisms (T_3)	2514	676	0.27
Composting using Trichoderma and worms (T_4)	3125	1132	0.77
Vermicomposting (T_5)	3176	1342	0.87
Varanasi composting (T_6)	1788	1547	0.86
Heap method (T_7)	1803	1072	0.60
Pit method (T_8)	2949	1258	0.43

*Cost of compost→ Rs.10.00 per kilogram

Discussion

5. DISCUSSION

An investigation entitled "Influence of composting methods on compost maturity and quality" was conducted to study the effect of various composting methods on compost maturity parameters and to study its suitability as organic manure for bhindi. Important results of the present study are discussed in this chapter under the following two major sections.

1. Influence of composting methods on physical, chemical and biological parameters of compost maturity and stability.

2. Suitability of compost obtained from different composting methods as organic manure for bhindi crop.

5.1. Influence of composting methods on maturity and stability parameters of compost

A number of criteria and parameters are proposed for testing compost maturity and stability but no single method has been universally applied due to the difference in substrate composition and composting methodologies. Evaluation of compost stability and maturity will help in the standardization of the quality of compost obtained from different methods of composting. The maturity and stability of compost depends upon the chemical constituents present in the initial substrate as well as the intermediates formed during different stages of composting.

5.1.1. Physical parameters

Physical characteristics such as temperature, colour, odour, moisture content, particle size, volume reduction, bulk density etc gives a general idea about the stage of decomposition but little information on the degree of maturation. Composting is an exothermic process and temperature development is as a result of microbial activity followed by decline in temperature due to the less availability of organic carbon. Variation in temperature with respect to the atmospheric temperature was recorded in all the methods of composting. Compared to atmospheric temperature, the temperature of compost material was high in all the methods of composting. This may be due to the decomposition of organic matter. However, except in heap method, none of the methods of composting showed temperature of more than 34°C (Fig. 4).

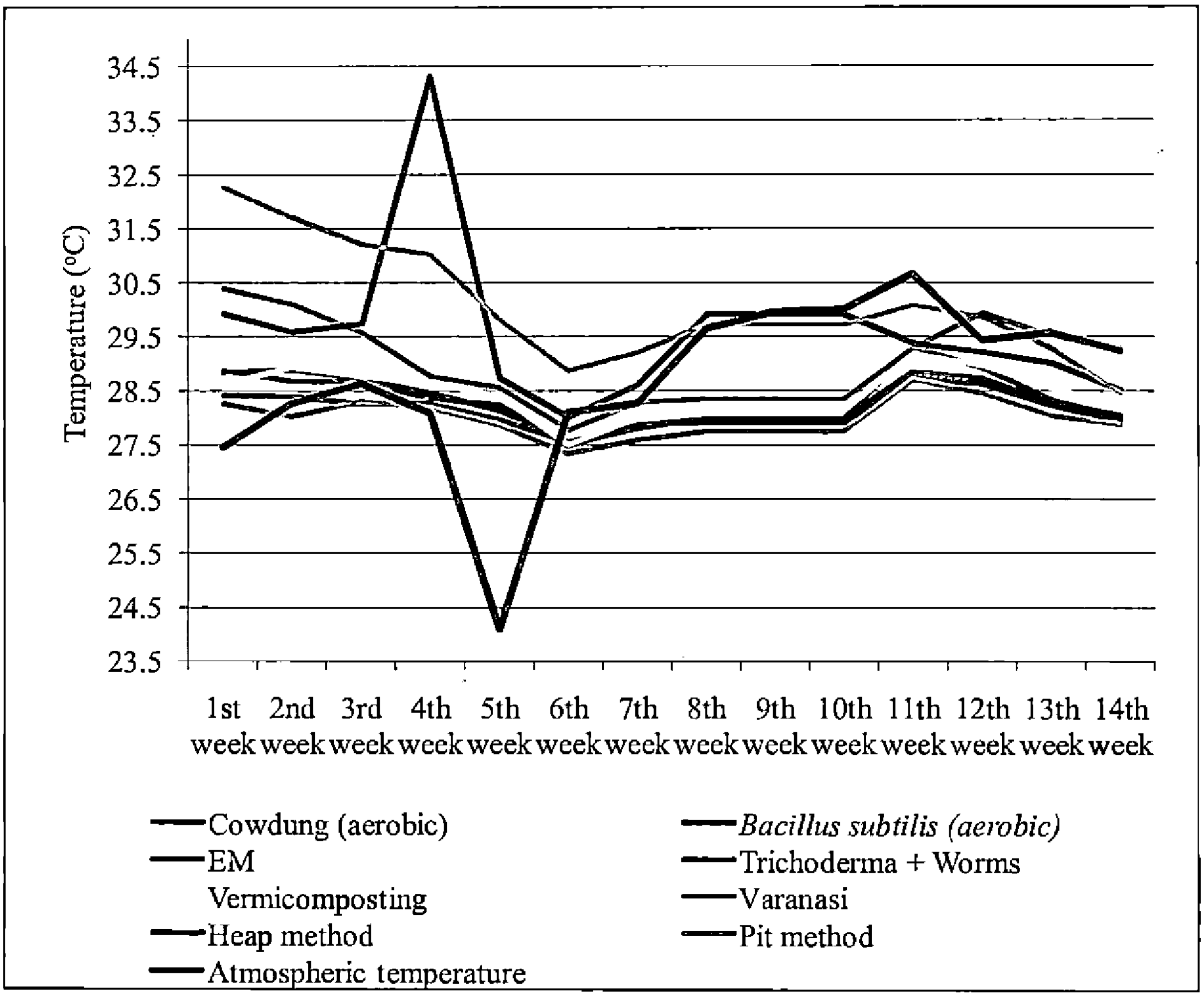
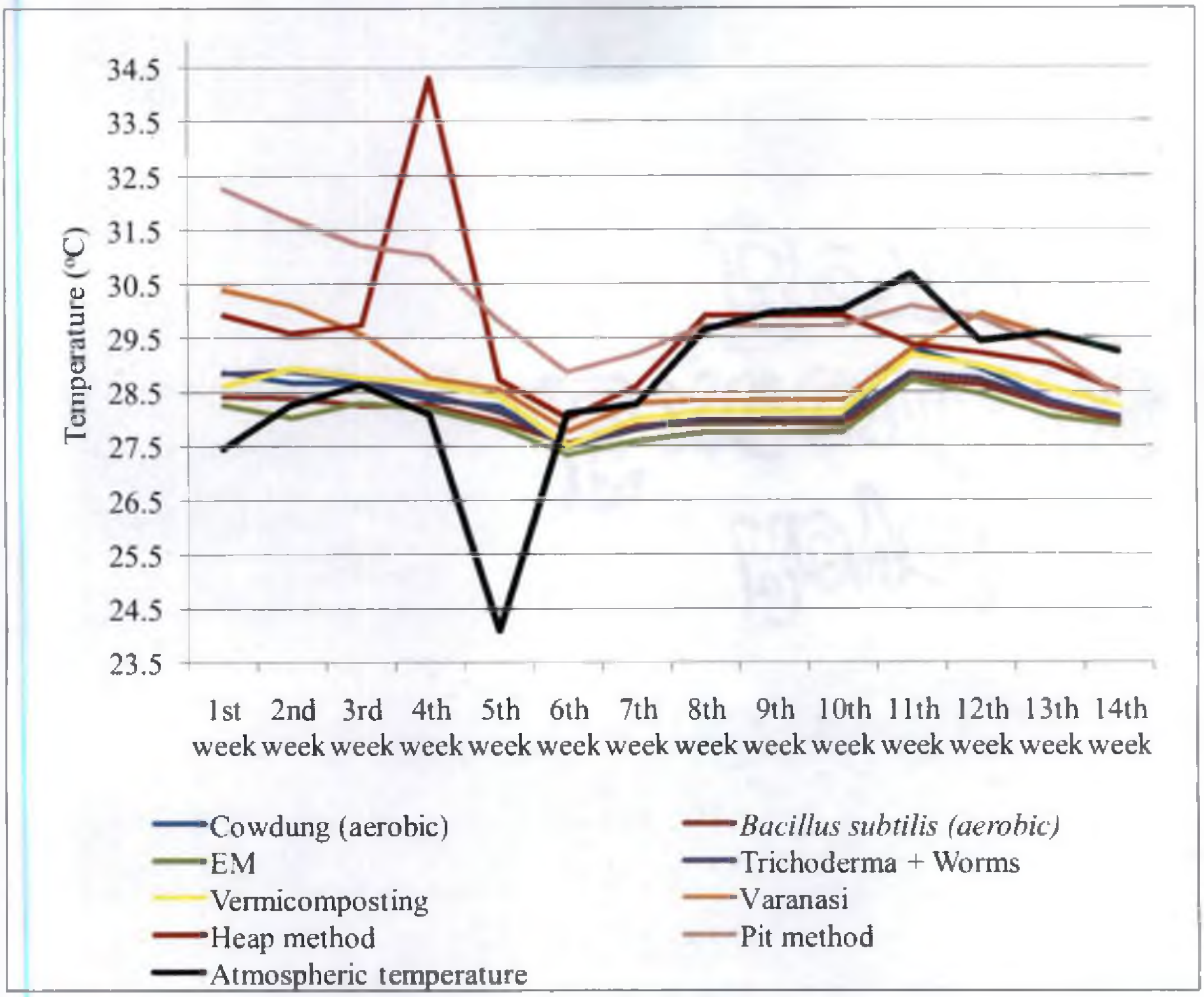


Fig. 4 Temperature variation of different composting methods

The non development of temperature beyond 34°C in the composting methods may be due to the small heap and frequent rain observed during the month of June and July. Taiwo and Oso, (2003) have reported that large heaps lead to generation of high temperature and small heaps generate low temperature. After 60 days of composting, the temperature development in all the composting methods almost equaled to that of atmospheric temperature. Initial temperature increase and a later temperature decline indicated that the decomposition of organic matter by microorganisms has stopped.

The initial moisture content was 86.78 percent. The moisture content was reduced to the range of 40-60 percent which was thereafter maintained continuously throughout the composting period by sprinkling water. Adequate moisture content (40-50%) was maintained throughout the composting period in all the methods as it was required for metabolic and physiological activities of the microorganisms and it provided a medium for the transportation of nutrients. Richard *et al.* (2002) reported that the optimum moisture content for biodegradation vary widely for different compost mixtures and times in the composting process, ranging from near 50 to over 70 percent on a wet basis. The study revealed that there was a significant reduction in biodegradation rate whenever operated from outside the optimum range. This was there in case of varanasi composting. The high moisture in varanasi composting may be due to the complete covering of the heap by UV sheet and hence the evaporation loss may be less. Except varanasi composting, the harvest of compost obtained from all the other methods was done on 100^{th} day. The moisture content was high in varanasi method and it was unable to sieve the compost on the same day. So the cover was removed and kept as such for another two weeks for sieving. Consequently the harvest of the compost in varansi composting was done on the 114^{th} day.

Colour change of compost is used as a parameter for compost maturity. Colour change was observed in all the methods of composting. A dark brown colour was observed in all the methods of composting indicating that decomposition had taken place in all the methods. Sughara *et al.* (1981) reported that colour of composting material will change from dark or grayish black while advancing maturity. No foul odour was noticed in compost obtained from any of the methods except an earthy smell which was an indication of humification of organic matter. Henry and Harrison (1996) reported that compost with an obnoxious odour indicates instability.



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Even though colour and odour are the simplest physical parameters to evaluate the maturity and stability of compost obtained from different methods, some additional physical, chemical and biological methods were also determined for confirmation.

The volume reduction during composting may be attributed to decomposition of organic matter by the microorganisms during different stages of composting. Significant volume reduction was recorded in all the methods of composting (Fig. 5). Except pit method, more than 80 percent reduction in volume was recorded in all methods of composting with highest volume reduction in composting using effective microorganisms and composting with Trichoderma and worms.

The composting methods were in earthworms were introduced recorded the highest reduction in volume after 60 days of composting with volume reduction percentage of 88.76 percent in composting using Trichoderma + worms and vermicomposting. The lowest volume reduction (66.29%) was recorded in varanasi composting. Due to the partial anaerobic condition, volume reduction was lesser in varanasi method of composting. The excess moisture content and lack of aeration in varanasi composting might have caused unfavourable condition for the microorganisms to multiply which resulted in lower volume reduction. Iyengar *et al.* (2006) reported that volume reduction depends upon the input of waste and the type of composting methods adopted. He also recorded more than 90 percent volume reduction in aerobic reactor as compared to 12.58 percent in anaerobic reactor.

In vermicomposting, more than 80 percent of the particles were of size less than 2mm (Fig. 6). Particle size reduction was highest in treatments were earthworms were introduced (vermicomposting and composting using trichoderma and worms). Although biochemical degradation of the organic matter is carried out by microorganism, earthworms fragment the substrate drastically altering the microbial activity and increasing the surface area (Dominguez *et al.*, 1997). Compost obtained from varanasi composting with larger particle size and comparatively higher moisture content had the lowest bulk density among the different methods of composting. Schaub-Szabo and Leonard (1999) also reported that the amount of moisture and particle size strongly affected bulk density. The pore space between the compost particles should be such that there should be retention of water and air.

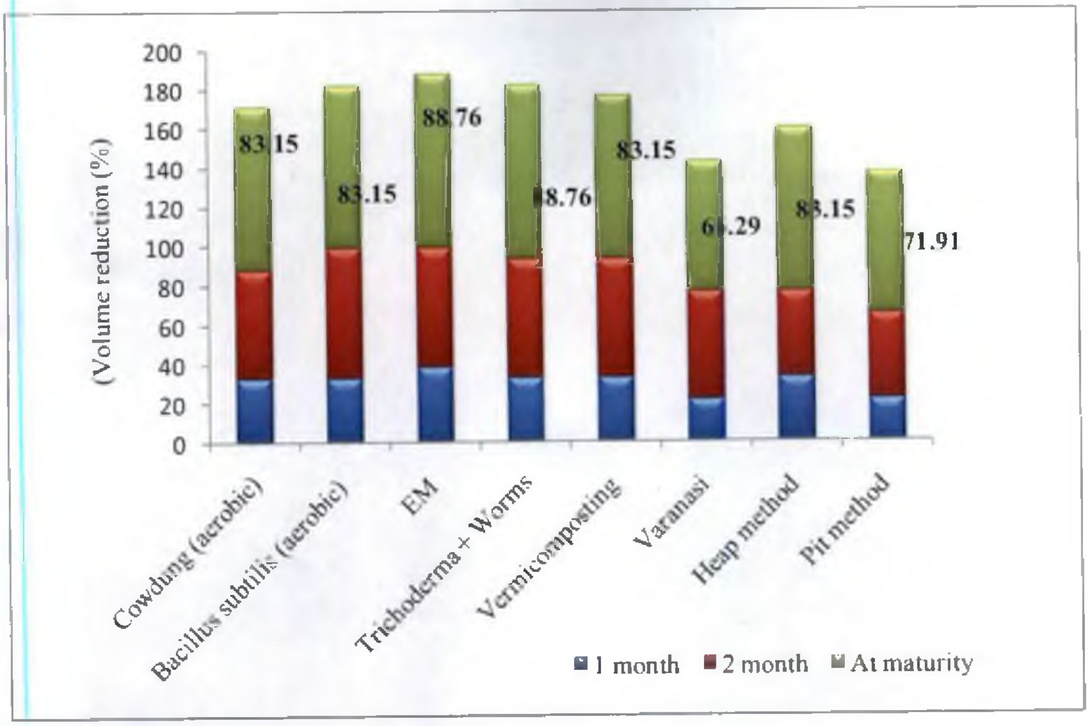

Fig. 5 Influence of composting methods on volume reduction

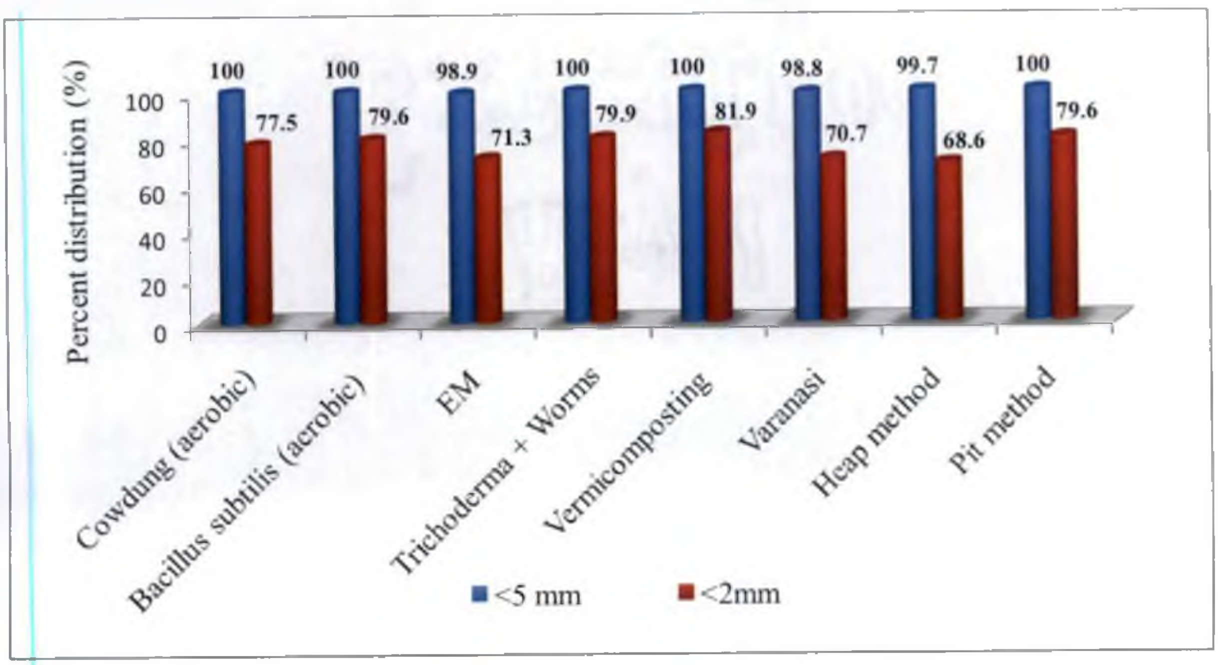

Fig. 6 Influence of composting methods on particle size of mature compost

If the particles are too close to each other, then the compost tend to compact, resulting in low air capacity, low infiltration rate and water holding capacity.

Yield from 100 kg substrate along with inoculum was high in varanasi method of composting (Fig. 7). The yield was less from composting methods without addition of cowdung (*viz.* composting using Effective microorganisms, *Bacillus subtilis*). This indicates that the final yield of compost obtained increased with addition of cowdung. Hence, in varanasi composting yield increase was mainly due to addition of three times more cowdung compared to other methods. Undecomposed material was also highest in varanasi composting compared to other methods. Even without the addition of cowdung, composting using trichoderma and worms produced comparable yield to that of aerobic composting using cowdung and vermicomposting. The percent recovery of compost was also higher in aerobic composting using cowdung. When we consider the compost yield from the substrate alone, the compost yield was higher in aerobic composting with cowdung, vermicomposting and composting using trichoderma and worms. Undecomposed portion were also less in these methods.

All the composting methods attained physical parameters of maturity at varying degree. The physical parameters like colour and odor of compost obtained from different methods did not show any variation. The mature compost obtained from all the method of composting was odorless and dark brown in colour. Physical parameters such as volume reduction, particle size, bulk density, yield and undecomposed material left after composting varied with composting methods. The yield in varanasi composting was high when total material added for composting was taken into consideration. But volume reduction and particle size reduction were less in varanasi composting method. Considering the compost yield from 100kg substrate used for composting and undecomposed material left after composting, aerobic composting using cowdung and composting using trichoderma and worms was found equally efficient. The volume reduction and particle size reduction were high in these treatments. Hence wherever there is no availability of cowdung for composting, composting with trichoderma and worms is suggested as an alternative method. Based on physical parameters of maturity, aerobic composting using cowdung, vermicomposting and composting with trichoderma and worms are suggested as good methods of composting compared to other methods.

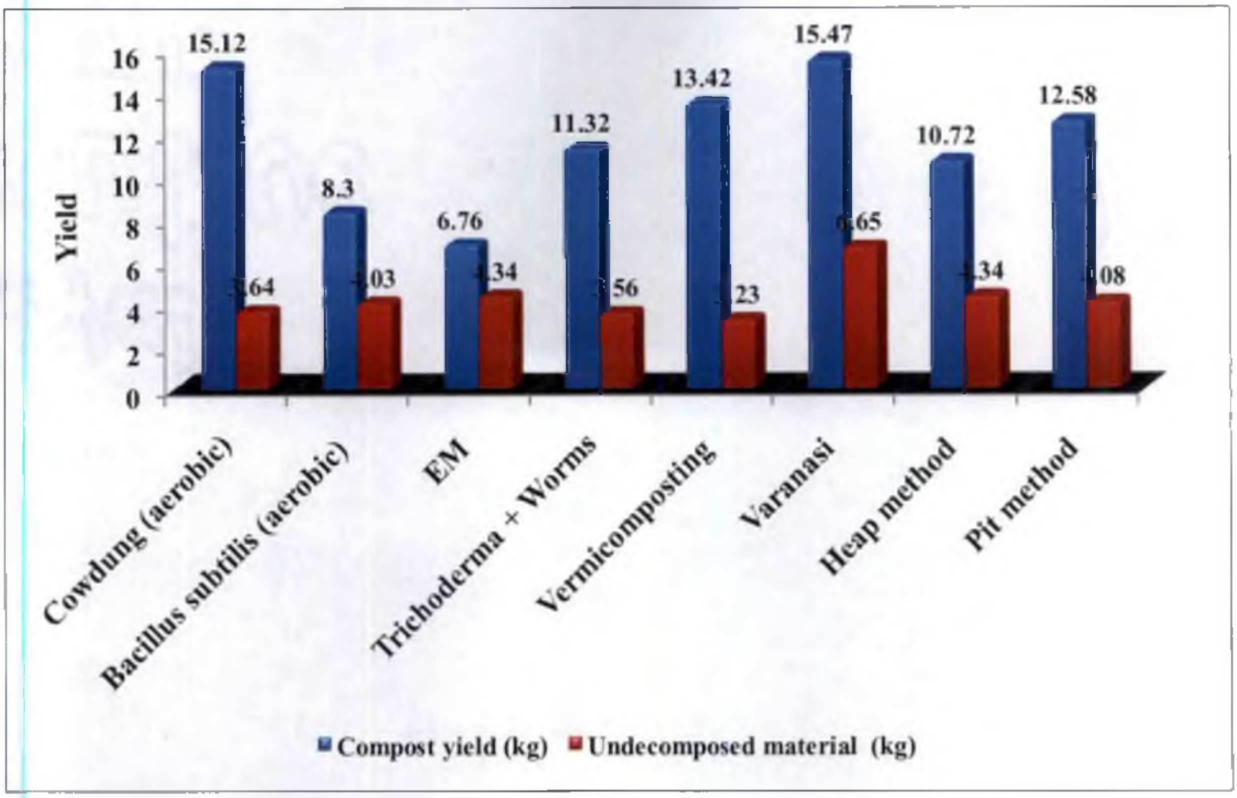

Fig. 7 Influence of composting methods on compost yield

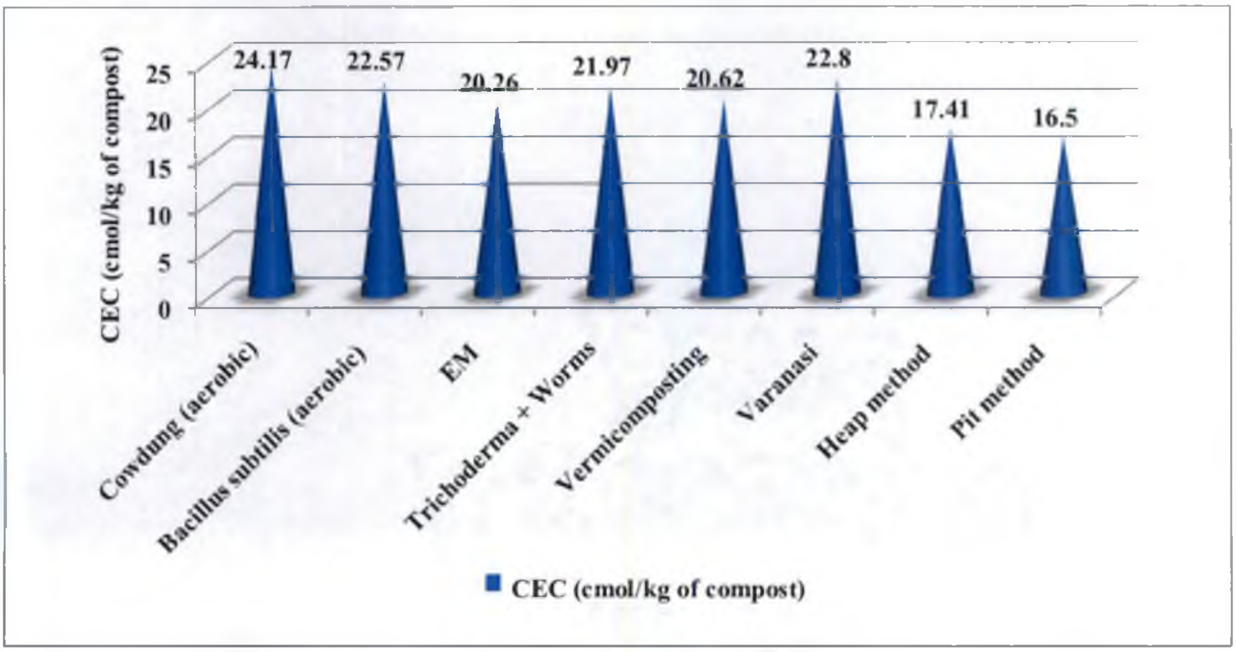

Fig. 8 Influence of composting methods on CEC of compost

5.1.2. Chemical parameters

Chemical parameters like pH, Cation Exchange Capacity (CEC), Total Volatile Solids (TVS), organic carbon, C: N ratio, NPK content and micronutrient analysis give more information on compost stability and maturity.

Compost obtained from different composting methods had attained a neutral to alkaline pH (7.9-8.0). Alkaline pH of 7.9 and 8.0 was observed in composting using trichoderma and worms and vermicomposting respectively. The alkaline nature of compost obtained through composting using trichoderma might be due to the presence of talc (which is chemically $CaCO_3$) used as a carrier in the preparation of trichoderma. The pH of aerobic composting using cowdung recorded almost neutral pH (7.0) during the final stage of composting. Iqbal *et al.* (2012) has reported that during the final stages of composting, pH becomes neutral when organic acids get converted to CO_2 by microbial activity. In vermicomposting pH recorded was 8.0. This might be due to the excretion of calcium from the calciferous glands of earthworms. It is more or less a substrate controlled factor in composting. However none of the methods of composting was found to have significant influence on pH of the compost.

Cation Exchange Capacity (CEC) is a chemical parameter used to determine the quality of compost as organic manure. CEC measures the quantity of negative charges in the matrix to hold the negative charges. It not only reflects the decomposition rate, but also measures the capacity of compost to hold nutrients. Neither of the composting methods could attain CEC greater than 60 C mol kg^{-1}. But among the different methods of composting, highest CEC was recorded in aerobic composting using cowdung (Fig.8). This might be due to the presence of readily decomposable cowdung which is rich in humic material with high CEC. Moreover higher CEC in aerobic composting is an indicator of more rapid decomposition of organic matter than in other methods. Iqbal *et al. (2012)* has stated that higher CEC in aerobic sample during active composting stage is an indicator of more rapid decomposition of organic matter. Except pit and heap method, all the methods of composting showed CEC in the range of 20-24 cmol/kg of compost. Lax *et al.* (1986) reported that CEC in organic material increases as function of humification due to the formation of carboxylic and phenolic functional groups.

CEC value greater than 60 C mol kg^{-1} (on an ash-free material basis) was suggested as the minimum value needed to ensure an acceptable degree of maturity (Harada et al., 1981). CEC greater than or approximately 60 is considered to be sufficiently matured for the application to crops. (Baca *et al.,* 1992). Humus is the major contributing factor for cation exchange capacity. In all the composting methods, the substrate used was crop residue and the humus contributing material was less. This might be the reason for lower values of cation exchange capacity. However the compost obtained from different methods did not show CEC greater than or approximately equal to 60, the compost obtained from different composting methods has helped in attaining other parameters of maturity.

The C: N ratio has been used as an index of compost maturity in composting process. Carbon reduction was greater when compared to nitrogen content in all the methods of composting. This might be due to the use of carbon as source of energy and nitrogen for building cell structure in decomposition process. Percentage reduction in C: N ratio one month after composting was 22.39 percent, 23.11 percent and 24.47 percent for pit, aerobic composting using cowdung and aerobic composting using effective microorganisms respectively. Higher reduction of C: N ratio in aerobic composting (Fig. 9) was due to the nature of aeration and the same became stable earlier than other methods. The C: N ratio showed a decreasing trend in all the stages of composting. There was a rapid reduction in C: N ratio with respect to composting using effective microorganisms. This may be due to the high count of microorganisms in the initial inoculum which might have lead to the consumption of large quantity of carbonaceous material. The reduction in carbon content when compared to the initial content was greater in all the methods of composting which might be due to the use of carbon as a source of energy for microorganisms. Use of effective microorganisms as inoculum has helped in increasing microbial activity. Except varanasi composting (16.05%), all the other methods of composting had lower C: N ratio. The lack of sufficient aeration might have hindered the decomposition process in varanasi composting which resulted in higher C: N ratio. As there is excess carbon, the nitrogen utilized was also less. Iqbal *et al.* (2012) have reported lesser utilization of nitrogen in anaerobic composting. C: N ratio <20 was established by Bernal *et al.,* (2009) as a maturity index for composts of all origins.

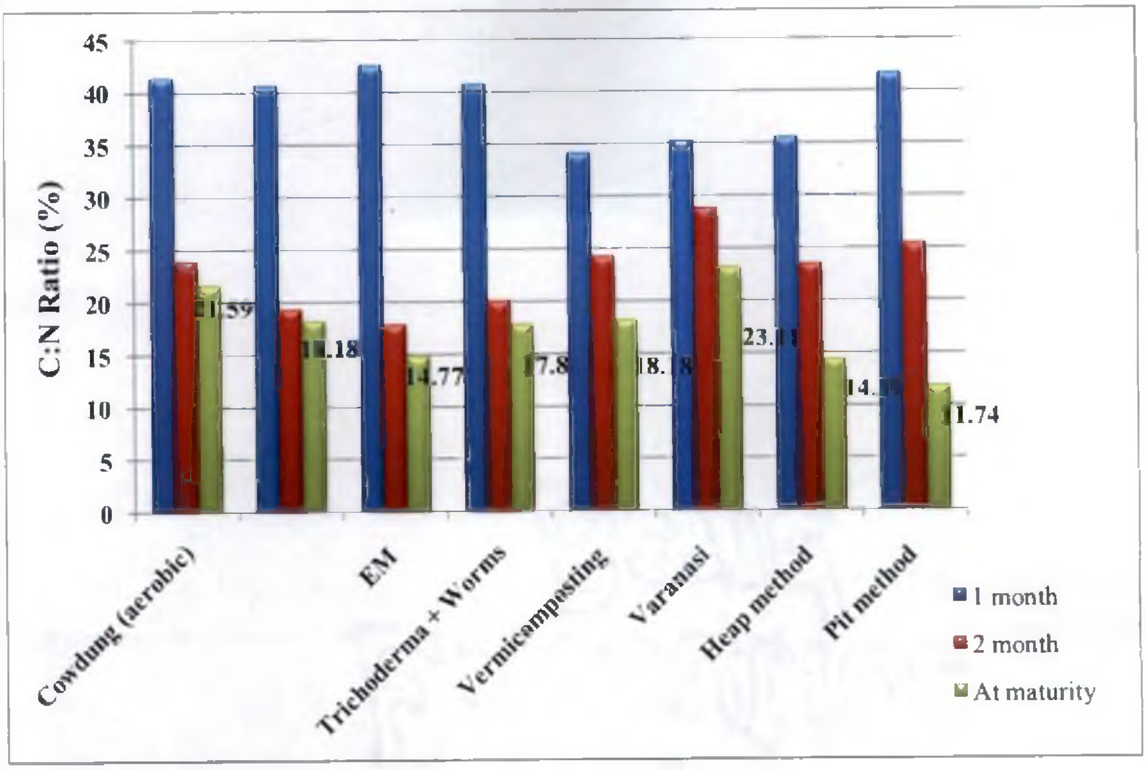

Fig. 9 Influence of composting methods on C:N ratio

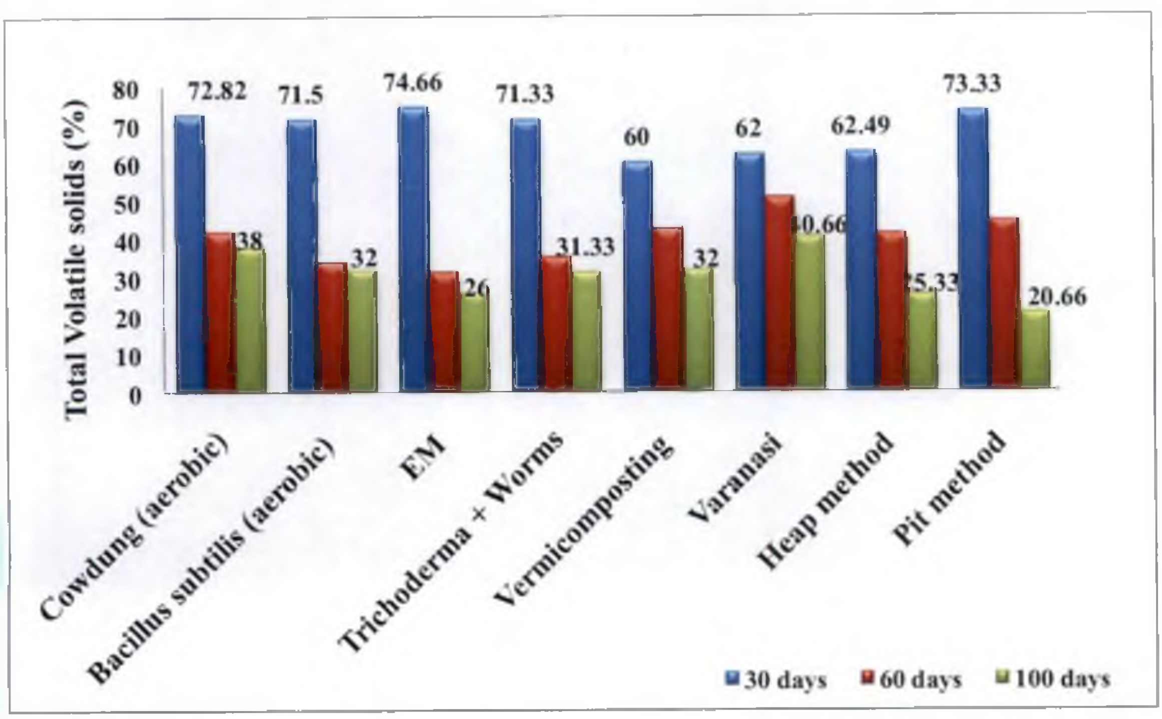

Fig. 10 Influence of composting methods on total volatile solids

The intense microbial activity during composting process will lead to the production and release of volatile organic compounds. Total volatile solids are found decreasing as the composting proceeds in all the methods (Fig. 10). Kumar *et al.* (2011) reported high emission rate of volatile organic compounds at early stage of composting than in the later stage. Aeration substantially influences emission of volatile solids. During the first month of composting, rapid reduction in carbon was recorded in composting using effective microorganisms accompanied by higher emission of volatile compounds. Kilikowska and Klimiuk (2011) reported that volatile organic compounds are significantly correlated with organic matter degradation. Moreover ventilation substantially impacts the emission of volatile compounds. In the later stages, volatile solids were higher in varanasi composting. The volatile organic production within the varanasi pile were not diffused timely after the emission due to the partial anaerobic condition. Muller *et al.* (2004) reported that excessive aeration speed up the process of emission of total volatile solids from compost pile.

Composting methods showed significant variation in nitrogen content (Fig. 11). Nitrogen content was found to be the highest in compost obtained using effective microorganisms followed by aerobic composting using cowdung. This was a consequence of strong degradation of organic carbon compounds at an early stage of composting which reduced the weight of dry mass. These findings were supported by (Bustamante *et al.*, 2008). Nitrogen content was significantly less in varanasi composting. The anaerobic nature of varanasi composting resulted in lower reduction of C: N ratio which in turn resulted in lesser utilization of nitrogen by microorganisms for building body structure. Phosphorus content was registered as the highest in varanasi composting. This might be due to the addition of rock phosphate present as one of the inoculum. Among the methods of composting, vermicompost had the highest potassium content. This might be attributed to the direct action of gut enzymes of the earthworm. Vermicomposting involves bio-oxidation and stabilization of organic material by joint action of microorganism and earthworms (Gandhi and Sundari, 2012). Rao *et al.* (1996) has reported that the increase in potassium in vermicompost in relation to that of the simple compost and substrate was probably because of physical decomposition of organic waste due to biological grinding during passage through the gut coupled with enzymatic activity in worm's gut, which might have caused its increase.

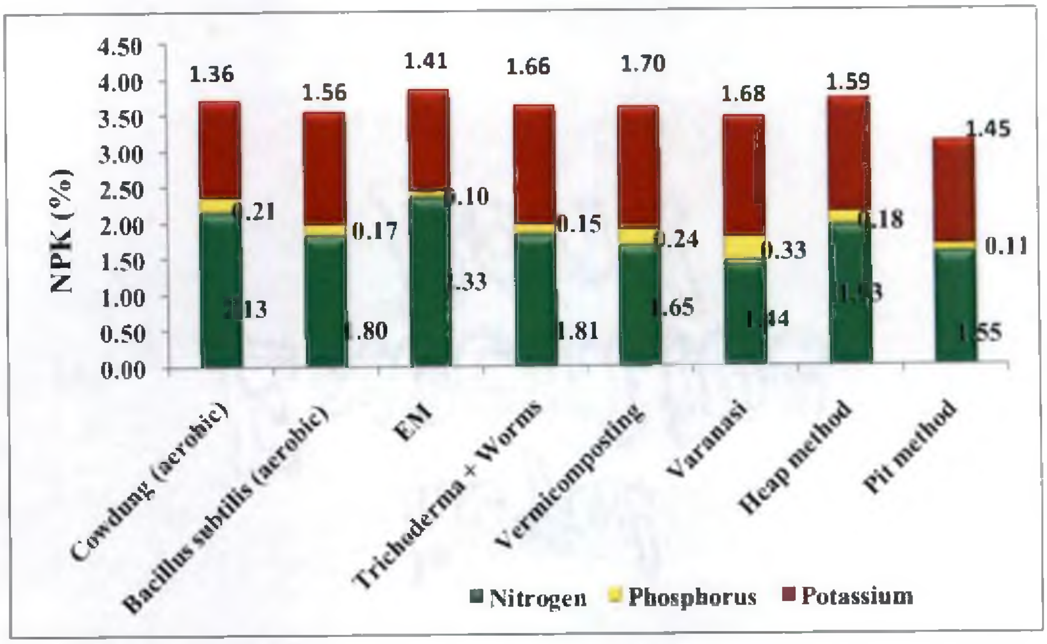

Fig. 11 Influence of composting methods on NPK content in mature compost

An increase in nutrients compared to the initial content was observed in all the methods of composting. Copper was highest in treatments were earthworms were introduced. This might be due to the biological activity of the microorganisms leading to increased nutrient availability. Freely available ions and minerals have been produced during ingestion and excretion of organic matter by earthworms. Zinc content was highest in composting using cowdung and varanasi composting.

5.1.3. Biological parameters

Presence of large and diverse population of micro organisms which got multiplied in the end product of composting indicated its potential in terms of fast and effective soil application. Microorganisms and macro organisms present in the compost vary with method of composting. Earthworm count was found highest in composting methods were earthworms were introduced.

Microbial colonies like bacteria, fungi and actinomycetes were also present in large numbers in mature compost. This shows the suitability of compost as an organic manure. The fungal activity was higher in composting using trichoderma and worms. This may be due to the presence of trichoderma. De Bertoldi *et al.* (1983) reported that fungi increase normally when remaining substrate in the compost are predominantly cellulose and lignin which normally occurs during the later stages of composting. The highest activity of actinomycetes was found in vermicomposting and varanasi method of composting. Actinomycetes also tend to grow in the later stages of composting which may attack polymers such as hemicelluloses, lignin and cellulose. They tend to grow in the later stages of composting (De Bertoldi *et al.*, 1983). The bacterial count was maximum in varanasi composting. Golueke (1992) reported that fungi were involved in the decomposition of cellulose and lignocellulosic compounds of the compost and they provided more readily available carbon to the bacteria.

Forster *et* al. (1993) reported that dehydrogenase activity could be chosen as an index of microbiological activity because it referred to a group of mostly endocellular enzymes which catalysed the oxidation of soil organic matter. The highest dehydrogenase activity was noted in aerobic composting using cowdung followed by varanasi method of composting. The dehydrogensae activity was significantly less in pit and heap method of composting.

The lack of air circulation through different layers of composting might have caused an unfavourable condition for active microorganisms to multiply resulting in reduced activity of dehydrogenase. Sufficient air circulation and more number of active bacteria in cowdung resulted in increased activity of dehydrogenase in composting using cowdung. Though varanasi method is partially anaerobic, the high enzyme activity may be due to the more number of active bacteria harbored in the immature cattle manure which was used as inoculum in the above method. Moreover in varanasi composting, the quantity of cowdung added was three times more than in other methods.

Immature cattle manure harbored high number of active bacteria and as the digestion proceeded, the bacterial number decreased (El-Shinnawi *et al.*, 1988). In addition to it, air circulation facilitated the growth and colonization of organisms. Towards the end of composting, no further decomposition was taking place as carbon and nitrogen became stabilized and as a result both microbial and dehydrogenase activities stabilized to optimum levels. Dehydrogenase activity is the simplest, quickest and cheapest method that can be used to monitor the stability and maturity of compost. Dehydrogenase activity demonstrated that it is possible to monitor the composting process more easily and rapidly by avoiding longer and more expensive analytical procedures.

5.1.4. Phytotoxicity studies

Phytotoxicity caused by the presence or absence of organic chemicals in stable compost impair germination and plant growth. More than 75 percent germination of tomato seeds was noticed in compost extract and compost used as potting mixture.

The response of germination in tomato seeds using compost extract and potting mixture differed on first day but increased to more than 90 percent by day five. Germination studies using compost extract indicated that compost obtained from none of the method is phytotoxic.

When seed germination using compost as potting mixture was carried out, high germination percentage was observed in all the methods of composting. In varanasi composting, germination of 96.67 percent was noted on fourth day. Germination percentage of more than 75 percent indicated that compost obtained from all the methods of composting can be safely applied to soil due to absence of phytotoxicity.

It was found that though phytotoxicity was not present in any of the compost, the quality was not the same as the germination percentage was different on the first day in both the tests.

The heavy metal content values of compost obtained from different methods of composting were within the permissible limit proposed by Fertiliser Control Order (FCO, 1985). Here the substrate used was similar. This indicated that methods of composting had no significant influence in the presence of heavy metals. If heavy metal contamination was reported in any method, this may not be due to the method of composting but may be due to the substrate used for composting.

5.2. Suitability of compost obtained from different composting methods as organic manure for bhindi crop

5.2.1. Influence of composting methods on biometric and yield attributes

Application of compost obtained from different composting methods has significant influence on the yield of bhindi crop. Varanasi composting, vermicomposting and composting using effective microorganisms produced higher yield in bhindi compared to other components. The lowest yield was obtained by adding compost obtained from pit method. As the quantity of compost applied to each treatment was based on the nitrogen content of the final compost obtained from different method of composting in comparison with nitrogen (N) content of farm yard manure (FYM), due to the low nitrogen content in varanasi composting, the quantity of varanasi compost added to crop in comparison to N content of FYM was higher (Table 3.2). This in turn benefited the crop in obtaining other nutrients present in the compost which in turn resulted in more number of branches and leaves of the crop. Except N, all the other nutrients in varanasi compost was comparatively higher. Hence by applying higher quantity of varanasi compost, the crop obtained higher quantity of organic matter and other nutrients. This may be the reason for higher yield in varanasi compost applied crop. The dry matter content was also higher in varanasi method of composting. It might be due to the availability of more mineral nutrients in the rhizosphere and flux of nutrients into the root due to the addition of more quantity of compost.

Even though the quantity of compost obtained from pit method of composting was applied in higher quantity, the other nutrient elements in compost obtained from the above method was less. The yield increase in varanasi compost, vermicompost and effective microorganism compost may be due to higher production of leaves and branches. This increase in growth parameter was due to the increased NPK uptake by plants in the above treatments. Nitrogen uptake was higher in crops treated with compost obtained using effective microorganisms and varanasi composting which may be due to the presence of high nitrogen content and addition of more quantity of compost respectively. Phosphorus uptake was higher in varanasi composting. This might be due to the higher content of phosphorus content in varanasi composting in which rock phosphate (RP) was an ingredient during the compost preparation.

The favourable effect of compost on the growth characteristics of plant may be due to the ability of the compost to enhance the physical, chemical and biological properties of soil. Similar findings were reported by Hanafy *et al.* (2002) on *Eruca vesicaria* Sub sp. *sativa*. Different rates of compost were added based on nitrogen equivalent basis. The improvement in yield and yield attributes made after the addition of organic manure not only depends on nitrogen content alone, but also on the quantity of compost added. The higher the quantity added, higher will be the improvement in the soil chemical and physical properties, which in turn resulted in higher yield. Comparitively higher quantity of compost was added in plant grown using vermicomposting. The earthworm count was higher in vermicomposting, composting using trichoderma and varanasi method of composting. The compost attracts earthworms and provides them with a healthy diet. The presence of earthworms, centipedes, sow bugs, and other soil organisms in the organic material might have slowly broken down releasing nutrients as food passed through their digestive tracts. This might have resulted in more balanced soil ecology for the growth of plants which resulted in higher yield. Moreover, this has also reflected in the yield and morphological characters of plant growth in the above treatments. The increase in yield in other treatments may be attributed to the increased fruit weight in addition to the nutrient supply from the addition of compost obtained from different methods of composting.

Compost amendments to soil stimulated the growth and nutrient uptake in bhindi. Potassium uptake was comparatively higher in vermicomposting. This might be due to the availability of potassium in easily available form in the compost.

Atiyeh *et al.* (2002) reported that during vermicomposting, the nutrients locked up in the organic waste were changed to simple and more readily available and absorbable forms such as nitrate or ammonium nitrogen, exchangeable phosphorus and soluble potassium, calcium and magnesium in worm's gut. However phosphorus uptake was higher in aerobic composting using cowdung. This might be due to the presence of higher CEC in the same. Epstein *et al.* (1976) reported that compost may affect the release of nutrients to plants directly through the nutrients present in them or indirectly by their effect on the cation-exchange capacity. Thus, higher cation-exchange capacity of compost materials might have been reflected in the nutrient uptake by plants in aerobic composting using cowdung.

Varanasi compost, vermicompost and composting using effective microorganisms significantly improved plant growth. Our results suggest that compost obtained from none of the composting methods has detrimental effect on plant growth as the yield of bhindi obtained by the application of different compost was either more or similar to that of FYM application as per package of practice recommendation.

5.2.2. Influence of composting methods on nutrient uptake

As regard to the effect of treatments on chemical composition of plants, significant difference was found in nitrogen and potassium uptake in plants treated with different compost, while the differences were not significant for phosphorus uptake in plants treated with compost. The increase in the nutrient content might be due to the positive effect of compost and microorganisms in increasing the surface area of root per unit of soil volume, water-use efficiency and photosynthetic efficiency which directly affects the carbohydrate utilization and physiological processes. Supporting findings were given by El-Ghadban *et al.* (2002) and reported that application of compost to crops lead to an increase in carbohydrate percentage.

The plant response to compost obtained from effective microorganism was higher in terms of nitrogen uptake because of high content of nitrogen in compost produced from effective microorganisms and the lowest uptake was recorded in crops treated with compost prepared using heap method. The phosphorus uptake was found to be the highest in varanasi applied crop due to the high content of phosphorus in varanasi compost. The compost prepared from heap method showed the lowest potassium uptake. The potassium uptake was highest in vermicompost applied crop as the potassium content was higher in vermicomposting.

5.2.3. Influence of composting methods on nutrient status of the soil

Even though the quantity of organic matter applied was different, no significant difference was noticed in soil organic carbon after the harvest of the crop among different treatments. Supporting findings were given by Giusquiani *et al.* (1995) who reported that rate of decomposition of organic matter in soils as not proportional to the amount of organic carbon added with soil. More the organic matter added, the more rapidly it disappears. But there was an increase in organic carbon in all the treatments than the initial content (0.9). Soil pH benefits with addition of compost. There was a slight increase in pH as compared to the initial value of 6.2. Compost buffer the soil pH by raising or lowering pH.

The result showed that the compost obtained from different methods of composting had a pH near to alkaline range except pit method which showed acidic range of pH. The acidic pH may be due to the presence of acidic nature of the soil. The addition of composts adds nutrients to the soil. There was a positive and significant increase in available NPK content as compared to the initial percentage in all the treatments after the addition of compost obtained from different methods.

Available nitrogen after the harvest of the crop was found higher in treatments receiving compost prepared using *Bacillus subtilis.* This might be due to the lower nitrogen uptake by crop in these treatments. The dry matter production was also comparatively less in the treatments. Available phosphorus content was significantly higher in FYM amended crop.

The quantity of Farm Yard Manure (FYM) was added at a higher dose in control due to the less nitrogen content present in FYM. This might have resulted in higher mineralization of available phosphorus. Joseph *et al.* (1995) reported that organic manure at higher dose enhanced mineralization of native P. But the uptake of phosphorus was relatively less which resulted in comparatively lesser dry matter production. Available potassium content was also more in FYM added crop due to the lesser uptake of potassium and lesser dry matter production. This lesser crop removal of phosphorus and potassium resulted in high soil phosphorus after the crop harvest.

Summary

6. SUMMARY

The present investigation entitled "Influence of composting methods on compost maturity and quality" was carried out to study the effect of different composting methods on compost maturity and quality and to evaluate the suitability of compost obtained from various composting methods as organic manure. The composting period was from June to September 2013 and suitability of compost as organic manure was studied from November 2013 to February 2014 in bhindi crop.

The experiment was conducted at Plant Propagation and Nursery Management Unit (PPNMU), Vellanikkara, Thrissur. Banana pseudostem both fresh and 2-5 week's old and green leaves of glyricidia was used as common substrates for all the methods of composting. The inoculum used in different methods of composting included cowdung, *Bacillus subtilis,* effective microorganisms, earthworm, rock phosphate, trichoderma and varanasi composter depending on the method of composting. There were eight methods of composting such as aerobic composting using cowdung, *Bacillus subtilis*, composting using effective microorganisms, composting using trichoderma and worms, vermicomposting, varanasi composting, heap and pit method of composting. The compost obtained from different methods was tested for its maturity and stability parameters. In the second experiment, composts obtained from the above composting methods were tested for its suitability as organic manure in bhindi crop (variety Arka Anamika) with farm yard manure alone as control. The dose as well as schedule for fertilizer application was carried out as per package of practice recommendations of Kerala Agriculture University. Biometric and yield observations, plant analysis, soil analysis and economics of cost of composting methods were worked out. The results of the study are summarized and listed herewith:

1. All the composting methods helped in attaining compost maturity in the period of three to four months. Physical, chemical and biological parameters varied with method of composting.
2. Based on the yield of compost obtained from total quantity of substrate and inoculum used for composting, the highest yield was obtained from varanasi composting followed by aerobic composting using cowdung.

3. Based on the percentage recovery, the highest yield was obtained from aerobic composting using cowdung followed by vermicomposting.
4. It was observed that the yield was increased with the addition of cowdung. More the quantity of cowdung added, the more will be the yield. That was the reason for increased yield in varanasi composting with three times additional quantity of cowdung.
5. Even though the yield obtained was less with composting using trichoderma and worms and aerobic composting with *Bacillus subtilis*, compost from these methods attained maturity and stability. Hence, these methods can be used as an alternative to cowdung whenever the availability of cowdung is less.
6. Compost obtained from all the methods attained physical parameters like dark brown to black colour and it was odourless.
7. Maximum particle reduction was observed in composting using worms and more than 70 percent of the compost obtained passed through 2mm sieve unlike in the heap method.
8. Volume reduction during composting was more than 80 percent in all aerobic methods except pit method.
9. All the composting methods helped to attain chemical parameters such as reduction in C: N ratio, increased cation exchange capacity and total volatile solids.
10. Nutrient content of the compost produced was more than the initial substrate and nitrogen was found to be highest in composting using effective microorganisms. Phosphorus and potassium content was found higher in varanasi and vermicompost respectively.
11. None of the composting methods had phytotoxicity effects as more than 80 percent germination was obtained when germination test was conducted in compost extract and compost as potting mixture.
12. Dehydrogenase activity was found to be more in aerobic composting followed by varanasi composting and it was an indication of the microbial activity of compost and was an easy method to monitor the compost maturity and stability.

13. Application of compost obtained from different methods of composting significantly influenced the performance of crop.
14. Growth and yield performance of crop due to compost application not only depended on the nutrient content, but the quantity of compost added as organic manure.
15. Crop performance was superior in varanasi compost followed by vermicompost. The application of compost was done based on the content of nitrogen equivalent to farm yard manure. Because of the low nitrogen content of varanasi composting the compost added was more which resulted in higher yield.
16. Compost maturity parameter and crop response to compost for all these rapid methods of composting such as aerobic composting using cowdung, *Bacillus subtilis,* composting using Trichoderma and worms, vermicomposting and varanasi composting was superior than pit method and heap method of composting.

The results of the study indicated that composting methods has significant influence on physical, chemical and biological parameters of maturity. Even though the yield produced vary with composting methods, all the methods helped to attain maturity and stability parameters. Quality of compost as organic manure also varied with the method of production. The growth and yield performance of crop depended not only on the nutrient content of the compost but the quantity of compost added as organic manure.

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Appendices

APPENDIX-I

Meteorological data for the experimental period

(from 01-06-2013 to 28-02-2014)

Standard week No.	Date and month	Temperature Max.°C	Temperature Min.°C	Relative humidity (%) I	Relative humidity (%) II	Total rainfall (mm)	No. of rainy days
22	28/5-3/6	29.4	23.5	96	79	217.8	5
23	4/6-10/6	29.5	22.8	95	79	160.4	6
24	11/6-17/6	28.1	23.2	97	87	330.3	7
25	18/6-24/6	27.7	23.0	98	86	308.4	7
26	25/6-1/7	28.7	22.9	96	83	104.5	6
27	2/7-8/7	28.7	22.8	97	97	6.5	7
28	9/7-15/7	28.2	22.8	97	97	4.2	7
29	16/7-22/7	27.3	22.7	97	90	277.4	7
30	23/7-29/7	29.1	22.3	96	79	191.6	6
31	30/7-5/8	28.4	22.8	96	81	271.4	7
32	6/8-12/8	29.5	23.5	96	72	4.3	1
33	13/8-19/8	29.9	23.1	96	71	41.3	7
34	20/8-26/8	30.1	22.5	97	70	16.4	3
35	27/8-2/9	32.0	23.2	94	68	0.4	0
36	3/9-9/9	29.5	22.0	96	76	66.5	4
37	10/9-16/9	29.0	22.1	96	79	196.9	6
38	17/9-23/9	29.7	22.8	96	76	66.4	4
39	24/9-30/9	30.7	21.6	93	69	14.8	3
40	1/10-7/10	31.0	21.5	96	62	15.2	1
41	8/10-14/10	30.9	22.6	96	69	69.3	4
42	15/10-21/10	30.6	23.1	96	72	152.6	5
43	22/10-28/10	29.8	23.0	97	77	104.1	4
44	29/10-4/11	32.8	24.0	89	65	29.8	2
45	4/11-11/11	32.6	24.1	76	54	0.0	0
46	12/11-18/11	31.9	23.2	87	63	61.3	3
47	19/11-25/11	32.9	23.9	94	63	13.2	1
48	26/11-2/12	32.8	24.0	92	60	6.8	1
49	3/12-9/12	32.5	22.4	81	44	0.0	0
50	10/12-16/12	32.3	22.5	87	51	0.5	0
51	17/12-23/12	31.2	21.8	71	43	3.0	0
52	24/12-31/12	31.4	22.1	66	39	0.0	0
1	1/1-7/1	32.9	22.4	74.0	34.4	0	0
2	8/1-14/1	32.8	23.1	67.6	36.7	0	0
3	15/01-21/01	33.0	23.7	63.4	36.9	0	0
4	22/01-28/01	32.7	23.3	63.1	38.0	0	0
5	29/01-04/01	33.9	22.3	60.3	32.7	0	0
6	05/01-11/02	35.2	21.0	74.4	25.1	0	0
7	12/02-18/02	33.5	22.6	89.3	51.3	0	0
8	19/02-25/02	35.2	24.3	70.3	37.9	0	0
9	26/02-04/03	35.2	24.7	77.1	41.6	0	0

APPENDIX-2

Variation in temperature of different composting methods during the period from June 2013 to September 2013

Treatments	1st week	2nd week	3rd week	4th week	5th week	6th week	7th week	8th week	9th week	10th week	11th week	12th week	13th week	14 we
Cowdung (aerobic)	28.85	28.66	28.65	28.34	28.23	27.46	27.84	27.97	27.97	27.97	29.29	28.90	28.31	28
Bacillus subtilis (aerobic)	28.40	28.37	28.24	28.24	27.94	27.53	27.85	27.89	27.89	27.89	28.71	28.61	28.21	27
EM	28.25	28.01	28.29	28.16	27.84	27.32	27.59	27.73	27.73	27.73	28.69	28.43	28.02	27
Trichoderma + Worms	28.84	28.88	28.70	28.44	28.12	27.49	27.80	27.96	27.96	27.96	28.83	28.71	28.30	28
Vermicomposting	28.60	28.93	28.76	28.65	28.39	27.49	27.98	28.13	28.13	28.13	29.16	28.96	28.55	28
Varanasi	30.38	30.09	29.56	28.75	28.54	27.76	28.27	28.33	28.33	28.33	29.28	29.92	29.50	29
Heap method	29.91	29.57	29.73	34.29	28.71	27.99	28.60	29.90	29.90	29.90	29.36	29.20	29.00	28
Pit method	32.26	31.69	31.19	31.01	29.81	28.86	29.20	29.72	29.72	29.72	30.08	29.85	29.26	28
Atmospheric temperature	27.44	28.26	28.63	28.07	24.08	28.10	28.26	29.64	24.96	30.00	30.66	29.43	29.57	29

APPENDIX-3

Benefit cost analysis of different composting methods converting one tone waste into compost

	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
Fixed cost								
Fixed cost of tank for 1 tonne	5500	5500	5500	5500	5500	–	–	–
Life period (10 yrs)	10	10	10	10	10	–	–	–
Depreciation (10%)	550	550	550	550	550	–	–	–
Repair and Maintenance (2%)	110	110	110	110	110	–	–	–
Total	660	**660**	**660**	**660**	**660**	**0**	**0**	**0**
Variable cost								
Cost of inoculum	120	150	170	770	820	930	120	120
Labour cost	1650	1650	1650	1650	1650	825	1650	2775
Interest on WC (7.5%p.a.)	33	34	34	45	46	33	33	54
Total	**1803**	**1834**	**1854**	**2465**	**2516**	**1788**	**1803**	**2949**
Total Cost	**2463**	**2494**	**2514**	**3125**	**3176**	**1788**	**1803**	**2949**
Returns	1512	830	676	1132	1342	1547	1072	1258
Earthworms	0	0	0	1260	1442	0	0	0
Total Returns	**1512**	**830**	**676**	**2392**	**2784**	**1547**	**1072**	**1258**
BC ratio	0.62	0.34	0.27	0.77	0.87	0.86	0.60	0.43

Abstract

INFLUENCE OF COMPOSTING METHODS ON COMPOST MATURITY AND QUALITY

By

HARSHA NARAYANAN

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ABSTRACT OF THE THESIS

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Kerala Agricultural University, Thrissur

Department of Agronomy

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

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ABSTRACT

One of the important factors affecting the successful use of compost for agricultural purpose is compost maturity because immature compost can be detrimental to plant growth and soil environment. Compost obtained from many of the rapid methods is found to be coarser and need to be evaluated for maturity and quality prior to its agricultural use. Although the practical applicability and benefits of composting methods are widely known, there has been very limited effort towards scientific documentation and evaluation of the biodegradation process, along with quality evaluation of its end product and post application efficiency. The present study was proposed against this backdrop to study the influence of various composting methods on its end product quality, particularly in terms of its stability and maturity status and to evaluate whether the compost obtained from these methods can be directly used as manure.

An investigation entitled 'Influence of composting methods on compost maturity and quality' was conducted at Plant Propogation and Nursery Management Unit, Vellanikkara to study the effect of composting methods on compost maturity and quality and evaluate the suitability of compost obtained from various composting methods as organic manure on the growth and yield performance of bhindi crop.

The experiment consisted of eight methods of composting (T_1-Aerobic composting using cowdung, T_2- Aerobic composting using *Bacillus subtilis* (KAU culture), T_3- Composting using effective microorganisms, T_4- Composting with Trichoderma and worms, T_5 - Vermicomposting, T_6- Varanasi composting, T_7- Heap and T_8- Pit method of composting).

The compost obtained from all the composting methods helped to attain physical, chemical and biological parameters of compost maturity at varying degree. The highest yield was recorded in varanasi composting followed by aerobic composting using cowdung. Based on the recovery percentage, the highest compost recovery was noticed in aerobic composting using cowdung. The nutrient content of compost obtained from all the composting methods was in the permissible limit. Even though the quantity of compost produced was less using microbial culture, compost produced has attained all the maturity parameters.

In the absence of cowdung, composting using *Bacillus subtilis* (KAU culture), and Trichoderma and worms can be used as substitute for cowdung. Germination studies using compost extract and compost as potting mixture revealed that the compost produced were not phototoxic in nature and the heavy metal content was in the permissible limit. Based on the compost yield and better parameters of maturity, aerobic composting, varanasi composting and vermicomposting were found superior.

The experiment to evaluate the suitability of compost as organic manure in the performance of bhindi crop consisted of nine treatments including compost obtained from eight different composting methods and farm yard manure. The organic manure requirement of the crop was substituted by compost and the quantity was decided based on nitrogen equivalent basis of farm yard manure requirement of bhindi (12t/ha). Crop performance was significantly higher with varanasi compost, vermicompost and compost using effective microorganisms. There was significant increase in available soil nutrient content after the addition of compost as compared to the initial content in all the treatments.