Madras Agric. J., 83(10): 609-618 October 1996
https://doi.org/10.29321/MAJ.10.A01062

REVIEW

COMPOST MATURITY : CAN IT BE EVALUATED ?

T.KALAISELVI AND K. RAMASAMY

Fermentation Laboratory
Department of Environmental Sciences
Agricultural College and Research Institute
Tamil Nadu Agricultural University
Coimbatore 641 003.

ABSTRACT

The preparation and use of different grades of composts has created a need for assessing the quality of the composts. A mature compost is hygienic and humified so that it improves soils and nourishes plants. An immature compost emits foul odours, may injure plants and pollute the environment. Assessing the maturity of the compost is however, a difficult task due to the present incomplete understanding of the parameters involved. Numerous indices that have been proposed in the literature for determining the maturity are reviewed in this article. Upon review, it is concluded that none of the parameters discussed is 90 per cent sure of deciding the quality. Combination of methods is required to test the quality standard. However, most of the methods are costly and require sophisticated instrumentation. Reliable methods and protocols are summarised for perfection.

KEY WORDS : Compost, Maturity, Evaluation, Parameters

INTRODUCTION

Degradation of soil physical condition and risk of erosion are closely related to intensive cultivations that cause a gradual decrease in the soil organic matter content. The agronomic utilisation of organic wastes such as agricultural industrial and domestic wastes has been increasing because of the need to lower disposal costs, recycle nutrient elements in the soil-crop system and counteract the decreasing organic matter content of soil. However, application of these organic wastes to soil is not always beneficial to crop growth. Maturity and stability of composts critically affect their successful utilisation in agriculture (Inbar *et al.*, 1990a). This is especially important when composts are applied before sowing or when they are used in container medium. When stabilisation is not achieved, decomposition continues after it has been applied to the soil. Due to this, foul odours emanate and metabolites toxic to plants are produced. Therefore, care must be taken in the reutilisation of wastes as organic fertilizers and it is essential to understand the characteristics of the compost to avoid any undesired effects. Numerous methods have been proposed for evaluation of maturity and stability of the composts. Although, the problem has been investigated extensively, unequivocal standards for maturity are yet to be established.

WHAT IS COMPOSTING?

Composting is a biological conversion of heterogenous organic substrate, under controlled conditions, into a hygienic, humus rich, relatively biostable product that conditions soils and nourishes plants.

METHODS OF COMPOSTING

The Indore Method

The Indore method was developed by Howard and Wad (1931) at Indore. This method requires a heap of trapezoidal cross section. The heap is about 4 m to 5 m in length, 1 m in breadth and 1 m in height. The heap is alternately layered with carbonaceous and nitrogenous wastes, starting with 20 cm of carbon rich and 10 cm of nitrogen rich material. Finally it is covered with soil or hay as thermal insulator. Under these conditions, the rate of decomposition is very rapid and high temperatures develop quickly. The process is accelerated by periodically turning the materials. In this method, losses of organic matter and nitrogen are very high, amounting to 50 to 60 per cent of the initial levels.

The Bangalore Method

Acharya (1939) developed the Bangalore Method to produce compost from city refuse and night soil in pits. Pits of about 1 m depth, breadth and length are used. In this process, at first the refuse is dumped into the trench and spread out with rakes to make a layer of 15 cm. Night soil is then discharged and spread over the refuse in a layer of about 5 cm. This is then covered with a 15 cm layer of refuse. The night soil and the refuse thus follow in alternate layers until the pit is filled to 15 cm above ground level, with a final layer of refuse on the top. This may be dome-shaped and covered with a thin layer of soil. The decomposition of dumped materials in the pit takes place largely in the absence of air except in the surface layer. This anaerobic decomposition is comparatively slow but markedly less wasteful.

High temperature compost

High temperature compost is prepared from night soil, urine, sewage and animal dung and chopped plant residues at a ratio of 1:4. The materials are heaped in alternate layers starting with chopped plant stalks and followed by human and animal wastes. Water is added to optimum amount.

At the time of making the heap, a number of bamboo poles are inserted for aeration purposes. After the heap formation, it is sealed with 3 cm of mud plaster. The bamboo poles are withdrawn after one day of composting, leaving the holes for aeration of the heap. Within four to five days, the temperature rises to 60 to 70°C and the holes are then sealed. The first sealing is usually done after 2 weeks and the moisture is made up with water or animal or human excreta; the turned heap is again sealed with mud. The compost is ready for use within two months and is considered free from pathogens.

The Windrow Composting

The windrow composting is a traditional and widely practiced method of composting in USA (Kuchenrither *et al.*, 1984). In this process, the waste materials are piled in long rows of 2 to 4 m width and 1 to 2 m height on a hard surface and usually in the open area. Aeration of the windrow is by periodic turning using equipment such as front end loader or by specially designed machinery. Occasionally forced aeration in conjunction with turning has been applied to the windrow process.

The Static pile Composting

In static pile method of composting a mixture of soild wastes is stockpiled in the open air and turned occasionally for aeration. This technology is considered to waste both ammonia and energy. But these disadvantage have been substantially mitigated by mechanical forcing of air through perforated pipes at the bottom of the static pile by a. continuous air suction, or b. continuous air blowing or c. alternate air blowing or d. alternate blowing and sucking or e. intermittent air blowing to keep the temperature below 60°c. There are two kinds of static pile composting system. One, the Beltsville process in which piles are aerated by time controlled system (Willson *et al.*, 1980). Another, the Rutgers process, involves blowing air through the compost mass in response to a thermistor and fan both controlled by a microcomputer to maintain temperatures below 60°C (Finstein *et al.*, 1980).

Composting in enclosed or reactor based systems

In the enclosed mechanical composting system, the process takes place in a vessel or bioreactor. Advantages of these systems are that external environmental factors do not affect the process, less land is required and that better odour and operational control are possible. Disadvantages are that these systems require high equipment, maintenance and energy costs.

Synthetic compost

In the preparation of synthetic compost, the organic nitrogen in the form of dung required by microorganisms can be completely substituted with inorganic nitrogen compounds like ammonium sulphate or urea which are utilised equally effectively for decomposition of carbonaceous materials into compost. This facilitates utilisation of large quantities of various organic waste materials where supplies of dung are limited or not available at all as in mechanised farms. The manure becomes ready for application in about 4 to 6 months (Gaur and Sadasivam, 1993).

Accelerated Composting and enrichment

The conventional method of composting takes a long time to produce quality compost. In order to hasten the process and to improve the quality of the end product, the material to be composted is inoculated with microbes such as cellulolytic, ligninolytic, nitrogen fixing and phosphate solubilising organisms. Addition of sources of nitrogen and phosphorus may also be desirable when the materials to be composted lack much of these elements. The best additive for a compost mix is to add mature compost that will produce a suitable starting population throughout the composting mass and furnish bioavailable minor elements essential to life.

DIFFERENT TYPES OF COMPOST

Leaf compost

Leaf composting is achieved by heap or pit or by windrow methods.Window method is preferred as it allows efficient material handling, provides good aeration, allows sufficient absorption of water and is easy to be formed. Eberhardt and Pipes (1974) discussed the production of leaf compost in detail, suggesting formation of windrows of 2.5 to 4 m width, 2.5 to 3 m height and of any convenient length. The waste materials *ie* leaves used for this process have high C/N ratio. Hence, it needs to be amended with nitrogen sources such as sewage sludge, urea and grass clippings. Aeration is provided by periodical mixing of the material. Under optimal conditions, leaf composting process will be over in 6 to 9 months.

Vermicompost

Vermicomposting refers to the use of earth worms for composting organic residues. Earthworms can consume all kinds of organic matter. Chemical changes in the degradation of organic matter occur through enzymatic digestion, enrichment by nitrogen excrements and transport of organic and inorganic materials. There are three species of earth worms, *viz. Eisenia foetida, Eudrilus eugeniae* and *Perionyx excavatus* which are called manure worms and these can be cultured on animal dung, poultry droppings and vegetables. The worms form the needed organic fertilizer which contain all the nutrients in an available form. Disadvantage with this type of composting is that it requires pretreated or partially decomposed waste material for the process.

Other types of composts available are farm yard manure, coir dust compost and green compost.

Compost maturity

Compost maturity is defined as the status of biological stability of compost conferring immediate improvement of soil productivity.

Need for assessment of compost maturity

The maturity of the compost is critical and the criteria for a mature compost reflect achievement of the objectives of composting. The composting industry is poised for new era where composts will be evaluated both for safety and quality. In this regard, quality calls for analyses both for its fertilizer value as well as any potential contamination that might limit the products use. The maturity of the compost affects their successful utilisation in agriculture.

The process of obtaining the final product, a good matured compost is influenced by a number of factors *viz.*, C/N ratio, blending or proportioning of wastes, moisture, aeration, temperature, pH, microorganisms involved, use of inoculants, destruction of pathogens, calcium phosphate addition etc. Immature composts induce high microbial activity in soil, potentially causing oxygen deficiency in soil and rhizosphere and biological blockage of available soil nitrogen (Zucconi *et al.*, 1981). They also leave odoriferous phytotoxic compounds into the soil *viz.*, ammonia, ethylene oxide and low molecular weight fatty acids (Morel *et al.*, 1985; Saviozzi, Levi-Minzi and Riffaldi, 1988). Animal or plant health aspects and disease suppressive properties of compost are affected by maturity. Although the solution phase of an immature compost may initially contain various aliphatic acids, phenols and ammonia, the intermediate stage will always contain water soluble humic substances. High concentrations of these water soluble organic nutrients in immature composts support growth of human pathogen like *Salmonella* (Hussong, Burge and Enkiri, 1985) and plant pathogen like *Pythium* spp (Chen *et al.*, 1988) and / or other pathogens which depend on free nutrients decline as composts mature and hence the growth of the pathogens. Therefore, high quality composts are required to avoid these risks. Herein the term "quality" denotes the ultimate value of a finished compost in its effect on plant life. The ultimate yard stick of quality is how well a compost nourishes the plant and does not harm them, and enriches the soil possibly suppressing soil borne pathogens at the same time. To be compatible with agricultural uses, a compost has to be transformed to a humus like product and sufficiently stabilised indicating the quality / maturity of the compost.

Indices to assess maturity of compost

A wide range of methods such as physical, chemical and biological have been developed to assess the maturity of compost, but none of them *per se* indicates the maturity completely and hence a combination of several parameters is required. Some physico- chemical and biological parameters often used as indicators of compost maturity are given in Fig.1.

CHEMICAL ANALYSES

Cation exchange capacity

The cation exchange capacity of composts has been related to the percentage of humic substances, which in turn refers to the degree of organic matter degradation in compost samples (Harada and Inoko, 1980 ; Estrada *et al.*, 1987). According to them, the CEC value of city refuse compost increased progressively from 40 meq/100 g to about 80 meq/100 g after composting. The increase in CEC value during composting might be due to the accumulation of materials bearing a negative charge such as lignin derived products, carboxy and / or phenolic hydroxyl groups in the material. Many authors have concluded that a CEC value to 60 meq / 100 g is the minimum value needed to ensure an acceptable level of maturity. However, this parameter cannot be considered as a reliable method since the CEC content of same type of compost or humus may vary due to the blocking of their exchange sites by certain ions such as Fe, Cu and Al etc.

Carbon / Nitrogen ratio

C/N ratio is the conventional index to establish the maturity of compost. This is based on the fact that during composting, carbonaceous materials are converted into microbial biomass, CO_2, water and humus. Therefore, the ratio between carbon and nitrogen ratio is progressively [illegible] with the age of the composting. Many authors have proposed that the C/N ratio below 20 is indicative of an acceptable maturity degree. But this value differs with type of original material. Hence, it is necessary to carry out a periodic monitoring of the C/N ratio during composting until stability is reached. However, a drawback herein is that the ratio can be altered to the desired level by the addition of nitrogen to the immature composts.

Humification parameters

It is based on the fact that during composting low molecular components are converted into heavy molecular humus like product. Hence, increase in humic substances is associated with stabilisation of organic matter. The following parameters are applied to evaluate the humification of organic matter in compost.

Humic acid per cent = C_{ha} / C_{ex} X 100
where C_{ha} - carbon content in humic acid fraction
C_{ex} - carbon content in alkali extract

Humification index (HI) (Sequi *et al.*, 1986)
HI = NH/HA + FA
Where NH - organic carbon content in the non humified fraction
HA and FA - organic carbon content in the humified (Humic acid and fulvic acid) fractions

Degree of humification (DH) (Ciavatta, Vittori Antisari and Sequi, 1988; Ciavatta *et al.*, 1990)
DH % = HA + FA/TEC X 100
where TEC - organic carbon content in the alkali extract

Humification ratio = C_{ex}/C_0 X 100
where C_{ex} - carbon content in alkali extract
C_0 - oxidizable carbon content

Humification rate (HR) (Ciavatta *et al.*, 1988; 1990)
HR % = HA + FA/TOC X 100
where TOC - Total organic carbon content in the solids

$$\text{Polymerization ratio} = \frac{\text{Carbon in fulvic acid}}{\text{Carbon in humic acid}}$$

Eventhough, these parameters are very useful in determining the extent of humification, they do not give information about the quality of the humic substances extracted. Hence, recently another important technique electrofocussing has been used. It is based on the electrophoretic fractionation of the organic compounds in a predetermined pH gradient. This technique has been found to be very useful in distinguishing a raw and a matured organic material in pig slurries and sewage sludge (Govi *et al.*, 1989; Govi, Ciavatta and Gessa, 1993).

Degree of polymerisation

The degree of polymerisation of the humic compounds can be determined qualitatively by paper chromatographic technique. According to Hertelendy (1974) and Inoko (1979), the very mobile, slightly polymerised components move towards the periphery of the paper, while the highly polymerised components stay in the centre. A compost is considered mature when the stain on the paper is more intense in the centre with a clear border (Morel *et al.*, 1985).

Alkali soluble organic matter

Studies have been done to characterise alkali soluble organic matter by sepectroscopic measurements in visible regions. (optical density at 400 nm, 550 nm, and 600 nm). It is considered that the change in colour of the alkaline extract might indicate the progress of the composting and maturation process, under the assumption that the greater the maturity degree, the higher the optical density of the extract. Contrarily, decrease in optical density value with increase in the age of the sewage sludge compost was observed by Garcia, Hernandez and Costa (1991). Hence, it cannot be considered as a reliable indicator of the organic matter humification process.

MICROBIAL ANALYSES

It is related to change in microbial biomass / activities which can be correlated with the rate of decomposition during composting.

Specific respiration activity

Kostov, Petkova and Van Cleemput (1994) evaluated some microbial index ratios as early criteria to evaluate the level of compost stability during aerobic composting of coniferous saw dust and bark. Evolution of the specific respiration activity (CO_2 - Carbon / Biomass carbon) and the ratios between some groups of microorganisms are found to be reliable.

The ratios of the number of fungi, ammonifying microorganisms and nitrogen fixing bacteria to the actinomycetes have been found to decrease with age of the composting as a result of increase in number of actinomycetes and decrease in the number of other groups of organisms. This indicated the depletion of the easily accessible substances in the composts and the beginning of decomposition of difficulty - assimilated chemical compounds. Faster growth of actinomycetes in the advanced stages of bark decomposition was similarly reported by Hardy and Sivasithamparam (1989).

Respirometry

Changes in compost stability or degree to which composts have been decomposed can be predicted with oxygen respirometry (Iannotti *et al.*, 1993). In this method, maturity is predicted based on the rate of oxygen uptake per kg of volatile solids per hour. The oxygen uptake rate is determined with dissolved oxygen respirometry.

$$\text{Mean oxygen uptake} = \frac{-C\ VS\ 60\ D}{K\ Wt\ VS}$$

Where C- Oxygen content by volume in the air, usually 0.2%

V - Volume of air in the flask (ml)

S - Slope of relative oxygen uptake rate (% saturation/min)

D - The density of the oxygen (g/lit) at experimental conditions is converted from STP

60 - Factor change from minutes to hours.

K - Constant factor based on the calibration value corrected for elevation above sea level

Wt - Compost dry matter weight in flask (g)

VS - The fraction of volatile solids (from 0 to 1)

Iannotti *et al.* (1994) used this respiration bioassay to determine the stability of municipal solid waste composts. The oxygen uptake rate has been found to decrease with age of the composts indicating the depletion of biodegradable organic material which is essential for microbial growth.

Spectroscopic Analyses

Compost maturity discussed above is related to the degree to which fresh organic matter has been transformed into a stable end product. Recently, tests have been developed to determine the amount of stable organic end products which are lignin and humic substances. These procedures do not distinguish residual biodegradable carbon from that resistant to biological decomposition. Hence, it is essential to analyse the bulk organic matter. The quantitative procedures developed to study the bulk organic matter are solid state Cross Polarization Magic Angle Spinning ^{13}C-Nuclear Magnetic Resonance (CPMAS ^{13}C-NMR) and Infra Red (IR) spectroscopy (Inbar, Chen and Hadar, 1990 b). A ^{13}CNMR spectrum can provide carbon "finger prints" of various solid samples such as peats, whole soils and humic substances etc. IR spectroscopy indicates the transformation of organic matter during composting. Therefore, with these spectroscopic procedures, it is possible to develop direct correlations between maturity and

i) The rate of decomposition of biodegradable components during the composting process

ii) The potential for regrowth in compost of pathogens

iii) biocontrol of plant diseases and

iv) plant growth response (Inbar *et al.*, 1990b).

Unfortunately, these studies require sophisticated and expensive equipment.

Plant growth response test

Blanco and Almendros (1995) assessed the factors potentially connected with the positive or depressive effect of composts in soil by involving mineral fertilisation and successive harvesting of rye grass. Based on the results obtained, they have concluded that the most classical maturity indices (germination index, water soluble organic fraction, sepctroscopic analyses of water extracts) applied to straw composts have limited diagnostic value as regards forecasting plant yield. These parameters may have applicability in differentiating raw materials from those subjected to composting, but they do not correlate with the crop yield when different composts are simultaneously evaluated. The latter difference can be revealed by plant response experiment in the presence of mature or immature composts.

Analyses of water extract of composts

Organic wastes comprise mainly of large molecular weight water insoluble polymers. The decomposing micro organisms in composts are mostly attached to the surface and are active in the water - solids interface. The microbially degraded substances are utilised to support their growth or accumulated in the liquid phase. This process changes as composts mature. Hence, characteristics of the water extracts of compost form an essential parameter to determine the maturity of the compost.

Organic carbon / Organic nitrogen ratio

Initially, water extracts of various composts will have various aliphatic acids, amino acids, phenols and other organic intermediates. As the decomposition progresses, these organic intermediates will be converted to water insoluble high molecular weight organic compounds. Therefore, organic carbon to organic nitrogen ratio declines with age of the composting process and normally it ranges between 5 to 6 (Chanyasak *et al.*, 1983). However, this ratio cannot be considered as a suitable method, since addition of nitrogen sources such as urea, sewage sludge etc to the immature composts will reduce the ratio to the desired level.

Water soluble organic matter

During composting, high molecular weight compounds such as proteins, lipids, cellulose, lignin and other compounds are enzymatically converted into low molecular weight water soluble peptides, amino acids, fatty acids, phenols and aliphatic acids. These are utilised by microorganisms and finally the recalcitrant compounds are converted into humus like product. Hence, the degree of maturity is determined based on the amount of above mentioned water soluble organic compounds present in the water extract. This has been supported by Chanyasak, Hirari and kubota (1982) and Hirari, Chanyasak and kubota (1983). They have reported that the water extracts of raw materials and immature compost always contained more aliphatic and amino acids than the extracts of mature composts.

Gel chromatography

Yoshida and kubota (1979) and Hirari *et al.* (1983) proposed the elution patterns of gel chromatography of water extracts on G- 15 sephadex column as a measure of stability. In this method, the decomposition process is monitored by following three kinds of gel chromatographic patterns, in which the nitrogen transformation is monitored indirectly.

Pattern I: Several peaks with a wide molecular weight range indicating the presence of degradable low molecular weight compounds.

Pattern II: Only one peak with a partition co efficient (Kd) value of zero became prominent. This indicates ammonia production and accumulation.

Pattern III: The peak with partition co efficient of zero became smaller compared to that of pattern II and some times a small but apparent leading peak with a value of 0.7 to 1.0 could be observed indicating that the accumulated ammonia undergone a nitrification process. Peak with Kd = 0.7 to 1.0 indicates the presence of nitrite ions.

Saviozzi *et al.* (1987) and Hirari *et al.* (1990) observed similar results with paper waste and pig slurry composts respectively. It indicated that as composts matured the organic matter in water extracts contained more of humic rather than non humic substances.

Using this method, plant growth inhibition by nitrite ion cannot be determined, since the nitrite ion cannot be distinguished from nitrate ion even when pattern III is observed. Thus an alternative monitoring method has to be developed.

Germination Index

Germination Index = Per cent germination x mean root length (mm)

The germination index is inversely related to the presence of phytotoxic substances in the composts. Moreover, this assay is the most sensitive parameter, able to account both for low toxicity which affects root growth, and heavy toxicity, which affects germination. The assay is performed on water extract prepared from composts using cress seed. The cress seed is used normally because of its small size, high rate of germination and sensitivity to environmental stresses (Zucconi *et al.*, 1981). Hence, the plant bioassay index is often used as an indicator of phytotoxicity. But the toxicity effect and sensitivity differ with various plants or their stages of development. Therefore, the above test has to be done for different crop plants for their specific tolerance to undecomposed or partially metabolised organic meterials. However, the germination index is rarely correlated to plant yield. It is useful only under laboratory conditions to distinguish composts from raw material (Blanco and Almendros, 1995). Under field conditions, phytotoxic substances of the composts are subjected to sorption, leaching and degradation processes in soil, which do not occur in the seed-water system. This will explain why the germination bioassay is not an accurate index in forecasting the behavior of the composts in the soil.

Spectroscopic analyses of water

The water extract from fresh organic wastes or immature composts is dark brown in colour and, as composting proceeded, the intensity of the colour decreased to light brown. Hence, the colour of the water extract has been often used as an indicator of dissolved organic carbon concentration. These changes can be monitored by reading optical density at 280 nm, 465 nm and 665 nm. A highly significant correlation between water soluble organic carbon and absorbance at 465 nm has been observed for peat (Moore, 1985) and separated cattle manure (Inbar *et al.*, 1993), providing a simple tool for the determination of dissolved organic matter. The extinction ratio between 465 (E_4) and 665 nm (E_6) is also used to determine the maturity. It is considered that the increase in the absorbance at 465 nm and the decrease in the E_4 / E_6 ratio are characteristic of the formation of humic - type substances. Changes in composition and in polydispersity of plant derived colloids are, in general, closely related to spectroscopic parameters in the visible range (Chen, Senesi and Schnitzer, 1977; Traina, Novak and Smeck, 1990).

Compost

Physical

1. Particle size *
2. Colour *
3. Moisture *
4. Porosity
5. Bulk density
6. Water holding capacity
7. Temperature
8. Total solids
9. Volatile solids
10. Total ash content

Chemical

1. pH * ■
2. EC * ■
3. C/N ratio * ■
4. Nitrogen test *
5. Sulphur test *
6. Starch - Iodine test *
7. Heavy metals
8. Pesticide residues
9. Plant nutrient content * ■
10. Cellulose
11. Lignin
12. Protein
13. CEC * ■
14. Humification index
15. Organic acids content
16. Solid state C^{13} NMR Spectroscopy □
17. Infra Red Spectroscopy □
18. Analyses of water extract □

Biological

1. Microbes *
2. Annelids
3. Worms
4. Collembola
5. Aerobes
6. Anaerobes
7. Thermophiles
8. Pathogenic microbes ■
9. Verticillium test *
10. Amoeba
11. Plant growth response test *

Regular tests * Quality control tests ■ Quick screening □

Fig.1 Methods to evaluate maturity of compost

Criteria for quality compost

☆ Mature compost should have a tea brown colour, no noxious smell and a good stability which would no longer produce high temperatures.

☆ The maximum diameter should not exceed 10 mm, with 5 mm as the optimum and the water holding capacity should be below 30 per cent.

☆ The most common pH values range between 6.5 and 8.0. Compatibility with plant growth is within the range of 5.5 to 8.0. If pH values are higher or lower than the above mentioned range, the reason for that should be specified.

☆ Total salinity should not exceed 2 g salt / l (expressed as NaCl) and the concentration of sodium and chloride ions should be specified in mature composts.

☆ Irrespective of the sources of composting mass, C/N ratio of the mature compost should be less than 20 and cation exchange capacity should be more than 70 meq/100 g of ash free material.

☆ Absence of transitory or permanent bio inhibiting factors such as ammonium, water soluble aliphatic acids, amino acids, proteins and polysaccharides in the water extract of compost indicates the maturity of compost.

☆ Decomposition of the organic matter involves both mineralisation and humification. Hence, formation of water insoluble humus is a characteristic of complete decomposition of organic matter. Atleast 10 per cent of the total organic carbon present in the original material should be humified at the end of the composting.

☆ A good quality compost should contain minimum levels of toxic components and non-biodegradable materials.

- ☆ Composting process should give complete inactivation of *Salmonella* sp in infected eggs of parasites (*Ascaris* as indicator organism), a reduction of four logs of paravirus and fecal *Streptococci* (indicator microorganism for bacteria) and five logs of *Enterobacteria.*

A marketed compost should possess the following specifications on the label.

- ☆ Origin
- ☆ Composition
- ☆ Moisture content
- ☆ pH
- ☆ Electrical conductivity
- ☆ C/N ratio
- ☆ Cation exchange capacity
- ☆ Organic matter content
- ☆ Mineral nutrients content
- ☆ Heavy metals concentration, and
- ☆ Inert materials.

Future prospects

Composting entails the degradation of organic compounds by naturally occurring microbes. This process could be accelerated by providing an environment in which the microorganisms involved in decomposition can perform most effectively, thereby reducing the time required for stabilisation to occur. In the traditional method of composting, addition of animal manure as a source of inoculum was practiced. This process was later improved by mechanically aerating the compost mix. For Indian conditions, this practice becomes a costly affair. Henceforth, it is necessary to formulate and provide farmers with an inoculum containing aerobic, anaerobic and facultative anaerobic organisms that accelerate the process. Since most of the nitrogen fixers are microaerophilic organisms and nitrogen fixation is an anaerobic process, the possibility of enriching the compost at time of maturity with beneficial organisms like plant growth promoting organisms and biocontrol agents will provide an added advantage to the end product. Granulation and sieving adopted by the compost industry in the west should be slowly introduced so as to eliminate the carry over of the undecomposed organic matter to the field.

REFERENCES

ACHARYA,C.N. (1939). The hot fermentation process for composting town refuses and other waste material **Indian J.Agric.Sci., 9**: 741-744.

BLANCO, M.J. and ALMENDROS, G. (1995). Evaluation of parameters related to chemical and agro biological qualities of wheat straw composts including different additives. **Biores. Technol., 51**: 125-134.

CHANYASAK, V.,HIRARI, M. and KUBOTA, H. (1982). Changes of chemical components and nitrogen transformation in water extracts during composting of garbage. **J.Fermen. Technol., 60**: 439-446.

CHANYASAK, V., KATAYAMA, A., HIRARI, M.F.,MORRIS, S. and KUBOTA, H. (1983). Effects of compost maturity on growth of komatsuna (*Brassica rapa* var. *peridis*) in Neubauer's pot II.Growth inhibiting factors and assessment of degree of maturity of organic carbon / organic nitrogen ratio of water extract. **Soil Sci. Plant Nutr., 29**: 251-259.

CHEN,Y., SENESI, N. and SCHNITZER, M. (1977). Information provided on humic substances by E_4/E_6 ratios. **Soil Sci. Soc. Am. J., 41**: 352-358.

CHEN, W., HOITINK, H.A.J., SCHMITTHENER, A.F. and TUOVINEN, O.H. (1988). The role of microbial activity in suppression of damping- off caused by *pythium ultimatum*. **Phytopathol., 78**: 314-422.

CIAVATTA, C., VITTORI ANTISARI, L. and SEQUI, P. (1988). A first approach to the characterization of the presence of humified materials in the organic fertilizers. **Agrochimica 32**: 510-517.

CIAVATTA, C., GOVI, M., VITTORI ANTISARI, L. and SEQUI, P. (1990). Characterization of humified compounds by extraction and fractionation on solid poly vinyl pyrrolidine. **J.Chromatography 509**: 141-146.

EBERHARDT, D.L. and PIPES, W.O. (1974). Illinois composting applications. In:**Large Scale Composting.** (SATRIANA, M.J.ed.). New Jersey: Noyes Data Corporation.

ESTRADA, J., SANA J., CEQUEIL, R.M. and CRUANAS, R. (1987). Application of a new method for CEC determination as a compost maturity index. In: **Compost : Production, Quality and Use** (De BERTOLDI, M.,FERRANTI, M.P., HERMITE, P.L. and ZUCCONI,F. eds). London : Elsevier Applied Sciences, pp 334-340.

FINSTEIN, M.S., CIRELLO, J., MACGREGOR,. S.T., MILLER, F.C. and PSARIANOS, K.M. (1980). **Sludge Composting and Utilization: Rational Approach to Process Control. USEPA Report on C-340-678-01-1.**

GARCIA, C., HERNANDEZ, T. and COSTA, F. (1991). Study on water extract of sewage sludge composts. **Soil Sci. Plant Nutr., 37**: 399-408.

GAUR, A.C. and SADASIVAM, K.V. (1993). Theory and practical considerations of composting organic wastes. In:**Organics in Soil Health and Crop Production** (THAMPAN, P.K., ed.), pp 1-21.

GOVI, M., CIAVATTA, C., VITTORI ANTISARI, L. and SEQUI, P. (1989). Characterization of organic materials by means of analytical electrofocussing. In: **Proceedings of the International Symposium on Humic Substances in the Aquatic and Terrestrial Environment**. Linkobing, Sweden, pp 143 - 149.

GOVI, M., CIAVATTA, C. and GESSA, C. (1993). Evolution of organic matter in sewage sludge : A study based on the use of humification parameters and analytical electrofocussing. **Biores. Technol., 44**: 175-180.

HARADA, Y. and INOKO, A. (1980). The measurement of CEC of composts for the estimation of degree of maturity index. **Soil Sci. Plant Nutr., 26**: 127-134.

HARDY, G. and SIVASITHAMPARAM, K. (1989). Microbial, chemical and physical changes during composting of a eucalyptus bark mix. **Biol.Fertil. Soils 8**: 260-270.

HERTELENDY, K. (1974). Paper chromatography, a quick method to determine the degree of humification. **IRCWA News (WHO) 7**: 1-3.

HIRARI, M.F., CHANYASAK, V. and KUBOTA, H. (1983). A standard measurement for compost maturity. **Biocycle 24**: 54-56.

HIRARI, M., KER, K.C., ENDO, T., FIJIE, K., SHODA, M. and KUBOTA, M. (1990). Method for monitoring the decomposition process in soil of organic waste waters with high strength and low C / N ratio. **Soil Sci. Plant Nutr., 36**: 397-408.

HOWARD C.N and WAD, Y.D. (1931). **The Waste Products of Agriculture: Their Utilization as Humus**. Oxford University Press, London.

HUSSONG, D., BURGE, W.D. and ENKIRI, N.R (1985). Occurrence, growth and suppression of *Salmonellae* in composted sewage sludge. **Appl. Environ. Microbiol., 50**: 887-893.

IANNOTTI, D.A., PANG, T., TOTH, B.L., ELWELL,D.L., KEENER H.M. and HOITINK, H.A.J. (1993). A quantitative respirometric method for monitoring compost stability. **Compost Sci. Util., 1**: 52-56.

IANNOTTI, D.A., GREBUS, M.E., TOTH, B.L., MADDEN, L.V. and HOITINK, H.A.J. (1994). Oxygen respirometry to assess stability and maturity of composted municipal solid waste. **J. Environ. Qual., 23**: 1177- 1183.

INBAR, Y., CHEN, Y., HADAR, Y. and HOITINK, H.A.J. (1990 a). New approaches to compost maturity. **Biocycle 31** (12): 64-69.

INBAR, Y., CHEN, Y. and HADAR,Y. (1990 b). Characterization of humic substances formed during the composting of organic matter. **Soil Sci. Soc. Am. J., 54**: 1316-1323.

INBAR, Y., HADAR, Y. and CHEN, Y. (1993). Recycling of cattle manure: The composting process and characterization of maturity. **J. Environ. Qual., 22**: 857-863.

INOKO, A. (1979). A rapid test for the check of maturity of city refuse compost using a paper chromatographic method. **J.Sci.Soil Manure (Japan) 50**: 127-132.

KOSTOV.O., PETKOVA,G., and VAN CLEEMPUT, O. (1994). Microbial indicators for saw dust and bark compost stability and humification processes. **Biores. Technol., 50**: 193-200.

KUCHENRITHER, R.O., MARTIN,W.J., SMITH O.G. and PSARIS, P.J. (1984). An economic comparison of composting and dual utilization. **Biocycle 25**: 33-37.

MOORE, T.R. (1985). The spectrophotometric determination of dissolved organic carbon in peat waters. **Soil Sci. Soc. Am.J. 49**: 1590-1592.

MOREL, J.L., COLIN, F., GERMON, J.C., GODIN, P. and JUSTE, C. (1985). Methods for the evaluation of the maturity of municipal refuse. In : **Composting of Agricultural and Other Wastes**, (GASSER,J. K., ed.). London: Elsevier Applied Science Publishers, pp 56-72.

SAVIOZZI, A., RIFFALDI, R. and LEVI-MINZI, R. (1987). Compost maturity by water extract analyses. In : **Compost: Production, Quality and Use** (De BERTOLDI M., FERRANTI, M.P., HERMITE, P.L. and ZUCCONI, F. eds.). London : Elsevier, pp 3593-67.

SAVIOZZI, A., LEVI-MINZI, R. and RIFFALDI, R. (1988). Maturity evaluation of organic wastes. **Biocycle 29**: 54-56.

SEQUI, P.,DE NOBILI, M., LEITA L. and CERCIGNANI, G. (1986). A new index of humification. **Agrochimica 30** : 175-179.

TRAINA, S.J., NOVAK, J. and SMECK, N.E. (1990). An ultraviolet absorbance method of estimating the per cent aromatic carbon content of humic acids. **J. Environ.Qual., 19**: 151-153.

WILLSON, G.B., PARR, J.F., EPSTEIN, E., MARSH, P.B., CHANG, R.L., COLACICCO, D., BURGE, W.D., SIKORA, L.J., TESTER, C.F. and HORNIC,S.(1980). **Manual for Composting Sewage Sludge by the Beltsville Aerated-pile Method. USEPA Report on C-340-678-011.**

YOSHIDA, T. and KUBOTA, H. (1979). Gel chromatography of water extracts from composts. **J. Fermen. Technol., 6**: 582-587.

ZUCCONI,F., PERA, A., FORTE, M. and DE BERTOLDI, M. (1981). Evaluating toxicity of immature compost. **Biocycle 22**: 54-57.

(Received : December 1996 Revised : December 1996)