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COMPOST FOR CONTAINER SEEDLING PRODUCTION IN FOREST NURSERIES

Editors

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PREFACE

The success of any afforestation/reforestation programme depends to a great extent on the health and vigour of seedlings used for planting. Recently, container forest nurseries, which have numerous advantages over conventional nurseries, have revolutionized production of forestry seedlings in large scale. Since, the volume of potting medium used in these containers, commonly called root trainers, is much smaller than conventional polypots, the nutritive values of the potting mixture used in these containers assume a great importance for producing healthy seedlings in addition to other nursery management practices.

Compost, an environment friendly biological product is used extensively in organic farming. Though compost has been used conventionally for centuries in agriculture and agroforestry systems, its introduction in forest nurseries is of rather recent origin. Compost, which can be produced either through aerobic or anaerobic methods or vermiculture and which has several advantages over chemical fertilizers, provide an excellent option to maintain balanced nutrition in the potting medium of containers.

In this Proceedings, collection of papers on various aspects of aerobic composting technology will fulfill the long-felt need of authentic information on composting for container forest nurseries not only in Kerala but in other states as well. Considering the scope of the book it is hoped that state forest departments, and others interested in raising planting stock of tree species will greatly benefit from this book.

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POTTING MEDIA: CHARACTERISTICS AND COMPONENTS

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INTRODUCTION

The purpose of a good potting medium is to enable vigorous and healthy seedling growth within the limited space of a container and to prepare seedlings for successful transplanting in the field. The potting medium physically supports a growing seedling, and stores and supplies nutrients, water, and air to the root system. The better the medium, the better will be the development of a healthy, fibrous root system and the quality of seedling produced. Since there are not many natural materials with all the elements required for healthy root growth, potting media are usually blends of different elements.

CHARACTERISTICS OF GOOD POTTING MEDIUM

For best results, growing medium used in container nurseries should be

- light in weight,
- having good porosity,
- well-drained but with good water holding capacity,
- slightly acidic with good cation-exchange-capacity,
- able to maintain a constant volume when wet or dry,
- free of insects, diseases and weed seeds,
- low in silt, clay and ash content,

- easily stored for long periods of time without changes in physical and chemical properties, and

- easily handled and blended.

The development of a healthy, fibrous root system needs a medium with these good physical properties. Any nutrient or chemical deficiency can be compensated for with additions of chemical fertilizers and other amendments. Some of the important physical and chemical properties of potting media are described below.

Physical Properties

Unless otherwise noted, much of the information in this section is based on Landis *et al.* (1990). Porosity is one of the most important physical properties of the growing medium because it determines the space available in a container for air (aeration), water and root growth (Liegel and Venator, 1987). Aeration is important because the root system "breathes" in the large, air-filled pores (macropores). Poor aeration affects adversely the root form (morphology) and structure (physiology) and it leads to decreased seedling vigor (Scagel and Davis, 1988).

The growing medium must also allow adequate drainage from macropores so that water does not remain at the bottom of the container where it would inhibit root respiration. The presence of macropores is a function of particle size, particle arrangement, and the degree of compaction.

Although good drainage is desired, the potting media should have high water holding capacity. Since the volume of the container is small, water must be available to seedlings between irrigations. The presence of small pores (micropores) help retain water. Organic material provides a large number of micropores.

The total porosity (percentage of air space divided by total container volume) of a good growing medium for container tree seedlings should exceed 50% and the aeration porosity (the percentage of air space remaining after saturation when water has freely drained) should range from 20 to 35% depending on the medium. Overall balance of both macro and micropores is necessary for a high quality container medium.

Porosity of growing medium is affected by its particle size range, size class mixture, particle characteristics, texture and their changes overtime: increase in particle size increases the aeration pores, but water-holding capacity declines. The optimal particle size range varies depending on the material. For example, the desired particle size for peat moss in growing media is from up to to 6.0 mm.

Procedure for determining total porosity, aeration porosity and water retention.

Step 1: Obtain the following materials: container with a drain hole at bottom, plug for drain hole in container and graduated cylinder or other device for measuring water volume.

Step 2: Plug drain hole and fill container with water. Measure volume of water in container (container volume) using a measuring cylinder.

Step 3: Empty container and fill with potting mixture that has been air dried slowly and thoroughly. Saturate by adding water at one edge of container and measure the quantity of water added (total pore volume).

Step 4: Unplug, drain and collect water that runs out. Measure volume of water drained (aeration pore volume).

Step 5: Porosity is obtained by dividing pore volume (Step 3) by container volume (Step 2).

Porosity (%) = (container mix pore volume/container volume) x 100

Step 6: Aeration porosity is obtained by dividing aeration pore volume (Step 4) by container volume (Step 2).

Aeration porosity (%) = (aeration pore volume/container volume) x 100

Step 7: Water retention porosity is obtained by subtracting aeration porosity (Step 6) from porosity (Step 5).

Water retention porosity (%) = porosity-aeration porosity

Over time, porosity tends to decrease due to compression, breakage, mixing and shrinkage of the materials used for potting medium. Drainage problems occur from decomposition of materials and saturation caused by irrigation or root growth or as the fine particles settle to the bottom of the container. Pore space becomes filled with roots during seedling growth which decreases aeration porosity. Plants which have to remain in container for more than one growing season may need a coarse textured material to accommodate roots. Naturally this will require more frequent watering of seedlings especially, during the first season.

Chemical Properties

The chemical properties which determine suitability of a growing medium are primarily pH, cation-exchange-capacity (CEC), and fertility. Additives can be used to correct the chemical characteristics of the potting mix. The desired pH of most growing media ranges from 5.5 to 6.5 (slightly acidic), but the pH for optimal plant growth is species dependent. When pH levels are not within the desired range, nutrients either become unavailable or toxic and microorganisms in the potting media will be affected. Chemical additives (eg. lime or sulphur) can be used to control pH.

Cation exchange capacity (CEC) is a measure of the ability of soil or potting medium to hold nutrients. A low CEC means that nutrients will not be retained, they will be washed out (leached) from the mix during watering. A high CEC results in nutrients being held to the mix and available to the seedlings. As a result, a high CEC medium is able to continually provide nutrients to the seedling. As a general rule, the greater the addition of organic matter or compost, the higher the CEC of the mix.

Management of nutrient supply to seedlings in the nursery is extremely important irrespective of the fertility of the individual component which make up the potting mix. The nursery manager must always be prepared to provide any additional nutrients which are required. Some nursery managers prefer a low fertility, so that they can control the nutrient balance for the young seedlings. Initially, low fertility in a growing medium may even be desirable during germination because nutrient requirements (except for phosphorus) during the early weeks of seedling growth are minimal. High concentrations of mineral nutrients at this stage can encourage the growth of fungi responsible for damping-off.

Testing of medium through seedling growth trials is always necessary to determine the appropriateness of a potting mix and to determine the type and levels of additional nutrients that must be supplied. This is also important because the presence of substances (eg. trace elements, heavy metals, phenols, salts) which are phytotoxic (reduce growth or kill plants) to seedlings must be guarded against. Such compounds may occur naturally in some media components.

COMPONENTS OF POTTING MEDIA

Potting media are either composed of a single substrate (unmixed material from a single source) or more likely are mixtures of various organic and/or mineral components. Mixtures of various components with complementary physical and chemical properties will produce superior potting media. Components of properties of individual potting medium are mentioned below.

Organic Components

Organic components used in growing media shall desirably have:

- a large proportion of micropores to improve water-holding capacity
- a good texture which resist compaction
- a relatively high CEC to help retain nutrients, and
- low weight (bulk density) to facilitate transport and handling.

Sugar cane wastes, coconut husk fibre, rice hulls, peat moss, saw dust and tree bark, are organic components which are commonly used because they have the desirable characteristics either before or after composting. Most organic materials (with the exception of peat moss and rice hulls) benefit from composting prior to their use. Composting improves their physical properties and balances the ratio of carbon to nitrogen in the material.

Inorganic Components

Inorganic components are included in potting medium to improve the physical characteristics by improving drainage and aeration by increasing the micropores. In certain cases, the inorganic components such as vermiculite, perlite, pumice, and Styrofoam are very light weight. However, sand which is one of the more commonly used components, adds considerable weight to a mixture. If possible, the use of sand should be avoided in order to reduce transport costs.

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GROWING MEDIA IN CONTAINER NURSERY: A WEST BENGAL EXPERIENCE

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INTRODUCTION

Field soil is a major potting medium used in many container nurseries. Because of certain problems with soil in containers, growers began supplementing soil with other materials to develop a mixture that would be suitable for container culture. Library records and archives indicate that in the 1930's John Inns of the Horticultural Institute of England was the pioneer innovator of a uniform, standardized growing medium. He developed a loam-based compost that was subsequently amended with peat moss, sand and fertilisers (Bunt, 1988). By the early 1950's the truly artificial growing media were created at the University of California which composed of fine sand, peat moss and fertilizers (Matkin and Chandler, 1957). The Cornell Peat Lite Mixes, the earliest made modern growing media were developed at Cornell University in the 1960's using various combinations of peat mixes, vermiculite and perlite (Mastalerz 1977).

Plants growing in root trainer containers have certain functional requirements. In this paper, an attempt is made to highlight the importance of suitable growing medium and its components, and methods of preparation in the State of West Bengal. The economics of the growing media in Southern and Northern Bengal is also presented. As the use of growing medium is now inescapable in modern nursery management, it is necessary for the prudent grower to consider the overall situation before making a decision about the economics of one particular practice. The combination of cultural practices that produces the best quality seedlings in the shortest period of time and at an acceptable cost will be the most economical in the final evaluation.

CHARACTERISTICS AND COMPONENTS OF GROWING MEDIA

Growing media have profound beneficial effect on the development of seedlings especially the root system. For optimum growth of plants, the growing media should have the following characteristics.

Characteristics of growing media

a. Light weight, easier to handle, friable and easily blended.

b. Good water holding capacity,but well drained.

c. Good porosity and proper balance of pore size.

d. Slightly acidic but with good cation exchange capacity.

e. Able to maintain a constant volume when wet or dry.

f. Freedom from fungal spores or insects.

g. Low in silt, clay and ash content

h. Easily stored for long period of time without change in physical and chemical properties.

i. Low inherent fertility.

j. High degree of uniformity and reproducibility.

k. Low bulk density.

l. Dimensional stability.

m. Durability and ease of storage.

n. Ease of mixing and filling into containers.

o. Ease in rewetting.

p. Promotion of firm root plug formation.

Components of growing media

Growing medium consists of two or more different components that are selected to provide certain physical, chemical or biological properties. Other amendments such as fertilizer or wetting agents are sometimes added during the mixing process. The survey of the records of modern nursery growing media reveals the existence of five materials: peat moss, saw dust, sand, vermiculite and perlite. A typical growing medium is a composite of two or three components. Mixtures of organic and inorganic components are popular because these materials have opposite, yet complementary physical and chemical properties. The organic component obtained on composting improves the physical properties viz. porosity, cation exchange capacity, water retentivity, etc. and maintain a balanced ratio of carbon to nitrogen. The physical attributes needed to be improved upon by the addition of inorganic component viz. sand, vermiculite, perlite etc. In some cases inorganic fertilizers like urea or rock Phosphate are used in calculated quantities.

METHODS OF PREPARATION OF GROWING MEDIA IN SOUTHERN BENGAL

Compost is the final product obtained from rotting of vegetative matters viz. leaf, bark, garden clippings, etc. During composting, the micro-organisms present in the soil and atmosphere hasten the breakdown of the vegetative matters to a usable form of organic carbon, nitrogen and other minerals, which are of great value to the plant.

In forests of Southern Bengal, large quantities of weeds such as *Chromolaena, Lantana, Combretum,* etc. are available. These weeds may be put to good use by composting in specially built chambers or bins. The compost would be of immense use in production of container grown seedlings and cuttings. It is well understood, that seedlings with well formed root system survive and grow much better in harsh conditions compared to those with poor root system. The use of compost in the potting mixture, which facilitates development of good root system in container grown seedlings, may therefore play a frontal role in the forest nurseries and later in the plantations established on poor laterite soils.

For successful composting operation, there are certain basic requirements. They are:

a. Size of chips of raw material,

b. Initial C/N ratio of raw material,

c. Aeration for aerobic processes,

d. Optimum moisture,

e. Optimum temperature.

The raw material such as straw, lawn clippings, weeds, etc. should be chopped to finer size. Larger the size, more time will be taken for composting and more will be the undecomposed materials retained on the sieve. It has been observed that the raw material should have an initial C:N ratio in the range from 25 to 30 for the composting to be successful, since this range of C:N allows the micro-organisms to multiply and manufacture their protein efficiently. The moisture content of the heap should be kept at 50 to 55% and the heap would be damp but not soggy. The temperature range in which the microbes work very well in between 50°C to 60°C and, therefore, temperature of the heap should never be allowed to exceed 60°C. Temperature monitoring is very important as also the moisture. Excess of moisture would retard aerobic process and encourage anaerobic process. For aerobic process of degradation, which is faster than anaerobic decomposition, aeration is a must to supply oxygen and for this, turning of the heap is essential after few days interval.

In Southern Bengal, composting from weeds was started by the Silviculture (South) Division. In most of the forest areas in Southern Bengal, *Chromolaena odorata*, or *Aegeratum conyzoides* or *Lantana camara* is available in plenty. These materials were utilised to prepare good compost for use in nurseries. Silviculture (South) Division adopted the Berkeley's method for aerobic decomposition for making compost. Of the various materials tried are *Chromolaena*, rice straw and a mixture of both.

The composting shed in use in Southern Bengal is of the size 4.90 m (length) x 2.20 m (breadth) x 1.00 m (height) (inner dimensions of chamber) which works out to 10.78 m^3. The plinth is about 0.45 m in height and there are two adjacent chambers. The walls have aeration holes (Jaffry type) and the roof is slopy, a metre above the wall and fixed on brick pillars. The roofing material is a low cost corrugated leathery, recycled material costing Rs.67 per sheet of 3 m x 1 m size.

For composting, the raw material is chopped in a manually operated wheel chopper and the chopped material is charged in the compost chamber. Urea is added in alternate thin layers, if the initial C/N ratio is higher than 30:1, it is adjusted to a range from 25:1 to 30:1. Water is also sprinkled so as to keep moisture at 50%. Temperature is recorded daily in the morning and as the temperature crosses 50°C the material is turned and transferred to the adjacent chamber for aeration and cooling. During decomposition, water is added if the heap becomes too dry. The colour of the material gradually turns deep brown to black with no foul odour. The compost is then taken out for sun drying. For nursery use, the C/N ratio of a matured compost must be less than 15. During the hot season, usually this process in Southern Bengal takes 30 to 60 days. During cooler months, however, the frequency of turning will have to be restricted.

For composting, various ingredients are being tried in Southern Bengal and all the essential parameters are recorded, including the daily temperature chart which is most vital. The results show that in Arabari, the out turn was apparently more than Jhargram Range. However, this can be attributed to the fact that the chopping of raw materials in Arabari Research Range was finer since it was done in a wheel chopper, whereas in Jhargram it was chopped manually. Consequently, the weight of dried material recovered after screening was only 20% (i.e., undecomposed twigs, sticks, etc. removed). The size of chopping should invariably be small. Also, in Jhargram, observation was taken after 6 hr of sun drying for three consecutive days. The final C:N ratio is appreciable being within a desirable range of 5 to 10.

ECONOMICS OF COMPOSTING

Although the economics of composting has not been worked out precisely, a preliminary exercise done in Arabari Research Range showed that the cost of preparing one kg of compost is Rs.3.38 as outlined below.

1.	Price of paddy straw @ Rs.1.50/-kg for 425 kg	= Rs.637.50
2.	Labour cost of collection of 3400 kg *Chromolaena* (weed) from adjacent forest floor over 34 man days	= Rs.1383.80
3.	Labour cost for chopping over 3825 kg of materials, 41 man days	= Rs.1668.70
4.	Labour cost for turning of the charge for 9 times over 10 man days	= Rs. 488.40
	Total	= Rs.4178.40

Note: One man day wage = Rs.40.70.

NORTHERN BENGAL SCENARIO FOR COMPOSTING

The weight of final product (of compost) is 1234 kg and the cost of finished compost works out to = Rs.3.38 per kg.

If we consider growing the seedlings in pure compost as a potting medium in root trainers of 120/150 cc capacity, we have to calculate the bulk density (kg/m^3) of the finished compost. Only then we can project the exact requirement of compost over a season in a nursery.

The nursery techniques in Southern Bengal have undergone tremendous changes in recent years. Root trainer system along with a suitable and improved potting mixture have been introduced. Composting on a bigger scale will, therefore, continue as a major programme. The following are the activities planned to be undertaken in immediate future:

1. Selction of good and easily available raw material having appreciable starter C:N ratio and calculation of economics in greater details.
2. Experimentation on addition of various doses of rock phosphate to the compost and its effect on establishment of root system.
3. Field trial of compost as regards growth of forest species vis-a-vis commercial organic products.

Composting is gradually emerging as a very important aspect of the development of modern nursery to West Bengal. If this makes headway in promoting better quality of seedlings, this would be one of the important achievement of forestry in recent times. We may then have to think to develop a compost manufacture and management unit as a peripheral body to support the cause of forestry.

In Northern Bengal, composting was first attempted by Berkeley's method. In this method, the organic wastes such as weed, grasses, etc. are cut broken into small pieces and assembled in a heap/mound, and allowed to decompose. Once in every 2-3 days the heap is turned upside down and mixed thoroughly since for aerobic deocmposition air supply is necessary for the microorganisms. Sufficient moisture was also required as the process was carried out in open and drying was quite rapid. This method was effective in the plain areas in the nurseries of Sukhna and Bhattanabart, but in hills this was rather difficult and time consuming because of prevailing low temperature and frequent rain fall. Moreover this was very much labour-oriented work since upside down turning was required more frequently and also it was difficult to manage the heap in open. Hence, the Berkeley's method was modified in which the entire structure was made to a heap of chopped organic waste, mainly the weed *Chromolaena* sp. obtained by cleaning up of plantation and nursery. Perforated bamboo was inserted from all the sides at different levels so that the air could be supplied to every part of the heap to allow aerobic decomposition. Further, to conserve moisture, the heap was covered with a polythene sheet. The size of heap mound was of 1.5 m x 1.5 m x 1.5m which could be managed easily. The decomposition rate of the material in the heap was very fast and very good quality of decomposed organic matter i.e., compost, was obtained at the end of the process. The compost was dried, sieved and stored in poly cloth bag for use in the nursery.

The time taken for the process of complete decomposition differed depending upon the places and season as follows:

i a.	Hills - at Lava. Somada (above 1800m) during summer	35 to 38 days
b.	Hills - at Lava. Somada (above 1800m) during winter	43 to 45 days
iia.	Hills at Kalimpong and Takdah (above 1200m) during summer	32 to 35 days
b.	Hills at Kalimpong and Takdah (above 1200m) during winter	36 to 38 days
iiia.	Plains at Sukna and Bhuttabari during summer	26 to 28 days
b.	Plains at Sukna and Bhuttabari during winter	30 to 32 days

In hills, it took 35 to 40 days and in plains less than 30 days for completing the process of composting (Table 1). Using this method, compost was made throughout the year in all the nurseries of Silviculture (Hills) Division.

Table 1. Temperature recorded in the composting heap of *Chromolaena* sp. over a period of 29 days at Sukna (Temperature was recorded at 12.00 noon)

Days after heaping	Date	Temperature (°C)	Remarks
1	17 November 1995	50	
2	18 November 1995	59	
3	19 November 1995	60	
4	20 November 1995	60	
5	21 November 1995	58	
6	22 November 1995	55	
7	23 November 1995	58	
8	24 November 1995	58	
9	25 November 1995	57	
10	26 November 1995	56	
11	27 November 1995	55	
12	28 November 1995	58	
13	29 November 1995	52	
14	30 November 1995	56	
15	1 December 1995	55	
16	2 December 1995	58	
17	3 December 1995	59	
18	4 December 1995	57	
19	5 December 1995	54	
20	6 December 1995	56	
21	7 December 1995	58	
22	8 December 1995	59	
23	9 December 1995	60	
24	10 December 1995	54	
25	11 December 1995	50	
26	12 December 1995	39	
27	13 December 1995	35	Process of decomposition completes
28	14 December 1995	35	
29	15 December 1995	35	Compost taken out

Although, this method was found very effective and useful, the process was becoming very costly since we required to provide polythene sheet and bamboo every time we made the compost. Chopping was to be done manually. So the recurring expenditure was becoming very high and the process of making compost was rather cumbersome (Table 2, 3 and 4).

Table 2. Weight and volume variation during the process of composting

Parameters	Observations recorded at a particular step of composting activity	Wt (kg)/ Vol (cft)
1.	**Weight**	
a.	Total weight of raw material put in compost house after chopping	450 kg
b.	Total wet weight of compost taken out after 29 days, i.e., after completion of compost	325 kg
c.	Total dry weight of compost after sun drying	149 kg
d.	Total weight of compost after sieving i.e., taking out the undecomposed woody materials	103 kg
	Therefore 450 kg of raw material reduced to 103 kg compost; Ratio (raw material: compost) 4.36:1	
2.	**Volume**	
a.	Total volume of raw material put in compost after chopping	85 cft
b.	Total wet volume of compost taken out after 29 days, i.e., after completion of compost	34.62 cft
c.	Total dry volume of compost after sun drying	22 cft
d.	Total dry volume of compost after sieving i.e., taking out the undecomposed woody materials	16.5 cft
	Therefore 85 cft of raw material is reduced to 16.5 cft compost; Ratio (raw material : compost) 5.15 : 1	

Table 3. Calculation for requirement of compost for forest nurseries in Silviculture (Hills) Division for production of 1,00,000 plants raised in the root trainer of 120 cc on an average at a mixture ratio (volume) of 2 part compost to 1 part moss

Total requirement of compost	
80 cc Compost and 40 cc Moss are required for 120 cc root trainer	
Therefore, total compost required is 80 cc compost x 1,00,000 root trainers	= 80,00,000 cc compost
∴ Total requirement is	= 8 m^3 of compost and 4 m^3 of moss to raise 1,00,000 plants
Production	
Production size of compost house	= 4.50 m x 1.5 m x 1.5 m = 10.125 m^3
Total quantity of chopped raw material	= 10.0 m^3
Final product of compost in one month	= 1.96 m^3
If there are 10 working months, then = 19.66 m^3 of compost can be produced in the compost house which is sufficient for more than 2 Lakh plants in nursery in the plain. In hills it takes about 40 days for compost production and therefore only 14.70 m^3 compost can be produced during 10 months which is sufficient to raise more than 1,50,000 plants.	

Table 4. Cost of production of 1.96 m^3 of compost (sufficient for 24000 plants) in Northern Bengal

No.	Activities	Cost (Rs.)
a.	Cost of collection of raw materials i.e., *Chromolaena* of 10m^3 (15 labour @ Rs.42.20)	633.00
b.	Cost of chopping of raw material and dumping in compost house - (6 labour @ Rs.42.20)	253.20
c.	Cost of spreading, drying and storage (4 labour @ Rs.42.20)	168.80
	Miscellaneous works	45.05
	Total	1,100.00
	Per plant compost cost	4.58 paise

Further modifications were tried in the process by making a permanent chamber of brick masonry with very light shed made up of fibre sheet and doors for feeding the organic waste and also for taking out the ready compost. The entire structure was provided with perforated pipe from all the directions to run through the structure for continuous supply of air required for aerobic decomposition of organic waste. The size of this structure was 15 ft x 5 ft x 5/6 ft and 2 or 3 chambers were provided in the structure so that different organic wastes could be used and also to get different stages of decomposition for study. These modifications helped to make a permanent structure for composting which facilitated the entire process. The organic wastes mainly the weeds and grasses, were chopped into small pieces by chopper machine and dumped into the structure in one chamber and then closed. Because of regular air supply, aerobic decomposition started immediately which was indicated by rise of temperature immediately after 4 to 5 hours of heaping the chopped weeds. Since the entire structure was closed from all the sides the moisture in the green weed is retained and also during the process, which helps to maintain the moisture content of the decomposing waste. The air was supplied to all the parts of structure through the perforated pipes, so there was no need of turning the decomposing material. After 25 to 36 days depending upon location and temperature, the ready compost was taken out from the compost house. This compost was then dried, sieved and stored in polythene bags and kept in the storage house for future use.

Two parts of compost and one part of moss was found ideal potting mixture for good growth of plants in nursery. Such potting medium is very light, with good porosity, well drained and good water retention capacity. The high, temperature in the process of composting helps to kill the larvae and eggs of insects, weed seeds and spores of pathogens. Such potting medium is of constant volume without any silt or clay or ash content. The pH of such organic compost is 6.82 and C/N ratio found to be 9.67 which is considered to be good growing media.

Since the compost is required regularly for raising container nurseries, a permanent composting unit should be made in the nursery for different works required for composting. For effective functioning, the following areas should be demarcated for a composting unit.

1. Area for storing the weed, grasses or other organic waste
2. Location for chopper for chopping the material
3. Area for chopped material
4. Compost house for composting
5. Compost drying and sieving platform
6. Store for storage of ready dried compost
7. Potting mixture platform

CONCLUSION

The selection of a growing medium is one of the most important decisions in the culture of root trainer container tree seedlings. The physical, chemical and biological characteristics of a growing medium effect not only seedling growth but also other aspects of nursery operations as well. The nursery techniques in West Bengal have changed in recent years. After some designed experiments, suitable potting mixture was developed and compost (two parts) and moss (one part) mixture gave very good results for the optimum development of seedlings in the State. Weeds were converted into compost used as growing medium and this practice was not only economical but also eco-friendly.

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COMPOSTING: MAKING SOIL IMPROVER FROM RUBBISH

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INTRODUCTION

Rubbish is one product our society makes in large quantities. The answer to solve the serious problem of accumulating rubbish would be to compost it and return organic matter to the soil. Here rubbish is referred to the many organic materials that we throw away or burn - lawn clippings, leaves, weeds, sawdust, paper, kitchen scraps, seaweed, etc. The compost heap can convert this bulky "rubbish" into a soil improver and fertilizer.

COMPOSTING - WHAT IS IT?

Any organic material thrown into a heap will eventually be reduced in size by small worms, insects, etc., and rotted down by microorganisms already present in them or that come from the underlying soil. This process of degradation has been going on for millions of years in litter deposited on forest floors and other places where organic material accumulate.

Composting is really just a method of speeding up the natural processes of rotting, but in the compost heap we can control the process to suit our requirements. Good technique ensures minimum losses of nutrients and hence their maximum return to the soil.

The Chinese and Japanese have been making compost for at least 4000 years, returning to their soils via compost heaps, every scrap of animal and vegetable "rubbish" and much mineral matter from canal bottoms. Their methods were made known through a book called "Farmers of Forty Centuries", written in 1911 by Dr. F.H.King, an American Soil Scientist. Sir Albert Howard, a British agronomist who worked in India during the first 40 years of this century, synthesized the best from these composting methods and devised, the Indore composting process in 1931, which has been the basis of most home garden compost heaps.

INGREDIENTS

The essential ingredients of a compost heap are organic materials, microorganisms, moisture and oxygen (and a small quantity of soil).

Organic materials

Compost of high fertilizer value can only come from "high quality" rubbish. The most important aspect of quality is the carbon: nitrogen (C/N) ratio of the organic materials used. Microorganisms need both carbon and nitrogen to make protein. As they use about 30 parts by weight of carbon for each part of nitrogen used. We need supply them with materials having a C/N ratio of about 30. Microbial activity is reduced at higher C/N ratios (low nitrogen supply) and valuable nitrogen may be lost as ammonia gas if the C/N ratio is lower than about 30. In practice, it has been found that the average C/N ratio of the materials in compost heap should be slightly less than this - in the range 25 to 30 - for the heap to "work". Table 1 provides C/N ratio in some of the commonly used organic materials in composting.

Table 1. C/N ratio and other characteristics in some of the organic raw materials

Material (Weight/Weight)	C/N Ratio	% Moisture in material	% Carbon	Moist material
Lawn clippings	20	85	6	0.3
Weeds	19	-	6	0.3
Leaves	80	-	-	0.4
Paper	170	10	36	0.2
Fruit wastes	35	80	8	0.2
Food wastes	15	80	8	0.5
Sawdust	450	15	34	0.08
Chicken droppings (no sawdust)	7	20	30	4.3
Chicken litter (Typical)	10	30	25	2.5
Straw	100	10	36	0.4
Cattle droppings	12	50	20	1.7
Human urine	-	-	-	0.9

Mixtures may be formulated according to the materials available. Provided the C/N ratio is right, it is not essential that animal manures are included. Urea can be used to supply extra nitrogen if high-nitrogen organics are not available in sufficient quantities to compost large quantities of leaves or other low-nitrogen materials. Two grams of urea contain 0.9 g N (equivalent to 100 ml urine). Alternatively, ammonium sulphate will supply 2.1g N in each 10 g used.

Microorganisms also need abundant supplies of other nutrient elements, with phosphorus being particularly important. A carbon/phorphorus (C/P) ratio in the range 75 to 150 is needed. As leaves (especially eucalypt leaves), woody plant residues and sometimes even lawn clippings have C/P ratios above 150, it is desirable to add extra phosphorus to most compost heaps so as to ensure rapid decomposition. Super phosphate can be used, but if one prefers a more natural source of phosphorus, a light application of bone meal or rock phosphate can be used as more than two percent by weight can inhibit decomposition. The other nutrients needed by microorganisms are usually present in sufficient amounts if a wide range of organic material is used.

Grinding or chopping up the organic materials enhances speed of decomposition by increasing the surface area available to microorganisms to feed. In practice, fine grinding is unnecessary; cheap chopper may be made by linking a 2 HP electric motor to the spinner side of an old twin-tub washing machine, suitably cut down and fitted with a beveled chopper blade and small (10 cm x 16 cm) outlet hole. Commercial shredders do a better job but they cost a lot more. Running a motor mower over the materials can also do a reasonable job. Alternatively an electric driven chaff cutter can be used.

Microorganisms

Numerous species of microorganisms, bacteria, fungi and actinomycetes are involved in decomposing organic materials. Most organic materials have a native population of microorganisms, mostly bacteria, fungi and actinomycetes (branching bacteria), which are involved in decomposing organic materials. Besides, small quantity of garden soil which contain large population of microorganisms is often mixed into or layered amongst the organic materials. These microorganisms start their work of decomposition as soon as the level of moisture and oxygen are favourable. Studies have shown that special preparations of fungi, bacteria or "enzymes" are not needed for rapid decomposition. Only where sawdust or other relatively sterile materials form a high proportion of the compost heap inoculation of microorganisms may be necessary. The claimed advantages of some commercial preparations are often due to the extra nitrogen and other nutrients they supply rather than to the microorganisms they contain. These nutrients can be bought much more cheaply in fertilizer form. If found necessary, as a starter culture small amount of mature compost can be added to each new heap.

Moisture

The moisture content of a compost heap is very important. Below about 40% moisture (40 g water in 100 g moist materials; i.e., 40 g water + 60 g dry matter), organic matter will not decompose rapidly. Over about 60% moisture not enough air can get into the heap and it tends to become anaerobic (no oxygen). It is best, therefore, to aim at maintaining 50 to 55% moisture. This is about the moisture content of a squeezed sponge. It feels damp, but not soggy. Keeping a compost heap moist enough is one of the main problems facing composters in Australia. In hot and dry weather, the heap should be moistened repeatedly. At the same time, cover the heap if it looks like getting too wet during rain.

Those microorganisms that need oxygen are called aerobes and those that do not are called anaerobes. Organic materials in heaps are decomposed most rapidly by aerobes. They need plenty of air, many cubic metres a day for a garden compost heap of reasonable size. Inadequate aeration allows anaerobes to take over from aerobes inside the heap, leading to the production of foul odours, mostly gaseous chemicals containing sulphur. Good aeration is very important, so it is better to turn on the side frequently rather than infrequent turnings.

CHANGES INSIDE THE HEAP

Temperature : Moist organic materials in the heap heat up because the heat given off by microorganisms as they feed and multiply is kept in the heap by the insulating properties of the organic materials. In large heaps the top temperature may exceed 60°C; in small heaps perhaps it may not exceed 55°C. This is because large heaps have a smaller surface area to volume ratio than small heaps, and so lose relatively less heat. Large heaps are, therefore, more efficient than small heaps in winter.

The microorganisms flourishing at or below the temperature of 40°C are referred to as the mesophiles and those above 40°C as the thermophiles. Marked changes occur in the microbial population as the temperature moves past 40°C. Later, as the temperature drops, mesophilic organisms re-invade the centre of the heap from the cooler outer layers. Decomposition of organic materials is fastest in the thermophilic stage. During turning for aeration, the interior temperature may drop 5 or 10°C, but it returns to the initial temperature in a few hours.

Thermophilic organisms die at temperatures over 60°C, so the maximum temperature of a heap tends to be self-regulating. The trouble is that this high-temperature dying off increases the time needed to finish the composting process. Heap temperature should be monitored, and if it gets too high the heap should be made smaller.

pH: Initially, the pH of a compost heap is slightly acidic because the cell sap of plants is acidic. Then the heap becomes even more acidic (lower pH) due to acids such as acetic, citric, tartaric, lactic, sulphuric, nitric, etc., produced by bacteria. During the thermophilic stage the heap becomes alkaline through ammonia formation and, finally near neutral or slightly alkaline as the ammonia is converted to protein and the natural buffering capacity of humus dominates the scene.

Tests at the University of California, Berkeley way back in 1953 showed that adding lime to a compost heap can cause serious losses of nitrogen. This happens mainly in the thermophilic stage of decomposition when the heap is alkaline anyway. Lime increases the alkalinity of the heap; this reduces the solubility of ammonia in the water of the heap thus increasing the proportion of ammonia which can escape into the atmosphere. Therefore, it is best not to add lime, dolomite, ashes or other limiting materials to compost heaps. The contents of compost bins may need to be treated differently. Because of limited air movement into bins, their contents are probably more often partially anaerobic. Compost produced in a partially anaerobic environment is generally more acidic. This happens in extreme form during the production of silage by farmers. Green grass is piled into a pit and air is sealed out with a layer of plastic sheeting or soil. The grass is preserved, or pickled, through the production of acids, mainly lactic and acetic acid. The pH of silage is around 4.0 to 5.0.

Lime added to a partially anaerobic compost bin would modify the composting process and would give a less compost. If our soil is alkaline we may prefer to have an acidic compost, but if our soil is acidic the addition of a small amount of lime to a compost bin could be worthwhile. To add lime or not to add lime is a question that we each need to answer after considering our own situation. We do not need to follow someone else's recommendation.

Chemical

Compost heaps are akin to complex chemical factories. Many changes take place in the course of decomposition. Even before the microbes start their work, enzymes in plant cells have started to break up proteins into amino acids. The microorganisms grab all the soluble compounds, such as sugars, amino acids, inorganic nitrogen (mainly ammonium nitrogen) and start breaking up the starches (into sugar), fats (into glycerol and organic acids), proteins (into amino acids) and cellulose (into sugars) and incorporating the bits into their own structures. At times more ammonia is produced from proteins than the microbes can handle and some may escape, but eventually they catch up. Plant nitrogen is converted to the protein of microorganisms and eventually some is converted into nitrate, a ready source of nitrogen for plants.

Lignin, a compound of the cell walls of plants, is some what resistant to microbial decomposition, but eventually it is broken down. Microorganism in the compost heap and later in the soil convert lignin and other plant components into the very large stable molecules that make up the black humus of soils. It is thought that these molecules are able to join soil particles together into aggregates and, hence, improve soil structure. As the humus components are slowly broken down by other soil organisms, the various nutrient elements they contain are released to plant roots.

Much of the carbon of the original organic materials is utilized by microorganisms which ends up as carbon dioxide gas. This loss causes a 30 to 60 percent decrease in dry weight of the heap and a volume reduction of around two thirds.

Microbiological

During aerobic composting, the microbial population is continually changing. In the first mesophilic stage, fungi and acid producing bacteria multiply on readily available nutrients such as amino acids, sugars and starches. Their activity produces heat and eventually the thermophiles take over in the interior of the heap. The thermophilic bacteria decompose protein and non-cellulose carbohydrate components such as fats and the hemi-celluloses (similar to cellulose but composed of mannose and galactose as well as glucose). Thermophilic actinomycetes appear to be more heat tolerant than many other bacteria and their numbers increase greatly during the thermophilic stage. Some are able to decompose cellulose.

Thermophilic fungi occur in the 40 to 60°C range, and fail to revive above 60°C. They decompose hemi-cellulose and cellulose and, hence are particularly important in the formation of compost. As the availability of food decreases, the thermophilic organisms decrease their activity, heap temperature falls and mesophilic organisms invade the interior from the outer layers that remained relatively cool during the thermophilic stage. It appears that at least some of these invaders can use cellulose and hemicellulose, but not as efficient as the thermophiles. They continue the decomposition process and no doubt also decompose the remains of many thermophilic microorganisms.

Microorganisms decompose plant materials mainly by means of enzymes they excrete. Enzymes are large, complex protein molecules that enable chemical reactions to take place without actually being used up themselves. In compost heaps, microorganisms produce several enzymes that enable them to break organic materials, into smaller bits that they can use as food. For example, an enzyme called cellulase can break up cellulose (a major component of cell walls, and of the paper of this page) into glucose. This can then be absorbed by the organism to provide energy for its life processes.

Pathogens

An important function of the compost heap is the destruction of pathogens and parasites of both plants and animals, and weed seeds. Most of these are killed at temperatures of 55 to 60°C and do not survive the thermophilic stage. If some are known to be present initially, it is important to make sure that all materials spend some time in the hottest part of the heap by turning the heap. Thus the bacteria that produce wilts in plants, the bacteria that blight nursery seedlings, the fungi that cause damping-off, wilt, and nematodes that attack roots can all be killed in a hot compost heap.

METHODS OF MAKING COMPOST

There are three common methods of making garden compost as described below.

Berkely Method

This is one of the best methods developed at the University of California, Berkeley.

Alternate layers of high and low nitrogen materials should be built upon top of one another into a heap about 1.5 m high. Experience suggests that it does not matter whether the materials are layered or mixed up before hand, so long as the C/N ratio is near the optimum of 25 to 30. Some people find it simpler to mix the whole lot together as they make the heap. The minimum size of the heap depends on air temperature. For summer, a heap volume of somewhat less than a cubic metre will "work". Larger heaps are necessary in cooler conditions, otherwise too much heat is lost from the heap. Hence, as a general rule, an initial heap volume of one or two cubic metres should be aimed at. Larger heaps may generate heat above 60°C, killing the microbiological population. It may be possible to use as little as half a cubic metre of heap by covering with bags or some other insulating material.

The heap is turned, mixed and aerated after three or four days and thereafter every two or three days until the fourteenth day, when the compost should be ready for use, although perhaps a little coarse. Another week of composting will give a finer product. Care should be taken to ensure that all materials spend some time in the hottest part of the heap, so that weed seeds and pathogens are destroyed. Frequent turning for adequate aeration is the secret of success with composting. The materials should be "fluffed up" with a fork during turning to maximize aeration. Aeration can also be improved by building the heap on a platform made from loosely fitted wooden planks. Air will then penetrate the heap from the bottom as well as the sides.

Indore Method

This is essentially the method devised by Sir Albert Howard. The name is that of town where he worked. The Indore method involves minimum effort, but it takes a long time to produce a usable product. Alternate layers of low and high nitrogen materials are heaped on top of one another to a height of about 1.5 m. The heap should be about 2 m square at the bottom, tapering to about 1.2 m if it is free-standing. Of course, if it is contained by boards, bricks or wire mesh it would have vertical sides. A foundation layer of brush, prunings or tree branches helps aeration. The heap is covered with a 5 cm layer of compacted soil to deter flies and to prevent the escape of foul odours. If, through lack of sufficient materials at one time, the heap has to be built over several weeks, each top layer should be covered with soil.

If the heap is turned, the first turning should be eight to ten days after making, and then again after a further thirty or forty days. The compost should be ready for use about a month later. The process takes a year if the heap is not turned at all.

The Indore compost heap can very rapidly become anaerobic and therefore does not usually generate sufficient heat to kill undesirable organisms and seeds. Its anaerobic nature can also generate foul odours, hence the need to encase the heap with soil, or to aerate it through turning.

Compost Bins

Bins are useful for people with small gardens and little space. They do an excellent job of garden materials. Add soil or finished compost in small amounts from time to time to prevent "pugging" in sloppy kitchen wastes and to provide a full range of microbes. Some bins have holes in the bottom or lower sides to allow air in to the bin to keep the contents aerobic. Other bins are open at the bottom and are simply flat on the ground. Leaving a small air space under them will help the composting process. Bins can also be made from old drums.

Gardeners with larger requirements can purchase several bins but it is cheaper to make rough bins from railway sleepers, scrap timber, bricks (leave air space), wire netting or old galvanized iron, or to simply make heaps. Some gardeners find that both, a bin and a large scale heap are needed – one for kitchen scraps and the other for garden refuse.

An alternative to bins, for those with enough space is to feed all food scraps to hens. Inedible materials are mixed by the hens with their excreta and the sawdust of the litter. From time to time some of the litter can be removed and incorporated into a compost heap that would otherwise be a bit low in nitrogen, phosphorous and potassium. This way we get a double return eggs and recycled nutrients.

TROUBLE SHOOTING

There are four main reasons why compost heaps fail to produce good quality compost.

a. They are too wet. The tell-tale sign of this is production of foul odours. The problem may be over-come by adding dry materials (with due regard to C/N ratios) and /or by more frequent turning.

b. They are too dry. The cause here will be obvious if the heap is dug into. Sprinkling with water during remaking is the cure.

c. Carbon/nitrogen ratio too high. This problem is indicated if the heap "works" for a while and then slows down, even though the moisture content is satisfactory. There are no foul odours produced. The cure is to add high-nitrogen materials such as lawn clippings, animal manure (including dog faeces and human urine) or a nitrogenous fertilizer.

d. Lack of other nutrients. Mixtures of organic materials as listed in this paper should usually contain adequate levels of the nutrients needed by microorganisms. Probably the only one likely to be limiting is phosphorus. Light sprinklings of rock phosphate, bone meal, super phosphate or other phosphatic materials can aid the composting process. Never add more than 2 per cent of the weight of the heap.

A CAUTION

Inside a partly finished compost heap one may often notice that the organic materials have turned white or greyish- white. This is because they are covered with thermophilic actinomycetes doing a good job of breaking them down. That's as it should be. But these microorganisms produce very large numbers of spores. If the compost heap dries out and is disturbed clouds of these spores go into the air. The compost maker will find them rather irritating to breath.

USING THE PRODUCT

If we supply the right conditions, microorganisms do the rest for us. At the end they give us a pleasant smelling, dark crumbly material ideal for use as soil conditioner, fertilizer and suppresser of soil-borne diseases of plants.

Compost may be used around mature plants as soon as the temperature of the heap has come down below 40°C, say three weeks after building the heap. Leaving it cure for a few more weeks will improve its quality by increasing its fineness and reducing the need of microorganisms in it for the nitrogen that we want our plants to have. Finished compost has an earthy smell, has few recognizable pieces of the organic materials and is a fairly uniform dark brown or black colour. Rain can leach nutrients from finished compost, so cover finished heaps until it is used.

Sieved compost may be used as a top dressing for lawns. Otherwise it may be either dug into garden beds for vegetables or flowers, spread as a mulch around shrubs and trees (keeping 40 to 50 cm away from the trunks of fruit trees) or spread between rows of growing plants. Rain or sprinkler water will wash nutrients from compost mulches into the soil and plant roots will grow up into the lower layer.

It is sometimes stated that it is best not to dig compost into soils as this does not happen in natural situations such as forest floors. Digging it in amongst established plants is certainly undesirable as the digging might damage roots. But in vegetable beds, which are unnatural anyway, distributing the compost down through the soil will give plant roots care and more intimate contact with it than if it were just spread on the surface. Australian research has shown that considerable amounts of nitrogen can be lost from organic residues such as grass tops and animal dung lying on the surface of the soil; burying has been shown to reduce this loss and to boost plant growth. Also, by digging it in we partly copy the natural activity of earthworms, only we speed the process up to suit our crops.

Perhaps a useful compromise is to dig out compost into beds for annual crops so that the roots of these crops get maximum amounts of nutrients early in their growing period, but to add a further layer to the soil surface during the growing season as a mulch and extra supply of nutrients; for perennials, surface application is really the only option available.

The physical or soil conditioner effects of compost are perhaps more important than the fertilizer effects. Poor soil structure inhibits root growth and consequently the over all growth of the plant. Compost promotes the aeration of soil particles so that structure is improved. The roots, air and water can move through the soil more easily. In addition, as the water-holding capacity of the soil is increased, plants become less prone to drought. Other soil conditioner effects include an increased ability of the soil to absorb rapid changes in acidity and alkalinity and the neutralization of toxic substances such as organic toxins produced by some plants, and toxic metals.

Rates of application of the compost needed to improve the physical properties of soils vary from soil to soil. Sandy soils and clay soils benefit from rates as high as 10 kg per m^2 for the first few years of an improvement program. Later maintenance application could be around 3 kg per m^2. This latter rate would also supply a fair proportion of the nutrient elements needed by many plants once severe deficiencies have been corrected.

The fertilizer value of a compost is directly related to the quality of the organic materials used. Materials of low nutrient content give compost of low fertilizer value. Typical contents are 1.4 to 3.5% nitrogen, 0.3 to 1.0% phosphorus and 0.4 to 2.0% potassium with smaller amounts of other nutrients. One advantage of compost is that the nutrients in it become slowly available throughout the growing season and so are less easily lost by leaching than are nutrients in soluble fertilizers. The effect is particularly beneficial for nitrogen, which can be readily lost as nitrate from applications of soluble fertilizers. Compost greatly reduces the rate of nitrate formation in soils and therefore reduces the contamination of ground water with nitrate. Another specific effect of compost is that organic acids released during microbial activity in it increase the availability of phosphorus to plants. Along with other organic amendments such as green manures, compost reduces the levels of plant pathogens and parasitic nematodes in soils.

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CHEMISTRY AND PROCESS OF COMPOSTING

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INTRODUCTION

Plants and animals are subjected to microbial decomposition once they are dead. Vast quantities of plant remains and forest litter decompose above the soil surface also. Subterranean parts and above ground portions of plants serve as food materials for the soil microflora for building up their cells. The cells of the microorganisms serve as source of organic matter for succeeding generation of the microorganisms. In this process, the original organic matter of plants and animals are converted to various inorganic compounds which are available to living plants as nutrients. This process is termed mineralisation.

CHEMICAL NATURE OF PLANTS

The organic constituents of plants are commonly divided into five broad categories; (a) cellulase and hemicellulase, constituting about 15-60 percent of plant biomass, (b) lignin, which usually makes up 5-30 percent of plants, (c) water soluble factors like sugars, aminoacids, etc. constituting 5-30 percent, (d) pigments, resins, waxes oil etc. which are alcohol soluble, (e) proteins, which have in their structure nitrogen and sulphur. Mineral constituents vary from 1 to 13 percent. On weight basis, bulk of plants is constituted by cellulose, hemicellulose and lignin.

DESIRABLE CHEMICAL QUALITIES REQUIRED FOR POTTING MEDIA

Chemical qualities desired for an ideal potting medium consists of slightly acidic or near neutral pH (5.5-6.5), high cation exchange capacity (CEC) and good fertility. The CEC is a measure of the ability of the potting medium to hold nutrients. Generally the greater the organic matter or compost content, the higher will be the cation exchange capacity of the potting mix. A low value of CEC (10 meq/100 g) means that nutrients will be washed out from potting medium during watering. A high CEC (140 meq/100 g) results in nutrients being held to the mix and available to the seedlings.

Other physical qualities required for a potting medium include presence of large proportions of micropores to improve water holding capacity, a good texture so that compaction is resisted and low weight (i.e. bulk density) to facilitate transporting and handling.

DESIRABLE QUALITIES OF COMPOST AS A POTTING MEDIUM

Compost incorporates all these chemical and physical properties to a potting medium. Addition of composted organic material is the easiest method to increase the organic matter content in potting media. A well managed composting operation can produce a compost with almost all the properties of a good fertile potting medium like light weight, good water holding capacity, high cation exchange capacity, good texture, etc.

PROCESS AND CHEMISTRY OF COMPOSTING METHODS

Composting with plant materials can be done in open space quantity (free standing) or enclosed space (in pits or trenches). The quantity of raw material for composting can vary from one m^3 to 100 tons. The work on composting is generally initiated six months before its actual use in potting media. Different steps of composting involve 1. preparation of raw material for compost, 2. piling, 3. turning, and 4. maturation. Details of these techniques are not provided in the topic since they are dealt with in detail in other chapters.

Raw materials for composting

Any organic material is suitable for composting. However, based on availability in our state, the organic raw materials can be weeds in forest plantations, sawdust, wood waste and bark, coir pith, vegetable and fruit waste, farm yard and poultry manure, water weeds, tea and coffee wastes, etc.

The most important factor required for a material for compostability is its C/N ratio i.e., ratio of carbon to nitrogen present in the raw material. The optimum range is 25-30:1. At C/N ratio above 30, nitrogen must be added in the form of either as high nitrogen containing wastes or nitrogenous fertilizers like urea or ammonium sulphate. The C/N of the common raw materials is given below.

Raw materials	C/N ratio
Farmyard manure	15-20
Cut straw	48
Sawdust	400
Wheat straw	125
Forest weeds	20-45

Composting is a process mediated by microorganisms. Microorganisms assimilate about 20 to 40 percent of substrate carbon present in the raw material and convert it into its own protoplasmic carbon. The rest of the carbon is released in the atmosphere as carbon dioxide or accumulates as waste products. However, the rate of decomposition (assimilation) of plant materials (raw materials) depends upon the nitrogen content of the plant tissues because nitrogen also is an important mineral in microbial metabolism. Thus, a low nitrogen content or a high C:N ratio is associated with decreased microbial activity leading to slow decay of organic matter.

During mineralisation i.e., during the process of composting C:N ratio tends to decrease with time, i.e., the proportion of N increases as compared to carbon. This is due to the loss of carbon from the substrate (raw material) as carbon dioxide because of the metabolic activity of microorganisms while the nitrogen remains more tightly bound in organic combination, especially in the microbial biomass. While organic carbon is lost as CO_2, N remains in the system itself, thus increasing the percentage of nitrogen in the residual substance. As the process of decomposition goes on, the C:N ratio narrows down increasing the N content of compost gradually until the equilibrium C:N ratio is attained which is approximately 10:1.

Other natural materials which affect the rate of composting is lignin, which is present in very high quantities in saw dust and wood waste, and tannin present in coir pith. Saw dust and wood bark, and coir pith have very high C/N ratio and, hence, they have to be mixed with materials having low

C/N ratio like cow dung and farm yard manure during composting. For utilization of coir pith, it is to be soaked in water for 24 hours so as to remove tannin. Fresh green weeds have to be dried preferably under shade and preserved under cover before utilizing for composting. Oxygen availability, temperature, moisture content and pH are the other important factors which influence the composting process.

TYPES OF COMPOSTING

The process of composting can be either aerobic or anaerobic. Aerobic composting is mediated by microorganisms which grow in the presence of oxygen (air). Generally, aerobic method of composting (Berkeley method) is more rapid and efficient than anaerobic method. In the aerobic method, air is present in the pile and aerobic microorganisms multiply feeding on the substrate. But gradually air gets depleted inside the pile due to the use of rapidly multiplying aerobic microorganisms or compaction of decomposing raw materials and sometimes due to increased moisture content. Turning the pile becomes necessary to improve aeration and for sustained aerobic decomposition.

As mentioned earlier, the process of composting starts with stacking various layers of substrate (piling). The decay of the organic matter is initiated by the microorganisms present in the substrate. If appropriate microorganisms are absent or less as in cold weather, small quantity of fertile soil has to be sprinkled on the stacks so that microorganisms present in soil can act as starter inoculum for decomposition. Under aerobic conditions organic matter breaks down into a mixture of carbon dioxide and nitrate of minerals. Under anaerobic conditions, the product will be a mixture of carbon dioxide, methane and various other foul smelling gases. A peculiarity of composting is that the life process of one group of microorganisms will create environment suited to other groups.

TEMPERATURE AND MOISTURE CONTENT

Aerobic decomposition of organic matter starts when oxygen, moisture content and temperature inside the pile are favourable for growth and multiplication of microorganisms; bacteria, fungi and actinomycetes take part in aerobic decomposition. At the initial stage of decomposition, the temperature inside the pile will be around atmospheric temperature which gradually increases and will reach beyond 65°C if the pile is not turned. The temperature inside the pile increases due to energy release as a result of the metabolic activity of large number of microorganisms. Upto 45°C mesophilic microorganisms i.e., the microorganisms which can grow and multiply up to 40 to 45°C, will be active. Beyond this, thermophilic microorganisms, which are most active between 45 and 60°C proliferate in the system. Thermophilic microorganisms include thermophilic fungi belonging to species of *Mucor, Humicola, Aspergillus, Chaetomium, Torula* etc. and thermophilic Actinomycetes belonging to species of *Streptomyces, Thermoactinomyces, Micromonospora*, etc. The Actinomycetes give an earthy odour to the compost. At about 60°C the decomposition will be rapid. The higher temperature will kill pathogenic microorganisms present in compost and destroy seeds of weeds which may otherwise germinate in potting medium. Further increase in temperature has to be prevented by turning the compost several times because microorganisms will be killed beyond 70°C and consequently composting process will be stopped. Turning the compost and mixing the outer cooler portion of the heap with the inner portion will kill the flies by destroying their eggs and larvae because of the high temperature inside the heap.

As mentioned earlier, moisture content of the raw material is an important factor influencing the process of composting. About 50- 60% moisture content is the optimum for composting. Below 40% moisture content, microbial activity will be slowed down affecting decomposition. If the pile is frequently turned or has a loose structure, the moisture content should be sufficiently increased.

pH OF THE COMPOSTING MEDIUM

The pH during composting does not change drastically because most plant materials added to a compost pile will have a pH from 5-7 which is appropriate for microbial decomposition. During the process, pH drops slightly due to the formation of organic acids by microorganisms but subsequently increases during the thermophilic stage and stabilizes between pH 6.5 and 8.5. However, if the pile becomes anaerobic, acids are generated due to fermentation and pH drops further. However, restoring aerobic condition through turning will lead to aerobic decomposition and reduction in pH. Addition of lime to the pile is not recommended because this will result in generation of ammonia and loss of nitrogen. However, lime is added to the finished product, if needed.

MATURING

Although the initial stage of decomposition of raw material is rapid, the final stage of ripening or maturing is a slow process and it may take a few months. It is during the process of maturing that most of the lignin and cellulose which are the most resistant components get decomposed. The final C/N ratio of the compost should be around 10 and 12. However, this depends upon the initial C/N ratio of materials, the initial particle size, moisture content and porosity of the mass during composting. Once the process is completed, the compost can be stored in piles under a protective cover with no increase in temperature and without anaerobic activity. The final product should have a dark colour, earthy odour and light fluffy structure. As a final step the dried finished product should be sieved to provide a homogeneous compost.

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BERKELEY METHOD OF COMPOSTING

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INTRODUCTION

Composting is a simple method of speeding up the natural process of rotting but the process of composting can be controlled as per one's convenience in the compost heap. Many microorganisms like fungi, bacteria and actinomycetes which are already present as natural contaminants or may come from neighbouring environment like air or soil or water, will reduce the organic matter under favourable conditions and decompose the organic matter to a utilizable substrate thus, improving and maintaining the soil fertility. Compost has most of the desired characteristics of a nursery potting medium with little modifications.

METHODS OF MAKING COMPOST IN SOUTHERN BENGAL

The widely used method to make compost is commonly known as BERKELEY method. It is an aerobic process. It takes little time and can be prepared from weeds, straw etc. which are easily available. As the temperature of the heap rises above 55°C any pathogen in the compost gets destroyed.

A masonry chamber with a very light shed (roof) has been constructed at all research Ranges of this Divisions. Generally, the size of each unit is 5 m x 2.40 m x 1.2 m (height) and it is divided into two halves by providing a partition wall of wooden plank. The entire wall is Jaffry type leaving only 15 cm height continuous masonry wall at bottom with cement plaster. The floor is cement concreted and plastered. The light roof of Janata Roofing is placed on wooden perlin and rafter is supported by masonry pillar. There is 90 cm wide space to get entry into the chamber to put in the raw materials or take out the final compost.

Raw materials

Perennial weed species like *Chromolaena odorata*, *Lantana camara*, grasses etc. are found in plenty in the forests of south west Bengal. They are a menace to the forest saplings specially in plantations, as they suppress other seedlings and compete for nutrients. They can provide steady supply of homogeneous uncontaminated raw organic materials in adequate quantity. With the onset of monsoon i.e., from the middle of June to last week of December the living, coppicible stool produce profuse succulent shoots and on repeated cutting, within 60 days they produce shoots of average height of 90-120 cm. Average availability of *C. odorata* (Asamdata) and *L. camara* (Shut Bhairab) in the forests of south West Bengal is estimated to be 50-70 and 40-50 metric tons/hectare respectively.

Collection and chopping

The succulent shoots of desirable weeds are cut manually close to the ground, stacked in field and carried by head load to chopping site where manually operated chopper machine equipped with double blades is installed. The shoots are then chopped by two bladed chopper machine to a size of 5-10 mm length and chopped raw materials are kept under shade.

Mixing

Keeping in view of the ideal C/N ratio of compost ingredients, which is 25-20:1 at start, for efficient composting, the proportionate weight of the mixture of primary and secondary ingredients is calculated based on the C/N ratio of raw organic materials. Prior to placing charge in compost shed, 50% water by weight of total weight of the mixed material is added, to have homogeneous mass and to expedite the microbial activity. However, care is taken to ensure that the water is sprinkled uniformly and that the charge does not become too soggy.

Compost heap making

The homogeneous mass of mixture is placed in the chamber of compost shed, layer by layer with water sprinkling to maintain the moisture content. As a general rule, the size of the heap lies between 2-3 m^3. In no case the temperature inside the heap should exceed 60°C above which the microbiological population will be killed.

Changes inside the heap

During feeding and multiplication of the microorganisms inside the heap of moist organic materials, temperature starts rising gradually. After a week or more when the temperature of the heap reaches about 55^oC, then the heap is turned over and thoroughly mixed. This aerates the heap; water is sprinkled, if necessary. During turning for aeration the interior temperature drops 5-10^oC sharply and again it rises in a few days and further turning of the heap is done and the process is repeated until the temperature of the heap stands constant for 7-10 days. Care to be taken to ensure that all materials remain for sometimes in the hottest part of the heap so that weeds, seeds and pathogens are destroyed. In no case the heap temperature is allowed to exceed 60^oC to avoid the death of microorganisms. The compost will be ready for use if there is no foul odour of any kind and the temperature remains constant. The final product looks deep brown to black in colour having a greasy feel and earthy smell. Table 1 and 2 compare the composting process using four different plant species.

PROCESSING AND PACKING

The ready compost removed from the compost shed is placed on a masonry platform for sun drying. After 2-3 days when the compost becomes dry and dusty then it is passed through a sieve in order to separate the seeds and small piece of woody particles. The compost is packed in sacks and stored in dry store house. Cost of production of compost employing the four species and its comparison with cow dung is given in Table 3.

TESTING

From time to time, samples are tested at the Midnapore Laboratory for total organic carbon, Nitrogen percentage and C/N ratio.

Table 1. Comparison of aerobic composting using four different plant species as primary substratum

Sl. No.	Name of substratum (ingredients) (primary)	*Chromolaena odorata* (with urea)	*Chromolaena odorata* (without urea)	*Andropogan* species	Paddy straw	*Leucaena leucocephala*
1	2	3	4	5	6	7
1.	Initial volume of the mixture in m^3	0.65 m^3	0.75 m^3	9.702 m^3	1.725 m^3	5.254 m^3
2.	Initial weight of the mixture in Kilogram	*Chromolaena* - 157.00 kg Urea - 100 gm	182.00 kg	*Andropogan* - 2100 kg Paddy stra - 525.00 kg	Leaves of weeds 87 kg Straw - 158.5 kg Urea - 0.4 kg	Leaves and twigs of *L. leucocephala* 375.00 kg. Urea - 5.0 kg.
3.	Quantity of water added in kg/lts.	45 lts.	50 lts	900 lts	90 lts	165 lts
4.	No. of days required for complete composting	31 days	27 days	130 days	40 days	44 days
5.	Final volume of compost in m^3	0.057 m^3	0.095 m^3	1.07 m^3	0.56 m^3	1.48 m^3
6.	Percentage of compost compared to total volume	8.80%	12.66%	11.00%	32.50%	28.16%
7.	Final weight of compost In kilogram	29.00 kg	48.00 kg	850.00 kg	201.00 kg	112.00 kg
8.	Percentage of compost compared to total weight	18.50%	26.37%	32.40%	81.70%	29.40%
9.	Bulk density of final product (kg/m^3)	508.77	505.26	794.39	358.93	75.67
10.	No. of days required for processing drying	3 days	3 days	10 days	10 days	5 days
11.	Laboratory Test result					
	a. Total organic carbon %	26.73	30.01	30.47	8.40	22.68
	b. Total nitrogen %	3.54	3.87	4.78	1.31	2.92
	c. C/N ratio	10.51	7.80	6.36	6.40	7.76

Table 2. Daily variation in temperature and turning schedule of compost heaps of four different plant species

Chromolaena odorata (with urea)			*Chromolaena odorata* (without urea)			*Andropogan* species			Paddy straw			*Leucaena leucocephala*		
Date	Tempe-rature (C)	Date of turning	Date	Tempe-rature (C)	Date of turning	Date	Tempe-rature (C)	Date of turning	Date	Tempe-rature (C)	Date of turning	Date	Tempe-rature (C)	Date of turning
23.10.95	45°		04.11.99	43°		18.10.95	29°		12.05.95	30°		21.03.96	24°	
24.10.95	47°		15.11.95	46°		19.10.95 to 22.10.95	33°-43°		13.05.95	35°		22.03.96	24°	
25.10.95	48°		16.11.95	46°		23.10.95	47°	23.10.95	14.05.95	39°		23.03.96	28°	
26.10.95	50°		17.11.95	48°		24.10.95 to 26.10.95	28°-37°		15.05.95	36°		24.03.96 to 25.03.96	32°	
27.10.95	54°		18.11.95	50°		27.10.95	40°	27.10.95	16.05.95	38°		26-03.96 to 28.03.96	34°	
28.10.95	57°		19.11.95	54°	19.11.95	28.10.95 to 09.11.95	43°-47°		17.05.95	42°		29.03.96 to 30.03.96	35°	
29.10.95	57°	29.10.95	20.11.95	53°		10.11.95 to 22.11.95	49°-36°		18.05.95	45°	18.05.95	31.03.96	36°	
30.10.95	44°		21.11.95	53°		23.11.95	35°	23.11.95	20.05.95	34°		03.04.96 to 07.04.96	38°	
01.11 95	43°		23.11.95	52°	23.11.95	24.11.95 to 09.12.95	36°-32°		21.05.95	34°		08.04.96	48°	08.04.96
02.11.95	43°		24.11.95	51°		10.12.95	39°	10.12.95	22.05.95	39°		09.04.96 to 10.04.96	40°	
03.11.95	41°		25.11.95	51°		11.12.95 to 15.12.95	42°-45°		23-05.95 to 24.05.95	40°		11.04.96	45°	
04.11.95	40°	04.11.95	26.11.95	51°		16.12.95	46°	16.12.95	25.05.95	42°	25.05.95	12.04.96	42°	
05.11.95	35°		27.11.95	51°		17.12.95	31°		26.05.95	28°		13.04.96 to 14.04.96	45°	
06.11.95	42°		28.11.95	50°		24.12.95	44°		27.05.95	30°		15.04.96 to 16.04.96	46°	

Table 2 contd..

Table 2 contd..

07.11.95	44^0		29.11.95	50^0		25.12.95	44^0		28.05.95	34^0		17.04.96	47^0	
08.11.95	44^0		30.11.95	50^0		26.12.95 to 01.01.96	32^0-44^0		29.05.95	40^0		18.04.96	52^0	18.04.96
09.11.95	40^0		01.12.95	49^0	01.12.95	02.01.96	45^0		30.05.95	47^0	30.05.95	19.04.96	42^0	
10.11.95	40^0		02.12.95	44^0		03.01.96 to 08.01.96	32^0-42^0		31.05.95	30^0		20.04.96	44^0	
11.11.95	40^0		03.12.95	40^0		09.01.96	45^0		01.06.95	32^0		21.04.96 to 22.04.96	45^0	
12.11.95	35^0		04.12.95	37^0		10.01.96 to 14.01.96	32^0-40^0		02.06.95	40^0		23.04.96 to 26.04.96	46^0	
13.11.95	35^0		05.12.95	34^0		15.01.96	45^0	15.01.96	03.06.95	43^0	03.06.95	27.04.96	47^0	
14.11.95	35^0	14.11.95	06.12.95	33^0		16.01.96 to 26.01.96	38^0-45^0		04.06.95	34^0		28.04.96	48^0	
15.11.95	37^0		07.12.95	33^0		27.01.96	46^0	27.01.96	05.06.95	38^0		29.04.96	54^0	29.04.96
16.11.95	35^0		08.12.95	33^0		28.01.96 to 10.02.96	38^0-44^0		06.06.95	42^0		30.04.96	42^0	
17.11.95	35^0		09.12.95	33^0		11.02.96	45^0	11.02.96	07.06.95	47^0	07.06.95	01.05.96	45^0	
18.11.95	34^0		10.12.95	33^0		12.02.96 to 18.02.96	30^0-36^0		08.06.95	25^0		02.05.96	44^0	
19.11.95	34^0					19.02.96	38^0	19.02.96	09.06.95	27^0		03.05.96	44^0	
20.11.95	33^0					20.02.96 to 27.02.96	28^0-32^0		10.06.95	32^0				
21.11.95	33^0								11.06.95	38^0	11.06.95			
22.11.95	32^0								12.06.95	30^0				
									13.06.95	30^0				
									14.06.95	32^0				
									15.06.95 to 20.06.95	32^0-32^0				
Total 31 days			27 days			130 days			40 days			44 days		

Table 3. Total cost (in Rs) of production of compost using four different plant species

Items	*Chromolaena odorata* (with urea)	*Chromolaena odorata*	*Andropogan* species	Paddy straw	*Leucaena leucocephala*
1	2	3	4	5	6
Collection and carriage cot	31.40	36.40	1,167.70	249.35	211.00
Chopping cost	39.25	45.50	747.60	81.40	85.00
Cost of mixing ingredients	7.85	9.10	113.90	81.40	42.00
Cost of making heap in shed	3.70	4.28	110.20	81.40	42.00
Cost of watering as per requirement	7.85	9.10	115.40	10.00	121.00
Cost of turning the heap	4.25	4.90	135.20	81.40	36.00
Cost of drying, seiving, packing	6.20	7.18	80.00	10.00	36.00
Price of ingredients, urea etc.	0.40	--	--	10.00	25.00
Total	100.90	116.46	2,470.00	604.95	598.00
Total weight of raw materials	157.00 kg	182.00 kg	2,625.00 kg	245.90 kg	380.00 kg
Cost per kilogram of raw materials	0.64/kg	0.64/kg	0.94/kg	2.46/kg	1.57/kg
Total finished products kilograms	29.00 kg	48.00 kg	850.00 kg	201.00 kg	112.00 kg
Cost per kilogram of compost	**3.48/kg**	**2.42/kg**	**2.91/kg**	**3.00/kg**	**5.34/kg**
Price of cowdung	3.00/kg	3.00/kg	3.00/kg	3.00/kg	3.00/kg

VERMICULTURE TECHNOLOGY AND ITS APPLICATION IN NURSERY

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INTRODUCTION

Earthworms play an important role in the process of soil formation and maintenance of soil fertility (Darwin, 1881; Kale and Krishnamurthy, 1981). They turnover large amounts of soil by burrowing, feeding and casting. In this process they incorporate organic matter in the soil leading to improved soil structure (Hoogerkamp *et al.*, 1983; Stewart and Scullion 1988), enhanced nutrient release (Barley and Jennings, 1959) and ultimately to better plant growth (Edwards and Lofty, 1980). Charles Darwin wrote about earthworms that "It may be doubted if there are other animals which have played so important part in the history of world as have these lowly creatures". He further said that "Plough is one of the most ancient and most valuable of man's inventions but long before he existed, the land was regularly ploughed and still continues to be thus ploughed by earthworms". Recently much attention is given to understanding functional role of earthworms in the ecosystem.

VERMICULTURE AND VERMICOMPOSTING

Vermiculture essentially means culturing of earthworms and their application for various purposes. Compost prepared by using earthworm is called as vermicompost which is a mixture of excrements/castings of earthworms. It also contains aerobically composted organic matter including humus, live earthworms and their cocoons. Earthworms are broadly divided into three categories based on nature of feeding and defecation activity and their vertical distribution in soil strata. These are epigeic, endogeic or anecic.

The epigeic worms are surface living worms. They inhabit litter heaps or any other degrading organic matter on soil surface. They feed actively on organic matter rich in nitrogen and their breeding rate is faster. Important species from this group are *Eisenia foetida, Perionyx excavatus* and *Eudrilius eugeniae.*

The endogeic species inhabit mineral soil horizon and feed actively on soil containing small proportion of organic matter. These species are difficult to breed in captivity. Majority of these species undergo seasonal diapause e.g. *Lampito mauritii, Allelobophora rosea.*

The anecics live in burrows by forming complicated tunnels under soil surface. Their movement in soil helps in regular mixing of soil surface matter with the lower strata. They have combination of characteristics of epigeic and endogeic but their breeding rate is poor. *Pheretima elongata, Pheretima posthuma, Drawidia nilamburensis* and *Lumbricus terrestris* belong to this category.

DISTRIBUTION AND PHYSIOLOGY OF EARTHWORMS IN INDIA

Distribution of earthworms

India being a subtropical country, activity of earthworms is observed for a short period, particularly during rainy season; hence not much importance is laid on their role as component of ecosystem. Dash (1978) highlighted role of earthworms in degradation of organic matter and stimulation of microbial activity in soil.

The distribution of earthworms in India is well defined in three geographic divisions, namely Himalayan region, Indo-Gangetic plains and Peninsular region. The Himalayan region and Indo- Gangetic plains have poor earthworm population which could be partly explained to the last glaciation in the quarternary period. Majority of the Indian species show endemicity in the Peninsular region which was part of Gondawanaland and never submerged. All the indigenous genera presumably evolved and developed in Deccan Peninsula. Approximately 350 species have been reported from India of which most commonly occurring are *Megascolex, Lennascolex, Nelloscolex, Perionyx, Tonoscolex, Lampitto, Pheretima, Curgeona, Deccanica, Eukeria,* *Malabarrica*, etc. *Megascolex Konkanii* and *Lampito mauritii* are widely distributed species in the Peninsular region.

Morphology and physiology of earthworm

Earthworms range in colour from pink to various shades of red, with the darkest colour being blackish red. The earth worm has a long and narrow

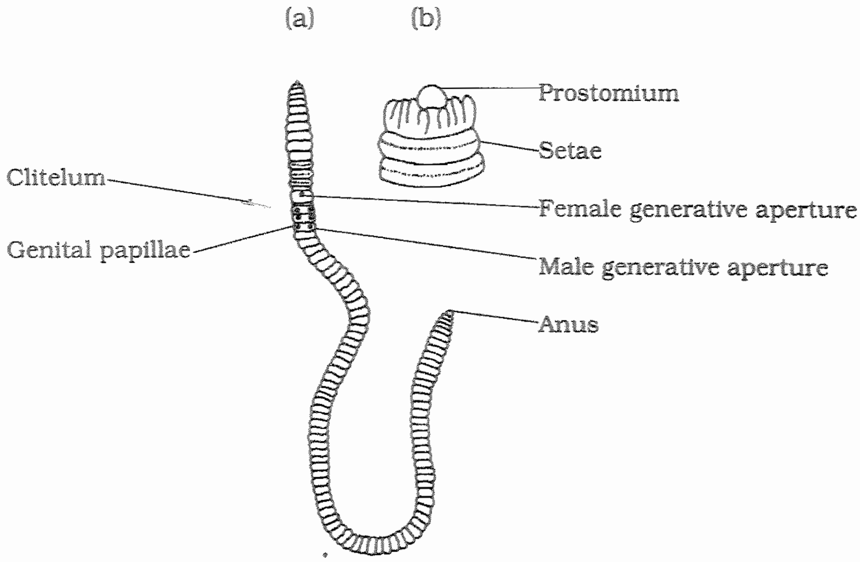

Fig.1. Morphology of earthworm
(a) Ventral view
(b) Dorsal view of prostomium and first three segments

cylindrical body divided into segments by inter segmental grooves which coincide with the internal partition of the septa (dividing wall or membrane). The clitellum is a prominent circular band of glandular tissue and indicates maturity (Fig.1). It consists of about four to ten segments and is located anywhere between the fourteenth and the thirty eighth segment, depending on the species. At the anterior end in the first segment is the prostomium, a fleshy lobe covering the mouth. The anus is located on the last segment. The male and female reproductive pores are located on the ventral region between the thirteenth and thirty eighth segments, and vary from species to species.

Earthworm moves due to complex set of actions involving the circular and longitudinal muscles, the setae, the septa, and the fluid filled body cavity. Since the earthworm has no skeleton, its shape is retained by the turgidity of the fluid in its body. The setae are chitinous structures embedded in the body wall and help the earthworm to get a firm grip of the substratum through which they are moving. The coelom is the body cavity between the digestive tract and the body wall and is filled with coelomic fluid. This helps the body of the earthworm to retain firmness.

The digestive system consists of a long tube running the length of the worm's body. At the entrance of the mouth is the muscular pharynx. Behind the pharynx is the oesophagus, a short narrow tube with which are associated calciferous glands. The calciferous glands, found in certain species, are partly responsible for regulating the pH of the coelomic fluid. Many species have a muscular gizzard which macerates food to fine particles before they pass into the intestine. The epithelium lining the intestine secrete various enzymes. Once the food is digested, it passes into the bloodstream through the intestinal epithelium and is used by the body. Digestion and absorption takes place in the intestine. The undigested material is excreted through the anus. Earthworms produce many enzymes including amylase, proteases, lipase, cellulase, chitinase, and invertase. However, all earthworms do not produce all enzymes.

Earthworms breathe through their body surface. Oxygen is dissolved in the moist surface and absorbed by the blood vessels which contain haemoglobin. The circulatory system consists of simple and closed ducts running from the anterior to the posterior end on the dorsal and ventral sides and is linked by lateral canals in the anterior region.

Neurons are concentrated in the form of a nerve ring to form a simple brain. Neurosecretions from cells of the nervous system regulate body functions to adapt to changing environmental conditions. Earthworms have special nerve endings which can receive various types of stimuli like light, vibration, taste, smell, and touch.

Nephridia are the excretory organs and are coiled tubes which act as differential filters. In many species, a pair of large nephridia is seen in each segment lying in the ventral and lateral regions of the coelomic cavity. The nephridia excrete waste products from the coelomic fluid and evacuates them through nephridiopores as urine which contains ammonia and urea with ammonia in greater quantity than urea (Mishra and Hota, 1986). Nitrogen excretion is an essential contribution of earth worms to soil fertility. Experiments on the starvation of *Lampito mauritii* has shown a greater production of urea than ammonia during the period of starvation. Worm urine is very dilute and the amount excreted each day is around 60 percent of the worm's body weight.

Earthworms are hermaphrodites, Most species reproduce by cross- fertilization, though some can reproduce parthenogenetically. Pairing usually takes place at night, and the two worms position themselves on opposite ends with their ventral surfaces adposed. Spermatophores are exchanged and then the worms separate. Copulation leads to the formation of cocoons in which the eggs are laid. Young worms emerge from the cocoons after couple of weeks. The number of young worms also depend on the species and stage of adulthood, with the number varying from one to five worms. In India, maximum cocoon production is seen during October and November (Dash and Senapati, 1980) which is the post monsoon period. During periods of high temperatures and dryness, earthworms in soils aestivate, and pass the dry summer in a state of dormancy.

METHOD OF VERMICOMPOST MAKING

Anybody with little training, capital, hardware and time can raise earthworms and process crop residues, tree leaves and animal dung into vermicompost. The species of earthworms used for composting are epigeic, namely *Eisenia foetida, Eudrilus eugeniae* and *Perionvx excavatus*. These species are fast breeders and feed actively on organic matter high in nitrogen.

Containers for culturing

The earthworms can be cultured under shelter to avoid direct sunlight and heavy down pour, either in brick lined pits, plastic tubs, wooden boxes, earthen pots or even on surface of soil by making heap of organic matter. The size of container should be 1m x 1m x 0.3m. In case of pit or heap method dimensions may be changed according to convenience, however, depth of pit or height of heap should not be more than 45 cm.

Selection of worms

Selection of worms for vermicomposting is based on (i) occurrence of high percentage of organic matter, (ii) high fecundity, low incubation period, short development period with high growth rate, (iii) wide adaptability for environmental variations and, (iv) high metabolic demand and presence of enzymes such as cellulase, chitinase and high assimilation and production efficiency. The epigeic species have been found to be useful for compost making and the most commonly used species are *Eisenia foetida, Perionyx excavatus, and Eudrilius eugeniae.* Vermicultural characteristics of these species is compared in Table 1.

Feed mix for worms

Agricultural wastes like sugar cane trash, weeds hedge cutting, saw dust, cattle dung, effluent slurry from biogas plant, excreta of sheep, horse, pig, poultry droppings (in small quantity) and vegetable wastes are ideal food for earthworms. City garbage or even biodegradable organic sludge, a waste product from industry can also be used for feeding worms.

Table 1. Vermicultural characteristics of earthworms

Worm species	Soil temp. for max. growth in °C	Age for Cocoon production in weeks	Vermistabilization in weeks	Number of young cocoons	Incubation period in weeks	Live wt
E. foetida	18-25	5-9	6-8	2-4	3-4	0.5
E. eugeinae	20-25	7-10	3-4	2-3	4	1.0
P. excavatus	25-30	15-18	4-5	1	4	1.0

Source : Vermitechnology : An option for Recycling of cellulosic wastes.

Preparation of bed

Step - 1:

Select a container as mentioned above or dig a pit of appropriate size where compost is to be prepared.

Step - 2:

Make a bed of 10 cm height using material like tree leaves, sugar cane trash, paddy husk, saw dust or coir waste. Give a layer of soil on it. Water is to be sprinkled on the bed to get moisture level of 40-50%. The bedding must appear wet.

Step - 3:

Mix organic waste with cattle dung in equal amount and pour appropriate quantity of water over it to make homogenous mixture. Effluent slurry from biogas plant can also be used. Keep this feed mix for two weeks. During this period heating of substrate will take place. Give turning to the material 2 to 3 times at 4 to 5 days interval and transfer it on the layer of bedding prepared earlier.

Step - 4:

Introduce cocoons or worms into the bed at the rate of 2000 worms for 400 kg feed mix. Then the feed mix is to be spread uniformly on the culture bed. Add 5 to 10% neem cake in the feed mix. Neem cake in small quantity has beneficial effect on growth of earthworms.

Step - 5:

Cover the bed with gunny cloth. Sprinkle water over the cloth periodically to keep gunny cloth wet. The worms feed actively on organic matter and assimilate only 5-10 percent and rest is excreted as loose granular mounds of vermicastings on the surface away from feed source. The worms will convert the feed mix into vermicompost in 60 days. Vermicompost will have a smell of moist soil.

Step - 6:

Take out the vermicompost and make a heap in sun light on plastic sheet. Keep for 1 to 2 hours. The worms will gather at the bottom of heap. Remove vermicompost, the worms collected at the bottom can be used for next batch of vermicomposting.

PRECAUTIONARY MEASURES FOR COMPOST MAKING

1. Moisture level in the bed should not exceed 40-50%. Water logging in the bed leads to anaerobic condition and change in pH of medium. This hampers normal activities of worms leading to weight loss and decline in population.
2. Temperature of bed should be within range of 20-30°C.
3. Worms should not be injured while handling.
4. Protect beds from white ants, red ants, centipedes and other predators like toads, rats, cats, poultry birds and dogs.
5. Frequent observation of culture beds is essential as accumulation of casts retards growth of worms.
6. Space is the criteria for growth and establishment of culture, Minimum space required is 2 M^2/2000 worms with 30 to 45 cm thick bed.
7. Earthworms find it difficult to adapt themselves in new environment hence addition of inoculum as a bait from earlier habitat helps in early adaptation to new site of rearing.

TIPS TO BOOST VERMICOMPOSTING PROCESS

1. Mixture of cattle, sheep and horse dung with vegetable wastes or crop residues forms ideal feed for worms.
2. Addition of neem cake in small quantities enhances growth of worms.
3. Biogas slurry aged aerobically for 15 days enhances vermicomposting process.

BENEFITS OF EARTHWORMS/VERMICOMPOST

The benefits derived from earthworms and vermicomposts are:

- Improved water holding capacity of the worm cast and drainage formed by movement of earthworms in soil strata has positive effects on plant growth.

- The intestinal mucus excreted by earthworms improve organic matter content of soil. The quality of soil organic matter acts as a regulating factor for mechanical activity of earthworms. The nature of organic matter particularly soluble fraction determines intensity and nature of microbial activity in the gut of earthworms.

- The worm casts have beneficial effects on growth promoting hormones like gibberellins, cytokinins and auxins due to metabolic activity of microbes harboured in the cast. Indole acetic acid is present in earthworm tissues.

- Chemical exudates of worms and those of microbes in the cast influence rooting and improve seedling emergence.

- Coelomic fluid of earthworms has antibacterial activity directed against pathogenic soil bacteria. The excrements of earthworms have high concentration of available nitrogen, phosphorous and potash. They have higher microbial activity and produce zones of nutrient enrichment in soil for plant growth.

- The castings of earthworms are stable aggregates which reduce surface crusting, increase water infiltration and resist soil erosion.

In addition to above mentioned benefits, indirect advantages like better quality of produce, high sugar content in fruits, and longer shelf life are seen in crops grown on vermicompost.

NUTRIENT CONTENTS OF VERMICOMPOST

A comparative study of vermicompost prepared by using different species of earthworms is shown in Table 2. There are appreciable differences in the nutrient content of vermicompost produced by different species of earthworms. On an average vermicompost contained more carbon and phosphorous than farm yard manure (FYM). The studies conducted at BAIF showed high contents of N in vermicompost compared to compost without worms; phosphorous and potassium levels were however same (Table 3).

Table 2. Comparison of nutrient status of vermicompost and farm yard manure

Parameter	*Eisenia foetida*	*Perionyx excavatus*	Farm yard manure (FYM)
pH	7.4	7.0	7.2
EC	0.9	1.2	0.18
OC	27.4	30.3	12.20
N	0.6	0.7	0.50
P	1.3	1.9	0.75
K	0.4	0.42	2.30

Source: Shinde, *et al.* (1992).

Table 3. Composition of compost with and without worms

Parameters	Compost with worms (vermicompost)	Compost without worms
OM	32.5	32.1
N	1.3	1.0
P	0.6	0.6
K	1.5	1.5
pH	7.6	7.3

Source : Sohoni *et al.* (Value addition to Biogas Effluent through vermicomposting)

VERMICOMPOST AS ORGANIC POTTING MEDIA

Considerable benefits may be gained by shrubs, flowers, vegetables and field crops by application of worm castings or vermicompost as they contain nutrients ready for assimilation by plants. Since vermicompost has most of the characters required for organic potting media used in nurseries for enhancing rooting it is necessary to explore the possibility of using vermicompost as organic potting media.

Vermiculture technology can provide a viable and eco-friendly alternative in the form of worm castings or vermicompost to conventional organic potting media. However, work on combinations of cast/compost and conventional potting media need to be carried out for different tree species for optimum results.

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