CONTENTS

- Flower or Garden pots
- In Horticulture
- In Agriculture
- Conclusion

CHAPTER 1

INTRODUCTION

Earthworms are 'tubular' creatures of some what lower evolutionary status than insects. However, these have many distinctly advanced features that add to their adaptabilities for life in soil. These are now being exploited by man for economic returns, as well for use in ecological management for soil fertility with organic waste recycling. Therefore, earthworms attain a high status in present day 'Economic zoology, with applications in many and distantly related fields. Among lower group of animals, earthworms therefore are now drawing more attention than others and deserve study.

Earthworms constitute a large part of the biomass (living bodies) inhabiting soil. In some situations, these may constitute 80% of the biomass. Zoologically, these have segmented body. So are classified under Phylum Annelida and Class Oligochaeta. Later one is from latin word oligos meaning few and chaete meaning hair like structures/ setae present externally over body of earthworms. Grossly, earthworms are tubular wriggling creatures with worm like appearance. Hence for these, usage of word worm or 'vermi' (latin) have come into popular usage. However, technically, earthworms considerably differ from other worms.

Earthworms of world are classified into 10 families, comprising 240 genera and about 3320 species. However, many areas still remain to be studied. So discovery of new species can not be over ruled. So far, Indian earthworm fauna is reported to comprise 509 species referable to 67 Genera.

In general, worms are divided into two groups :

(1) Microdrilli worms - which are aquatic and represented by 280 species;

(2) Megadrilli worms which are terrestrial and are called earthworms.

CHAPTER 2

ORIGIN AND EVOLUTION

Not much scientific information is available on origin and evolution of earthworms. This is because body of earthworm is very soft and decay quickly. Due to these reasons fossil formation had been difficult and fossils have not been found to appropriately interpret origin and evolution of earthworms. However, fossilizable parts or organelles on earthworm body are 'chaetae' or setae. These are chitinous, but with these organelles, tracing of evolution is extremely difficult. However, shape, arrangement and number of ,setae, comprise important taxonomic, character for identification of existing earthworms.

There are indirect interpretations on evolution due to want of fossils. Thus two school of thoughts are widely referred. J. Stephenson in 1930 opined that origin of earthworms is around 120 million years ago, i.e., the origin of w.rms is after origin of dicotyledonous plants. Other school opined that origin of worms is prior to origin of dicotyledonous plants. This was based on finding of vascular bundles of ferns in fossils of some worms. This school supported view that Annelids originated in precambrian and cambrian periods, i.e. around 570 million years ago. It is also opined that earlier worms had their origin in water and slowly got adapted to life on land.

CHAPTER 3

DISTRIBUTION

Present day distribution of worms is result of activities of their ancestors and their migratory capabilities ability to survive in old and new environment. Earthworms are widely distributed in the world in most ecosystems excepting in sea, desert and areas devoid of vegetation or in permanent snowy areas. With criteria of 'adaptability', two types of earthworms are found, namely, peregrine species and endemic species. Former ones are highly adaptative and are widely distributed. Such species are numerous exotic species like Eisenia foetida, the sewage worm and Eudrilus eugeniae, the African Night Crawler which have got established with introduction by man in countries other than their natural homes. Such species are called Peregri4e. Endemic species are less adaptive and have remained indigenous or localised unless specifically maintained by man in habitats other than natural homes. In present day, there are many endemic species which are being maintained in different countries for vermiculture works and some are gradually getting distributed, viz., through cocoons transported with plants and vermicompost. Some new or introduced species can dominate over 'local' or endemic species in natural environment due to various factors like adaptability.

Natural distribution and population of earthworms is largely affected with habitat destruction. These involve activities like clearance of land, tractor ploughing, chemical pollution, viz., discharge of various chemical waste, use of fungicides, insecticides, weedicides and chemical fertilizers. All these activities can not be easily done away for demands of technological development, production and also to grow more food etc. Therefore in terms of environment management we have to adopt approaches that are not conflicting to beneficial faunal activities.

In nature, earthworms are not uniformly distributed everywhere. Their distribution varies horizontally as well vertically. Horizontal distribution of earthworms depends upon many factors like soil temperature, moisture, mineral contents, aeration/ availability of food, reproductive potential and their overall adaptability. Vertical distribution varies seasonally due to habitat preferences and feeding habits etc. Depending upon habits etc., some earthworms are surface dwellers while others burrow in soil. Some species burrow deep in soil, viz., Drawida grandis has burrow depths of 2.7 to 3.0 mtrs.

SIZE

Body size of earthworms greatly vary. Among Indian species, Bimastos parvus, Dichogaster saliens, Microscolex phosphoreus are even less than 2 cm. long. Some southern species like Drawida nilambinensis and Drawida grandis may be upto 1 mtr. length. Australian species, Megascolides australis is reported to be 4 mtr. long. A South African species, Microchaetus microchaetas is reported to be 7 mtr, long and has the distinction of worlds largest earthworm.

CHAPTER 4

FOOD AND FEEDING HABITS

Earthworms mainly feed on organic matters like leaf litter, humus, dung, compost, effluents, weeds and vegetable peels. These are also reported to derive nutrition from micro-organisms and decaying animals in soil. Surface dwellers largely feed upon leaf litter on surface. Burrowing forms swallow soil and derive nutrition from soil. In nature the quantity and quality of food determines, size of population, species composition, growth and reproductive potential. One south African species is carnivorous and feed upon other worms.

Daily consumption or uptake of feed varies from species to species. In general daily uptake vary from 100 to 300 mg/ g. body weight. Various estimates have been made. Thus, according to one estimate, an earthworm can consume 8 to 20 gm. dung/year. So at a population density of 1,20,000 adults/ha., dung consumption would be 17.20 tones/ha/year. This is fairly high organic matter turn over rate in relation to organic matter conversion and mixing in soil done by feeding and cast shedding activity of earthworms. This is further ellucidable from an estimate given by Satchell that in a temperate deciduous forest, annual leaf fall (leaf littering) of approximately 3 tones/ha ./ year, will be consumed (taken as feed and casted) just in three months at average feed consumption of 27 mg/g. body wt. of leaf litter/day. For forestry and related vegetable matter growth, this is cnormously efficient ratc of organic matter recycling. These estimates

thus amply indicate that earthworms are irnportant soil biotic

components for mixing and incorporating organic matter into soil.

CHAPTER 5

GENERAL BODY STRUCTURE

Earthworm body is muscular tubular (elongated) with numerous external rings which more or less internally correspond to internal segments. On these, internal and external rings body segments are organized over boy system.

In order to maintain simplicity and scientific account, descriptions in this publication on various body systems are being dealt with in continuation of pertinent aspect of vermiculture.

EXTERNAL CHARACTERS

All earthworm species have long elongated tubular body which is generally circular in section, with annuli (formed with superficial grooves). This represents typical vermiform body. However close examination reveals that shape of body, if cut into section vary in different species, from nearly circular, squarish, or trapezoidal. In some species like an arboreal Pexionyx spp., body is dorsoventrally flattened, which is in most live forms of other species. Body colours also somewhat vary in different species due to pigments and range from typical/rich brown, various hues of red grey and purple. In some, there is some luminence too. In live earthworms, colour can help in differentiating habitat, viz., burrowing forms have light pigmentation, while top soil dwellers have darker pigmentation.

Externally whole body has series of circular depressions or furrows called segments or metamers. These tally with internal segmentations too and their numbers, as well, in relation to internal organs which are characteristic in different species. Mouth lies at the anterior most tip with a bulbous lip called prostomium. Shape and placement of prostomium is also characteristic in different species. This first metamere with prostomium is called buccal segment as does not correspond to internal segmentation.

All along metameric segments or mid region are attached chitinous hook like structures called chaetae or setae. These are retracticle and provide hold in locomotion. Their number, placement, shape, arrangement pattern and descriptions in relation to characteristic features (the pores) are taxonomic character.

There are numerous pores opening out externally-These have been named with functions and location on body and are of taxonomic importance. Most of these are not visible without use of magnifying glass. Various pores are : (1) Dorsal pores located within inter segmental furrows; (2) Nephridial pores which are minute and scattered irregularly over body surface-

DIGESTIVE SYSTEM

The digestive system comprises a tubular alimentary canal extending from mouth to anus. On dissection various parts of the system can easily be differentiated, namely buccal chamber/cavity, pharynx, oesophagus, crop, gizzard, intestine and rectum.

Mouth is at extreme anterior end (1st segment) and opens into a short buccal chamber. At tip of mouth a bulbous lip is attached and is called prostomium whose size, shape and location varies between species. So it is a taxonomic, character. In some species like common Indian Earthworm Metaphire posthuma buccal cavity is continuously protruted out to pick food particles. Lining of prostomium and buccal cavity is very sensitive as contain receptor cells. Due to these perhaps earthworms can discriminate and show preference to different kinds of food items.

Buccal cavity joins a muscular pear shaped structure known as pharynx. In some species pharynx can also be turned inside out (evaginated) to pick food particles with help of prostomium. Pharynx is pulled back (evaginated) and food is pushed in alimentary canal. **In some species within pharynx, there are pharyngeal glands or salivary glands which produce mucin for lubrication of food. This secretion of mucin perhaps helps in formation of stable soil aggregates excreted as 'castings' (faeces). It is also believed that mucin also promotes bacterial growth and rate of humification in soil, which is a very important process for soil fertility maintenance. Pharyngeal glands also produce proteolytic enzymes which convert ingested protein materials to simple absorbable forms for plants, majority of these pass out or excreted as casting. This in turn increases plant absorbable nitrogen content of soil.**

Pharynx joins a tubular structure called oesophagus in which calciferous glands open. These secrete calcium and carbon dioxide. calcium probably neutralises contents of alimentary canal making excreted cast alkaline, thereby helps in reduction of acidity of soil (i.e., through cast and with use of vermicompost). Posterior end of oesophagus is thin walled in some species and can be called as crop which acts as storage organ. This joins gizzard.

Gizzard is a prominent muscular structure which functions as masticatory or for grinding of food substrate. This is with the help of grit particles within food and with internal cuticular epithelium or lining within gizzard, besides muscular contractions etc. Ingested food at this stage is grinded into fine particles. Some species of worms have two gizzards in sequence and some have upto ten gizzards that appear as a beaded muscular tube. These also comprise taxonomic characters. However, some aquatic species do not have crop and gizzard.

Gizzard follows, tubular canal which has sphincters valves at both end and internally has epithelial folds having glandular and non-ciliated cells. This portion of alimentary canal was named by Kirtisinghe in 1939 as stomach. In stomach proteolytic enzymes are secreted which digest proteins. In some species, namely common Indian earthworm (Metaphire spp.) and in Eutyphoeus spp. there are calciferous glands also. These however show structural variation between species and are important from research points. These were studied by few top zoologists so deserve mention here. Charles Darwin opined that functionally secretions of calciferous gland is to neutralize humic acid of decaying leaves that earthworm consume. Robertson disagreed and opined that the function is to excrete extra calcium. while top old era Indian Zoologists, namely S. Stephenson, Bani Prasad and K.N. Bahl gave structures of these calciferous glands between 1930-1950. Since then, however, not much has been studied despite curriculum studies of earth worm all over country and rather world over.

Stomach follows or joins a thin-walled tubular structure called intestine that ends at body end the anus. Functionally this is the main this is the main organ wherein digestion and absorption of ingested food takes place. Structurally in intestine, three regions can be differentiated. These are namely : (i) Pre-typhlosolar region which has vascular internal folds. In the region after few segments, there are conical outgrowths called intestinal caeca. These, according to Chen and Puh, structurally, caecae have glandular epithelial cell and secrete amylatic enzyme, so these are digestive glands. (ii) Typhlosolar region is the middle part of intestine and structurally is differentiable with a medium longitudinal folds inside the intestine called typhlosole. This structure shows variation in content to its size, shape and blood supply. In common Indian earthworm, it is more or less rudimentary, while in common European earthworm, Lumbricus spp., typhlosole is very well developed and contain chlorgogen cells, Functionally this is to increase food absorption with increased surface area. Chlorgogen cells functionally, are believed either excretory or function as storage cells of nutriments in absence of liver in earthworms. (iii) Last part of intestine is known as rectum and contain faeces as rounded pellets which are excreted through anus.

The excreted faeces are known as castings or casts-Collective mass of casts from earthworm culture or decomposable organic wastes are generally called "vermi-compost." However, technically cast and vermi-compost are differentiable, former being excretment from soil and later being casts from decomposed organic matter.

Physiology of digestion in earthworms in many respects is similar to functions in higher animals. Depending upon feeding habits, different species have different enzymes for digestion. In most species, enzyme Amylase is secreted that digests starch, thereby C/N ration of substrate is reduced after passing through intestine, the material is converted in readily assimiable form for plants. Other species may have enzymes like diastase which converts starch into sugar. Some have glycogen hydrolising ferment, lipase (for digesting fats), invertase (acting of cane-sugar) and oxidising ferment-catalase. In some earthworms evidence of presence of cellulose and chitinase have been reported, but are suggested to have been produced by symbiotic bacteria and protozoans within gut of worms. The absorbed food is carried through blood and coelomic fluid to different parts of body.

BODY CAVITY OR COELOM

Body structure in worms is simple and is comparable to a tube, with a tube inside (digestive organs or body organs). In between these two is the body cavity called coelom which is generally filled with milky fluid called, coelomic fluid. The coelom is covered on outer side with inner peritonial lining of body wall. While on inner side it is covered with peritonial lining of alimentary canal" coelom is partially or completely divided by muscular partitions called septa which stretch along inter segmental furrows to alimentary canal or organs. Disposition, thickness, position, number(s) and attachments to organs are characteristic features of various species. We can refer these as internal morphological taxonomic characters. For scientifically accurate differentiation of species, such characters are intensively studied and are difficult for non biologists to follow up. Therefore in this introductory description account is being abbreviated. However, appreciation can be had from the figure on the aspect.

Coelomic septa have apertures with sphincters to control fluid movement. Prof. K.N. Bahl first described these in common Indian earthworm *Metaphire posthuma.* He suggested that function of these apertures is to regulate flow of coelomic fluid to different segments of body for making these turgid which helps in locomotion.

Coelomic fluid mainly comprises of some what colourless plasma fluid. In this various types of corpuscles float and vary in different species. Commonly found corpuscles are, amoebocytes. Granulocytes and leucocytes-Amoebocytes are defence cells against parasites and pathogenic cells which are devoured. Granulocytes contain granules are believed by many scientists as nutritive in function and carry digested granules to various tissues. Function of leucocytes is not very well known. Liebmann in 1942 opined that leucocyrtes are also modified amoebocytes. So are expected to have some defence function.

Biochemically, coelomic fluid is slightly alkaline (pH 7.9) and is at higher osmotic pressure than surrounding water in substrate. On movement of worm, the fluid appears moving forward and backwards. It is still not known whether it is only in appearance due to turgidity in segments or actually in process. However, exudation through skin pores does take place. This is believed to protect worm from bacteria and similar pathogens. The fluid exudation also keeps body surface moist and is also believed to help in respiration besides excretory in function. This is also opined to help in formation of stable aggregate in casts. Thus stimulates growth of certain bacteria that help in humification of organic matter present in soils.

World wide common prank in children is sprinkling of common salt over live earthworm to see violent contractions and ultimate killing of worm. This is due to ex-osmosis of coelomic exudations of fluids which further cause violent contractions leading into ultimate death.

In squirter worm, *Dielymogaster syluaticus*, body fluids are elected to a height of 30 cms to avoid predator.

BODY WALL

The body wall of earthworm is complex as in other advanced animals. Complete description of its body wall would necessitate background of animal morphology. Therefore to simplify only brief description is being dealt with. Technically, body wall comprises of 5 layers. These are, (i)Cuticle comprising two fine transparent layers. Colour hues on earthworm body is due to stridulations on these layers. Below the layers is (ii) Epidermis which comprises of four types of cells (Glandular mucus, albumin, supporting basal and receptor cells). These serve various functions. Below epidermal layer is (iii) Muscular layer which has two types of muscles, in layers. These are outer ones (circular) and inner ones (longitudinal). within epidermis are follicles which secrete chitinous setae that protrude outside body. These are located in single line around periphery of each segment. Structurally setae arc fine microscopic, needle like.

Setae, being chitinous and supported with muscles largely serve functions of locomotions. In some species these comprise important taxonomic characters.

LOCOMOTION

Setae of earthworms are mainly locomotory function organs. Some setae also play role in copulation. Locomotion in earthworms involves set of co-ordinated activities from circular and longitudinal muscles, the setae, the septa and body cavity. In soil when space is available, worm will elongate extending its interior end into the space, grip the surface with setae, expand side ways by contracting longitudinal muscles and finally pushing aside soil particles form its burrow. Thus by burrowing, burrow formation is affected. If space is not available, viz., there is a non-burrowing object or hardened soil, worm will circumvent such obstacle. On finding palatable material, worm will swallow by gripping it with everted pharyx and swallowing with retraction of pharynx. Due to this activity, many refer locomotion and burrowing as 'worms eats its way'. Occasionally even in language, process is referred as proverb, viz., eating like a worm or eating its way through.

RESPITTATION

Respiration in earthworms is simple but very efficient. Terrestrial worms do not have any specialized organs for respiration, but some aquatic worms have gel like organs. In most worm species, respiration is through skin, i.e., body wall having abundant blood supply. Body wall is kept moist by mucus glands, oozing coelomic fluids through dorsal pores, nephridial excretions and also the ground moisture. Exchange of carbon dioxide for oxygen is done through permeable body wall epidermis and blood capillary network containing respiratory pigment, the haemoglobin which transports exchanged and dissolved oxygen to various parts through blood vessels. This oxygenation or respiration occurs both at row oxygen pressure, as well as at high pressure from air. However, efficient respiration takes place when skin is moist. It is also reported that earthworms can live with low levels of oxygen for 6 to 30 hours. Perhaps this explains reasons of its survival while burried in soil.

EXCRETION

Excretion processes are brought about by various developed body functions. Main organs for excretion are tubular structures called Nephridia, present in different body segments within coelom. Numbers, shapes, sizes and location considerably vary between species and in some these aid in identification. In most species, broadly structure of nephridia comprises of a funnel shaped structure with ciliated cells called Nephrostome which lies in the segment preceding to one occupying main body of nephridia. Nephrostome or Nephridiostome is connected to a small tube which joins the convoluted mass. The body of Nephridia which remain attached with tissues. According to excretory action: outside (exonephric) or inside (enteronephric), nephridia are named. Also, according to location within body, nephridia are named, viz., Septal (on septum), Integumentary (on integument) and Pharyngeal (on pharynx). Nephridias also differ in sizes, large (meganephridia) and small (micronephridia).

Excretory functions commence with nitrogenous wastes from different organs and systems that are diffused in coelomic fluid, getting into nephrostomes. The ciliated funnel of nephrostome allows only selected entry of materials. The fluids then pass through canals of nephridia which with selective absorption extract water and other useful materials, but allows passage of only nitrogenous wastes. These comprise materials like Urea, Ammonia and Amino, acids, besides some other materials like Creatinine. These pass out through nephridiopores. In nephridia that are devoid of nephrostomes, wastes are directly absorbed by body of nephridia and passed out of nephridiopores or are transferred into gut. Entero-nephric nephridia are perhaps adaptive features for conservation of water within worm body. Exo-nephric nephridia excrete wastes to exterior through nephridiopores as urine. Urine binds soil particles and forms stable aggregates of soil, stimulating microbial growth for humification or organic matter.

There are several other excretory mechanisms working in earthworms, but are poorly understood. Certain special cells called chloragogen cells present in the coelomic epithelium of intestines are believed to be important in removal of excretory materials from blood. These thus act like a mobile liver to maintain required levels of certain substances in blood and coelomic fluid. In *Eutyphoeus spp.* even hepatopancreatic glands have been reported. Other excretory cells are uric or bacteriocidal cells which also function like amoebocytes. Of all these, nephridia remain as most important excretory organs/ functioning like kidney of higher Vertebrates, performing functions of excretion, filtration, re-absorption and chemical transformation.

CIRCULATORY SYSTEM

Blood of earthworms is also pecurlar to its life activities. Blood plasma or fluid is red coloured due to dissolved haemoglobin (the transporter and absorber of oxygen) while corpuscles suspended in the fluid are colourress and are nucleated. The haemoglobin getssaturated with oxygen to as high as 95% (in form of oxyhaemoglobin) and gets unloaded with transfer of oxygen to various organs in blood circulation process, i.e., in respiratory physiological process that continues even at lower (generally above 19 mm) pressure of oxygen. Thus earthworm haemoglobin very efficiently functions both at saturation point, as well at low environmental oxygen levels. These qualities surpass even so advanced creatures like Homo sapiens, the man, whose haemoglobin at a level lower than oxygen saturation point, would drown in oxygen' , i.e., scumb. Further man cannot easily survive in prolonged low or high levels of oxygen; but earthworms can.

The blood vessel system in earthworms is complex as in higher animals' It would necessitate very lengthy coverage to describe the system. Therefore, broadly main features are being discussed here. For increasing understandability of persons with average background of biology, it has been appropriately described into three parts by legendary Indian Zoologist, late Prof. K.N. Bahl. These are in the region of Intestine, in first 13 body segments and circulation course of blood.

Circulatory system comprises of three principal blood vessels, namely, dorsal vessel, sub-neural vessel and ventral vessel. The dorsal vessel runs along the upper mid line of the gut and is main blood collecting vessel. By contractile actions of dorsal vessel, blood is moved in forward directions. Lying close to nerve chord is sub-neural vessel. Some earthworm species do not have this vessel, while most (excepting Megascolecid species) have two such vessels. Its branches collect blood from anterior tissues and organs, and return it to dorsal vessels by dorso-sub-neural vessel which run in the septa of each segment. The ventral vessel supplies blood to organs, including skin. In this vessel, blood flows anteriorly to posteriorly. By neural and sub-neural vessels, blood is collected and passed to dorsal vessel. Pumping of most of the blood from dorsal vessel is into ventral vessel by several (3, 4 or 5 nos.) pairs muscular hearts with valves surrounding oesophagus. In these, flow of blood is unidirectional. The blood this way distributes digested nutrients from food to various body regions and collect waste materials which pass out to nephridias, coelomic fluid and to skin. From capillaries of skin, haemoglobin carries the absorbed oxygen to various other tissues.

NERVOUS SYSTEM

Nervous system of earthworms consists of brain which is in form of fused ganglia lying dorsal to pharynx and is known as Supra-pharyngeal ganglia. From this brain, a pair of circumpharyngeal connective arises, it encircles pharynx and ventrally joins with a pair of sub-pharyngeal ganglia. From this ganglia starts nerve chord that runs upto posterior end. On nerve chord are swellings, i.e., ganglion which give off nerves to various structures within segments. These nerves have both sensory and motor fibres. Sensory fibres carry stimuli to nerve chord and stimulus is transferred to motor fibre going to muscles affecting them contract. In the epidermis of earthworms, at places, there are localised nerve cells in the form of receptors. These are of various kinds. Epidermal receptors are sensitive to touch and also perceive thermal and chemical stimuli. Buccal receptors are found in the epithelium of buccal cavity. These receptors can perhaps smell and taste food. Because of these, earthworms are able to differentiate their food items. Photoreceptors are mainly concentrated on prostomium and first body segment. Due to these, earthworms negatively respond to strong lights and somewhat positively to weak light. These explain process of retraction of worms during bright days and their emergence during nights. However, these responses vary in different species. There are some that emerge only during night like African Night Crawlers, the *Eudrilus spp.* Interestingly it is reported that in Canada, collection of Lumbricus terrestris during night (through Flash lights) is widely done. So collected earthworms are exported to U.S.A. for amount exceeding 30 thousand dollars annually for use as fish baits-Its time that developing countries start paying more attention to such aspects.

REPRODUCTIVE SYSTEM

Earthworms are hermaphrodite having ovaries and testes in same individual. However, due to relative positions of male and female genital apertures, mostly cross fertilization occurs. Earthworms are protandrous, i.e., male sex cells ripen much earlier than female cell,, so also self fertilization is prevented.

Male sex organs consist of two bag like sacs comprising testes, that produce spermatogonia (immature sex cells). Spermatogonia are shed in testes sacs and pass into seminal vesicles where these under go further maturation and form spermatozoa (mature male reproductive cells), pass through funnel shaped structure to vasdeferens (tube like structure) and finally are discharged to exterior through male genital pores located on ventral side. Position of mare genital pores vary in different species, so the character is of taxonormic importance.

Female sex organs consist of ovaries in which egg cells are produced. Below ovaries are located ovarian funnel, that lead to tubular oviduct opening to exterior through female genital pores located on ventral side.

Besides, male and female organs, there are paired organs called Spermatheca in which sperms flowing from other partners are stored and are nourished by some fluids.

REPRODUCTION AND COCOON FORMATION

Fertilization as a rule in earthworms is cross fertilization, i.e., eggs of one individual are fertilized by sperms of other individual. For this exchange process copulation takes place which is typical. Two individuals lie opposed to each in head to tail position with spermathecal pores, closely addressed to each others pores. Each copulating individual move sequentially till an sperms are discharged into spermathecae. This process is also referred by some as charging of spermatheceae.

Copulatory activities to some extent differ in some species. In some species, male sex pores are raised to form a papillae with a cup like attachment. The prostatic duct (sperm duct), is evaginated to form a penial structure that is inserted for direct transmission of sperms.

Separation of copulating individuals succeed changes in clitellum which gradually gets covered with a mucilage. This follows release of ovum by individuals within mucilage cover and comprise the stage when fertilization takes place with simultaneous release of sperms. In some species, fertilization within mucilage cover occurs when copulating individuals retract backwards from the albuminous mucilage rings. In some, it is after separation. Fertilization from single individual is also reported in some species, viz., *Dichogastet bolaui*.

After fertilization, the cocoon or the egg capsule is formed from clitellar gland. It is three layered and is believed to be made from some kind of chitinous material and also has proteins. This is actually formed in most species when individual worm refracts out from the albuminous mucilage ring over its clitellum. This contains albumen and outer covering gradually hardens on exposure to air.

It would surprise many that in most parts of world, nearly 90% zoologist have not seen earthworm cocoon. With this background besides importances of cocoons in Vermiculture, aspect deserves attention.

Shapes of cocoons in general is ovoid but with careful observations, shape(s) can be defined in different species. Freshly laid cocoons are whitish or dull white, soft and jelly like. In most species, cocoons are laid on surface of substrate when temperature (for embryo development) and moisture is suitable. In most parts of India, viz., in common Earthworm, *Metaphire posthuma*, cocoons are laid from April-October with peaks between August to October. In *Drawidabolaui*, peak cocoon laying (5000/m^2) has been reported during mid September at population of 1150/m^2 individuals. All these indicate reproductive activity, i.e., survival of juveniles in summers. Vermiculturists therefore should periodically monitor these in their culture troughs or beds. The information so generated will enable vermiculturist maintain profitable culture and eventually better compost productions from material under use.

Shape, size and colour of cocoons vary between different species. Colour variations range from yellowish brownish to greenish brown. In some, these are milky white like pearls. Shape is mostly coriander seed shaped with both tapering ends-These vary and in Criodrilus spp. ornamentations on spindle shaped structures {are reported by Prof. B.K. Senapati) are long (1.5 - 7 cm) corresponding to length of clitellum. Size of cocoons also vary between species. professors B.K. Senapati and S.K. Sahu have studied in details on 15 temperate and tropical species respectively range as follows : Those, in temperate species have : dry weight (mg) 0.86 to 12-0 mg; diameter 1.3 to 3.7 mm and length 2.0 to 6.9 mm. In most commonly use species *Eisenis foetida*, dry weight is 3.7 mg; diameter, 2.9 mm and length, 6.0 mm. In tropical species, dry weight ranges from 0-65 to 32.5 mg; diameter, 1.0 to 9.0 mm and length 2.0 to 15.0 mm. Cocoons of world's largest Earthworm of Australia, *Megascolides australis* has diameter of 20 mm and length of 75 mm. It contains single embryo which on emergence measures nearly 30 cms, i.e., one foot.

Production of cocoons and its survival for further progeny is very important. These are dependent upon several factors. In general, optimal condjtions are at substrate temperature range between 15 - 25^{0}C (depending upon species, design of the vermiculture container and weather control measures like shade see under vermiculture), with 20 to 40% moisture in substrate, i.e., 60-100% air humidity, ionic conductivity below 3 m. mhos/cm darkened environment. Feed substrate preparation is essential step and should not have contamination with lethally toxic chemicals.

On cocoon production so far limited information is available and according to an estimate, only 5% is known out of world species.

Amongst Indian species, information on only 20 species is known. Information aided with cocoon has varied usages in different disciplines of science like environmental pollution, using earthworms as biological indicators and development of vermiculture or vermicomposting, besides its promotion. Obviously with knowledge on earthworm development from cocoon, we can easy wonk out easy transportation for promotional activities.

In each cocoon, number of eggs may range high. However, survival is only in one or two or three. Production of cocoons with favourable conditions is throughout the year. During colder months, less number is produced than in warmer months. So cannot be generalised for reproduction rates (cocoon production as indicator) of various species in different regions. Prof. B.K. Senapati and S.K. Sahu have reported annual cocoon production per adult/year in 15 Temperate and 15 Tropical species. These respectively range 8.00 to 92.00 (E.foetida ave. 17) and 1.30 to 46.59 per adult/year. Since by and large, at a time two individuals mate and release their individual cocoons and so cocoon production is actually double the number. Incubation period ranges 3 to 30 weeks in temperate species and 3 to 8 weeks in tropical species. In two common earthworms widely used in Vermiculture, namely , *Eiseria foetida* incubation period is 3-4 weeks and in *Eudrilus eugeniae* it is 2-3 weeks. Incubation and further development 4lso depends upon temperature, moisture and substrate conditions.

On average, young ones grow to maturity in 2 to 13 months. In species used for Vermiculture, preference is given to those which have higher reproduction, quick maturity and faster development, besides other parameters. In African species widely used for Vermiculture, freshly emerged individuals have rapid growth and attain reproductive stage (develop, clitellum) within 6 weeks. In such individuals cocoon laying continues for 3 to 6 months when gradually number decreases. Worms should then be harvested for other purposes.

In natural conditions, reproductive potential and other activities of earthworms depend upon some important factors, like environmental conditions and soil pH. Most earthworms prefer neutral soils. *Eisenia foetida*, common sewage worm, prefers alkaline soils and some prefer or tolerate slightly acidic soils. Moisture conditions of soil as well that of worm body influence its distribution, viz. vertical distribution to soil surface when availability of leaf litter is more. So better growth and soil conditioning is expected unless humus is available in lower reaches (as in pits). Under decreased moisture conditions, worms go in deeper layers and may undergo diapause. Temperature has also direct bearings to reproduction and distribution etc., as affects various activities like metabolism, respiration, growth, reproduction, production and hatching of cocoons. Temperature tolerance range are different

CHAPTER 6

ROLE OF EARTHWORMS

Role of earthworms in aspects related to recycling of decomposable wastes and to soil, viz. for Agriculture and Forestry, besides in many aspects are very high. These are basically due to life activities of earthworms in soils and their importance in utilization of earthworms for human welfare, viz. Vermiculture and Vermicomposting. These conform to truest definition of Biotechnology. Vermiculture thus is one of the oldest example of Applied Zoology that is present day's Biotechnology. Some historical details are being dealt with under heading 'Vermiculture'.

It deserves mention that many of the bio-technological aspects of Economic Zoology remain unutilised due to lack of perception amongst ill informed ones. Much is being talked and published on Animal, Wildlife Environmental Management, sustainability of biomass productivity etc. etc. Some of the basic components like Economic Zoology in its truer modern perspectives have gone into shadow due to over emphasis to certain super specializations. Both are essential but those simpler forms and in 'simpler formatics' should not be discarded in developing countries which can perhaps derive equal economic returns with lower investments spread over little longer period, at the same time providing higher employment generation potentials than others. Thus in totality, these provides considerably higher annual and percapita returns than others. These and such aspects, infact should be eye openers for Zoologists as well for Economists. In these, conventional poultry and animal husbandry are well known others of smaller scales like Quil and Rabbit farming etc. can be boons as a single person managed home or cottage industry even. List of such aspects is long.

INSUSTAINABLE AGRICULTURE

Before proceeding further towards appreciations of roles of earthworms, it is desirable to have an introductory perusal of sustainable agriculture. It is defined that 'Sustainable Agriculture should involve the successful management of resources for agriculture to satisfy the changing human needs while maintaining and enhancing quality of environment and conserving resources' (CIAR-1989 in Shastri Memorial Lectures, IARI). On this, attention is invited to account dealt with by renowed Agricultural Scientist, Environmentalist, Conservationist and Administration, Dr. M.S. Swaminathan in his monographic work : Stockholm to Rio to sustainable Agriculture. With several related aspects, Dr. Swaminathan has referred role of earthworms to maintenance of the sustainability. To appreciate these a brief perusal of introduction to agriculture is warranted.

In India, in last three decades, food grain productions increased from 50 million tons to 170 million tons. This was with increased intensive farming with modern agricultural technologies that ushered in Green Revolution. Basically all these were attributed to use of high yielding varieties, more of inputs like fertilizers, pesticides, weedicides and better irrigation facilities besides efficient management. These resulted in increased productions of wheat and rice, but variously affected sustainability of Indian Agriculture. Problems that emerged are varied, notably, heavy dependence on fertilizer inputs, increased micro-nutrient deficiency, reduced cultivation acerage for pulses and others, depleted sub-soil water table, increased dependence to pesticides and weedicides, and deterioration of plant substrate the soil, etc. Dr. M.S. Swaminathan pointed out way back in 1968 at usherings of Green Revolution that without conservation and management of soil fertility or its sustainability, continued intensive farming would turn green cultivable lands into deserts. Without drainage management, continued irrigation would degrade soils to 'kallor'/salty/leechy and sandy. These are now noticeable in many parts of India, viz., Punjab, Haryana, Rajasthan and elsewhere. Unscientifically managed exploitation of sub-soil ground water would fast deplenish the resource. This is well appreciated now in several parts of India. Lowered water table due to over and improper management, besides reduced impercolation or charging has also created many problems, some of which remain unexplained, viz., increased fluoride in sub-soil water, it is due to decreased water table or with better testing facility now available that widespread reports of Fluoride problems are appearing. Context of all this herein is due to fact that earthworms in nature also promote infiltration or impercolation of water in ground as make soil porus, and promote drainage etc., besides others like increasing natural fertility of soil. Thus would help in cutting down chemical fertilizer use and increase the fertilizer efficiency in biological or natural way. Present situation of fertilizer efficiency is reportedly getting to alarming stages.

High yielding varieties respond well to fertilizers. However, food grain produced and assessed with attributes of fertilizers, viz., with input vs. output ratio, the yields appear decreasing i.e., fertilizer efficiency seems decreasing. A. Sankaran (1990 In Fertilizer, Efficient use of Fertilizer : Survey of Indian Agriculture, the Hindu, pages, 163-70) reported that fertilizer efficiency in 1970-71 ranged 17.1%, declined in 1980-81 to 10.3% and in 1988-89 ranged to 8.1%. He further stated that by year 2000 AD, at expected food grain production, fertilizer efficiency is expected to go down to 6.5%. To overcome such situations biological components like utilizations of earthworm activities warrant attention. These have been pointed out by numerous world renowned biologists like J.E. Satchell, E. Lofty and M.S. Swaminathan.

Excessive use of chemical fertilizer also has ecological and economic implications. These are well known to affect soil chemistry, deplenish soil micro-nutrients and cause water pollution. Some of these as chain reaction affect human health, viz., higher nitrogen application in some leafy vegetables lead accumulation of nitrites in leaves which affect various body functions in humans. Utilizations of earthworm natural activities reduce these problems.

Improper management of soil largely with our activities are doing enormous harms to soil as an asset that has taken millions of years to form. According to one estimate 30 to 507o of soil from earth surface is degraded due to mismanagement. Deforestation, over grazing and improper watershed management is increasing soil erosion. It is reported that in some areas with wind erosion each hectare of land loses 1 mm of its top fertile layer weighing 15 tons, while rate of replenishment of soil is hardly 7 ton/ha/year. Thus in 500 years only 2.5 cm top soil layer is formed. During erosion, humus is also lost which supports microbes like algae, fungi, soil bacteria and macrobes like earthworms and insects. In consequence recycling of nutrients and decomposition of organic matter, i.e., the fertility of soil is lost. Earthworms interestingly and variously help natural maintenance of all these beneficial factors towards soil management with its activity. However, increasing usages of chemicals adversely effect the ecosystem.

Indiscriminate rather injudicious use of pesticides and weedicides besides increasing environmental degradations by other means are also causing environment threats, killing of beneficial non targets organisms, like earthworms. These are essential for maintaining ecological balance. Obviously to have an efficient, eco-friendly sustainable agriculture, there is a high need of cutting down usage of chemicals in agriculture, especially insecticides and weedicides etc. However this is not easy in developing countries where demands for increasing food grain productions outweigh other approaches. Solution therefore is to take up gradual switch over with increased awareness development. Many European countries are reducing the use of chemicals. It is reported (Warrel, E. 1990 Shell Agriculture,8,3.20) that by year 2000 AD, Denmark will cut down 50% use of pesticides. Europe envisages 20% production of food grains using biological methods and similar low input sustainable agriculture programmes are being implemented in America.

ORGANIC FARMING

Principles of Organic Farming is to produce food of good quality and quantity by using eco-friendly technologies, which can co-exist with nature. Such practices exclude use of chemical fertilizer, pesticides and weedicides etc. The system depends upon use of leguminous plants and microbial inoculations for nitrogen fixation; crop rotation, organic manures and wastes (viz., Vermiculture and Vermicompost) and biological control methods. To all these, vermiculture and its utilization can be important components.

A Japanese scientist, M. Fakuoka recommended in 1978, agriculture in nature's way and stated that there is no need for ploughing or over turning of soil. In natural way, thc process is done by roots of plants, microbes and earthworms. He further opined that there is no need for any chemical fertilizer as soil can replenish itself with action of microbes, arthropods and earthworms. However, under existing deteriorated situations natural supplementation through biological processes like microbes and earthworms, may not yield required results. It is only after overcoming external stresses, results will be gradually faster. Dr. M.S. Swaminathan recommended in 1973, to increase number of earthworms to increase fertility of soil, and to help achieve goals of sustainable agriculture. On this, Prof. M.R. Bhiday's estimate deserve mention that 1 million earthworms per acre would produce cast/compost @ 500 kg/day, i.e.,200 tones per years. The cast/compost contain all nutrients in form required by plants. Dr. K. Bano gave estimate that 1 kg earthworms will decompose approximately 4-5 kg of organic waste every 24 hours. All these necessitate perusal of activities of earthworms, i.e. their roles and vermiculture.

EARTHWORM ACTIVITIES

Activities of earthworms on soil are varied and numerous. In consequence beneficial effects are numerous, covering perhaps every important aspect(s) towards sustainable agriculture, excepting control of insect pests. However, indirectly soil pathogens are reduced. These commence with movement, burrowing, feeding, casting (defecating consumed organic matter) and moving in soil profile. Earthworm activities in soil or in nature are numerously beneficial. These deserve careful appraisal before getting on to conventional enlisting of economic importance.

Activities are direct action of feeding and burrowing along with related biological activities. These are, therefore, dependent upon habitat where different species live in their natural way. These in consequence are in accordance with their habitat preferences. There have been some generalization made in relation to burrowing depth(s) in soil profile wherein basic preferred conditions (like pH, humus, moisture and temperature) are available. These range as leaf litter dweller, in top soil, in profiles below top soil (say below 20-30 cm) and deep soil dwellers etc. on these scientific Latin names have been assigned like epiges and endoges etc. Thus activities of different species from feeding, burrowing, casting and related actions would be varied. Therefore, increase of soil fertility by different species would be varied.

Exploitation of activities of various species in different soil profile layers in accordance with their preferences has not been attempted. Technically this is possible and is done in composite fish farming wherein three species feeding at different water depths are cultured in a single pond. This provides more utilization of culturable water area and so yield is more from same area. In earthworms, this is perhaps easily possible in orchards. However, so far, by and large, attention is towards vermiculture and composting. These necessitate a general perusal of activities, namely different ways to appreciate beneficial activities performed by earthworms on soil, a conceptual activity programme of a worm is desirable.

As discussed in preceding pages, earthworm eats its way through soil and organic humus etc. In this process it continuously keeps its body moist and passes out urine. Thus, keeps on adding micro-quantities of humidity (more or less recycled) and urea. Burrowing of earthworms brings about tillage of soil. Interestingly in most conventional forms of tillage, it is up to depths of 30 cms while earthworms do tillage up to 3 mtrs without adversely affecting plants in any manner, excepting some species in special situations. This also accompanies feeding of soil, so there goes on breakdown of soil particles and mixing of soil nutrients and bacteria in digestive process as well with deposit of casts of various levels/points. These affect automatic conversion of organic wastes. These micronized soil particles, lead increase of particle surface area which leads increased moisture absorption and holding and air circulation etc. This also increases microbial action. Casts are fine bio-fertilizer having upto 1000 times more microbes than in surrounding soil. Feeding on soil particles with burrowing promotes porosity. These eventually increase impercolation of water generally referred as charging of sub-soil water. On many slopes, drainage is promoted and in many soil erosion is checked as with casts. There is a degree of particle binding which promotes growth of grasses. However, for effective utilization of these aspects; species selection is warranted and can be got through some expert. Soil porosity so affected lead increase in soil aeration. This in turn lead maintenance of soil temperation which adds to toleration in soil faunal and floral components. These reduce severely of soil temperature fluctuation essential for plant growth.

SOIL FERTILITY AND TEXTURE

It is thus apparent that different species of Earthworms would variously aid in enhancing soil fertility but not in same way. These deserve attention.

1. Earthworms incorporate plant residues, organic wastes and dung with soil from surface. Many take the material inside burrows where these are left for decomposition. Thus, in different soil layers, organic matter is mixed. However, many factors affect incorporation of organic matter with soil. These are, chemical and physical nature of Organic matter, its origin and distribution within soil profile, besides feeding behaviour of involved earthworm species. In totality recycling of organic matter is very high. On extent of conversion of organic wastes, numerous estimates for different niches are available. According to one estimate, average individual consumption ranges 15.0 to 40.0 gram (dry weight) cow dung in two years, as per this range, at average Population density of 1,20,000 adults/hectare, organic waste conversion would be 17 to 20 tones/ha. One million earthworms can convert 120 tones of decomposable organic waste every month i.e. within 500 m^2 surface area (22.6 x 22.6 mt plot). As yet no mechanical conventional process can convert at this pace, Space and economic, besides at equal composting quality. For temperate deciduous woods, estimations have been reported that average leaf litter consumption is 27 mg/g body wt/individual/day. Thus annual leaf fall of 3 tones/ha would be consmed and recycled in just 3 months. This activity is highly beneficial for natural forests, where soil fertility maintenance can not be otherwise done. In other situations, decomposable organic wastes would be kept clean by earthworms alone' Some experts have even opined that earthworms control pollution of decomposable organic waste. It is true and easily feasible.

Incorporation and mixing in soil by earthworms result in redistribution of nutrients, which are brought closer to roots of plants for absorption. This feature has high importance as it prevents loss of nutrients by erosion' This feature of feeding and casting that affect mixing has many other attributes too. while tolerance and responses of insecticides and other chemical vary, insecticides like DDT are accumulated and tolerated well. Such worms with accumulated insecticides when preyed by other animals like birds, suffer with secondary hazards and may die. In fact it is believed that it was these large scale mortalities of European Robin due to preying on earthworms with accumulated DDT that eventually led to world wide scare of pesticide pollutions causing secondary hazards. This finally opened up variety of subjects. However, mixing, accumulation and taking so accumulated insecticides to deeper layers in soil may have some beneficial effects too, viz. reducing pesticidal residues from top soil layers. This obviously reduces further pollution with drainage. It has been reported in New Zealand that DDT taken into deeper soil layers by earthworms reduced grass grub larvae. Thus helped in forage grass production. Even lime and fertilizers applied on surface are thoroughly mixed in the top soil bringing about increase in fertilizer efficiency. Some experts have even speculated that every possibility exists of removal of certain pollutants (accumulated) including some pathogens. This process is referred as Vermifiltration and is at development phase.

In some areas of USA, fallow cultivated fields are partitioned with raised ridges within which organic wastes (like crop stables) are moistened and dumped. These are later inoculated with live worms to affect direct on field bio-fertilization process. capacity of earthworms in mixing and turning over of soil varies within different species, physical and chemical characters of soil. Annual soil turn over may range from 2 to250 tones/ha. This almost equals to bringing up a layer of soil of 1.0 to 5.0 mm thick to surface every year. This is apparently not feasible to technically compare with other mechanical means.

2. Earthworms break up large mineral particles to smaller units during ingesting and distribute with expulsion as casts. These promote better root system in plants. However, in stray caseg large accumulation of earthworms at roots is reported to show adverse effects.

3. Above processes also bring about breaking up of complex organic matters in soil into forms that are in readily absorbable or assimiable forms to plants (See para-4 in col. 4).

The capacity to break up complex decomposable organic matter into composted form is extremely high and efficient. This is 2 to 5 times faster than conventional methods. In conventional pit composting of animal dung, full conversion is done in approximately 6 months. However, through earthworms, 10 kg worms (1.e., 10,000 nos.) would convert 1 ton/month within 5 m2 composting pit. One million earthworms 'housed' in organic wastes spread just in an enclosure of 22.6 x 22.6 mtrs have potentialities of composting the waste of 250 tones every month. Such composting limits or capabilities can be exploited as "Mini Fertilizer Plants". Already in America this is being practiced. It is this reason, mainly that vermiculture for vermicomposting is recommended by most specialists.

Feeding process on organic matter subjects it to enzymatic actions (within gut). These convert organic matters to simple fractions which are expelled, as droppings which are referred as 'casts'. In casts, aggregates of mineral granules are bound in such a manner that these resist wetting, erosion or compaction and remain loose even while soil is either dry or wet. These provide high degree of soils conditioning, besides fertility that is beneficial to plants as if continuously super micronized soil raking has been done. In nature or in fields 'casting' have multiple importances to plants and soil. However, mechanism(s) how such soil aggregate are bound are not yet well understood. One school opines that particles are cemented together by calcium humate which is synthethised in the intestine from organic matter and calcium secreted from calciferous glands. In addition to these, vascular bundle of ingested plants, also provide mechanical binding of aggregates. According to another opinion, some micro-organisms grow on ingested materials in the gut or develop after the material is excreted. These bind materials is casts. One of such binding materials is fungal hyphae. Some workers also opine and believe that it is secretions of body wall and gut of earthworms which stabilize the cast aggregates. These in turn provide resistance to soil towards water and wind erosion-Thus generally earthworm rich soil are less liable to soil erosion.

4. Final process of organic matter decomposition i.e., humification is hastened by earthworm activities. This is brought about by passage of organic matter through gut of earthworms. Microorganisms within gut increase those in soils with casts as many also pass out within casts. Thus there is a dissemination of several types of micro-organisms. However, many are reduced during passage within earthworm intestines. Further, earthworm activities like feeding, burrowing and excretion on soil favour growth of soil micro-organisms which synthesize polymers present in humus substances.

Process of humification is further hastened or facilitated by Castings which contain enzymes like proteases, amylase, lipase, cellulase and chitinase. These actually facilitate humification even after expulsion as casts.

Thus, earthworm activities, promote, hasten and enable humification process keep going at an optimal pace (Refer para-2 under col. 3). All these lead maintenance of sustainable soil fertility and agriculture. All these are ellucidable from certain basics.

For example phosphorus is more than 15-30% and Nitrogen more than 6% made available to plants by worm activities in soil. Similarly trace plant nutrients are like calcium, magnesium, potassium, phosphorus and molybdenum are made more available to plants through worm casts than direct through surrounding soil without earthworms.

Humification enhances water holding capacity of soil, improve soil structure and increase ionic activity. All these further add to fertility and fitness of soil for agriculture.

5. Earthworm activities have important roles in maintenance of C/N and perhaps C/P relationships for soil micro-organisms. Many of us are not fully conversant with these to fully appreciate major role of earthworms into these relationships.

In composting of organic matter, important factors are nature of material, environmental factors and growth of soil microbes. On these depends the end product, i.e., the compost. For all these important factors are pH, temperature, particle size, aeration, moisture, pH and carbon-nitrogen ratio etc. Of these, all former ones have been discussed in proceeding pages. Here only later one : C/N ratios are being dealt with to apprise readers and vermiculturists.

Growth of micro-organisms is essential for decomposition of organic wastes. For these, appropriate nutrition should be available besides other conditions to micro-organisms. All these are measurable for decomposition rate with ratios of carbon to nitrogen and carbon to phosphorus within waste put for decomposition. Ideally these should be 30 carbon 1 nitrogen and 100 carbon 1 phosphorus. Functions and usages of these four elements in stated ratios are important so deserve perusal.

In decomposing material, micro-organisms, use carbon for energy (anaerobic), Nitrogen for growth (cell building) and Phosphorus is used for digestion. With onset of decomposition process in C/N ratio is reduced due to utilization of N and release of C as CO_2. Reduced ratio increases decomposition process.

In substrates, C/N ratios are wide i.e., greater than 80, decomposition will not set in. This is seen in decomposition of cereal plant residues wherein farm yard manure or nitrogen rich plant material (legumes) or even green manures are added.

Earthworm activities are important in aiding decomposition process mainly done by microbial actions. Earthworms by break down of substrate material, bring out materials of low C/N ratios to about 20:1. This is achieved mainly by combustion of carbon during respiration and adding N with excretions perhaps in concentrations that is readily assimiable to microbes. These promote microbial growth and hence enhance decomposition process. With these activities earthworm lower C/N ratio and makes Nitrogen available to plants which in consequence adds to the soil fertility.

SOIL AERATION

Earthworms improve soil aeration by making Pores with its burrowing, feeding and 'casting' activities. Aerating pores made by wormic activities vary from large ones (2.0-11.0 mm) to small ones (viz., feeding and casting).

These aeration pores have important roles in total decomposition process. This is because with appropriate oxygen supply, growth of aerobic micro-organisms dominates anaerobic decomposition with total break up is brought about. This is faster and reduces fowl smell. In reduced aeration, oxygen supply is less. This results in dominance of anerobic micro-organisms and so decomposition in which breakdown is only partial. Aeration is, therefore, essential requirement in decomposition process. In conventional composting this has to be brought about with periodic turning over and mixing, i.e., process is labour intensive. In vermi-composting all processes related to aeration, mixing, turning over is done with earthworm activities.

In natural field conditions soil aeration by earthworm activities have many other roles too that add to soil improvements. These improve soil water drainage and aeration. So help in better root penetration. Medium sized pores improve water holding capacity. Thus, impercolation of surface water to ground water system (= charging of ground water) increase is also brought about.

WATER IMPERCOLATION

Water impercolation and other functions of porosity in soil brought about by earthworms depend upon pore size distributional stability and applied stress, viz., rain drops and soil compaction. Earthworm activities increase soil air volume from 8 to 67.0%. Reported estimates indicate that drainage in soil with earthworms is 4 to 10 times faster than in soils without earthworms. This has both types of actions : beneficial as well harmful; but exploitation studies have been scarce. These deserve attention. It is established that after 24 hours of free drainage, soils without earthworms were waterlogged but in 'worm worked soil, soil particles were well aggregated and water was present in capillaries with aggregates. Thus some species of earthworms can also be useful natural biological tools in reclaiming waterlogged wastelands. In regard to wild bird habitat conservation, earthworms have high roles as variously support whole faunal and floral com position. With improvement of drainage, volume of surface run off is also reduced. This in turn reduces erosion. With such, binded soil particles with all aggregates in 'casts' if seeds of natural soil binding grasses are present in the niche, better growth of such grass clumps are promoted. This obviously has high importance in control of erosions from variety of topographical slopes. Thus roles of earthworm activities on soil moisture maintenance are numerous. Discussions on all these would involve very lengthy coverage. Therefore, present account is being restricted to selected ones only, i.e., in natural conditions and for vermicomposting.

DECOMPOSITION AND MOISTURE

From preceding paras, it is well appreciable that vermicomposting is a faster and good process for composting. To fully appreciate a brief introduction to role of moisture in decomposition is also desirable.

Optimal decomposition in conventional method is achieved at moisture levels of 50-60% by wet weight. At excess of moisture, beyond 60%, compaction of composting material occurs which also reduces aeration, that in consequence lead to an-aerobic conditions. At lower moisture levels, i.e., less than 45%, there is inadequate supply of moisture to micro-organisms. Earthworms maintain these conditions with their activities, but supplementation of moisture has to be done. To utilise earthworm activities, design of vermicomposting troughs or pits need considerations, as well to further utilise worms adaptable to higher moisture level conditions, selection of suitable species is warranted. These are some of the aspects of studies of bio-diversity of faunal groups in highly economic applied aspects. It would not be too speculative to indicate possibilities of some countries attempting Patenting of some species. These deserve attention with a purposeful insight of related aspects. One such example is semi-aquatic habitat earthworm species, Perionyx sansbaricus.

It has been reported that for composting cereal straw, moisture level of 80-100 per cent is required and material is to be supplemented with 200 per cent dry leaves. For vermicomposting such material, appropriate earthworm species is semi-aquatic ones like Perionyl spp.

Of various roles of live earthworms, benefits acrue even after death of worms in natural conditions. Nitrogen content in the soil is increased with decay of dead earthworms. It has been estimated that in a earthworm species, dead individual can yield up to 10 mg of nitrates. At a population of 3.75 millions per hac, even after death earthworms would yield approximate 277 kg of nitrate of soda/hac.

CHAPTER 7

ORGANIC WASTES

It is now well known that there are urgent needs to maintain environmental and agricultural sustainability without reducing productivity; but cutting down inputs that are adversely affecting these with these, numerous considerations or factors of importance are prohibitory costs of energy productions and its inputs. Therefore, there is need to appreciate needs of integrating various systems, viz., IPNS, Integrated Plant Nutrient systems, various related systems covering recycling, production, protection, conservation and IVCCS, Integra ted vermiculture and composting system. With these several aspects related to increasing human population and its needs or demands cannot be overlooked. All these are interlinked. To these, earthworms provide various levels of solutions. So, before moving over to Vermiculture, an appreciation of certain points on wastes are obviously desirable.

MUNICIPAL WASTES

With increasing human population and its demands there is increase in production of various types of wastes, ranging from agricultural, domestic, city or municipal sewage and various types of Industrial waste. All these are causing various types of pollution problems, which cause hearth hazards and put tremendous stress on our economic resources. Leaving aside industrial non-recyclable waste, most decomposable organic wastes can be recycled with utilisation of earthworm activities. Benefits of these would be high and would cut down problems of pollution, reduce chemical fertilizer inputs and economic inputs, simultaneously enable employment generation. Therefore, at various levels, in rural and urban areas there is need to have information on daily, monthly and annual turn over of wastes.

In India, potentials of manurial resources and organic wastes are very high. These are from human wastes, livestock, crop residues, plant wastes (tree etc.), aquatic weeds, green manures/ urban rural waste, and agro-industries, etc. etc.

There are numerous estimates on production of wastes. Dr. B. K. Senapati in 1991 gave an estimate that annual production of organic wastes in India to about 3000 million tones. Most of this with recycling could be utilized for recovering fertilizer, fuel, food and production of fodder, besides having potentialities of producing 400 million tones of plant nutrients, biogas and alcohol.

According to conservative estimate given by Prof. S. Jairajpuri, annual waste production in India ranges to 200 million tones of liquid, animal excreta, besides huge quantity of garbage, convertible wastes and industrial wastes.

Municipal wastes are largely generated by urban human population and are some of the most problematic polluting, and expensive to dispense. It is very well known that in terms of quantification, easiest estimation is from simple equation given by U & V Bhawalkars of Pune that higher living standard generate more mean wastes with lesser bio-degradables, while lower living standards less wastage and lesser non-biodegradables. In very developed cities of Hamburg, Hongkong and Singapore, daily production of municipal sewage waste (MSW) per person is 4 kg, in New York it is 2 kg. While in Bombay and Calcutta it is 600 gm. In Delhi it is not less than 800 gm with definite increase of non-degradables. Disposal of such a tonnage of garbage is very expensive. Published reports reveal that New York daily produces 30,000 tones of Municipal Sewage Wastes. Bombay alone reportedly daily generates 5000 tones of MSW for disposal of which annually Rs. 100 crores are spent.

It is beyond reconcilations that at conservative estimates India, annually generates 25 million tones of MSW. Disposal from 4 metropolises (Delhi, Bombay, Calcutta and Madras) alone annually involve expenditure amounting approximately Rs. 7 to 8 crores. Unfortunately, published figures on tonnages of production, recycling, expenditures involved and recovered are not yet available. These with proper processing (viz., Vermicomposting) are expected to generate high economic returns.

Japan reportedly has most efficient recycling of organic wastes in the world. It recycles nearly 65% of its wastes. Prof. B.K. Senapati has reported that Japan annually imports 3000 million tones of earthworms for recycling wastes from paper and spinning mills. Of these nearly 1,80,000 tones/year is utilised for use in Eel Fisheries which is a delicacy. Canada also reportedly exports live worms by hand catching during night to America at annual value of approximately 30,000 dollars. A1l these amply indicate scope of vermiculture and vermicomposting besides potentialities of economic returns for developing countries. These, if projected with utilizations of livestock dung and plant waste would be interestingly enormous.

ANIMAL DUNG

In India, annual production of cattle and buffalo dung is 2027.80 m tones (estimated by Professors A.G. Gaur and K.V, Sadasivam) and comprises 80% of all recyclable organic wastes. Professor A.G. Gaur also reported in 1992 that nearly 75% at total cattle dung may be being utilised for fuel against 30-50% in 1970's, Present estimations warrant attention. Estimated manurial potentials of N, P_2O_5 and K_2O from bovine dung alone is reportedly estimated to be 3,442, 1.307 and 2,214 million tones annually. As discussed in preceding pages, Vermicomposting of these for recovery of nutrients at source of production would be efficient in terms of savings on transportation, time, energy, economics and with least labour employment besides in main point, i.e., immediate usages, etc.

This can be visualised from a conservative estimate that 1 million earthworms housed in space of 22.6 x 22.6 mtrs would convert 1000 tones organic waste, upto 240 tones vermicompost and cast in approximately one month. Projection of the estimate with extrapolation indicate high return. This may generate income upto Rs. 2,00,000 at conservative rate of Rs. 2 per kg vermicompost. As yet no mechanical or chemical process is available that offers so input efficient and remunerative that can generate such profit margins from garbage. All these need evaluations for practical level usages. These further invite our attention to a brief perusal of Agricultural Wastes.

AGRICULTURAL WASTES

Generation of Agricultural Wastes has been estimated by Bhawalkars to a tune of 320 million tones annually. These comprise residues as of rice, wheat straw, groundnut and coffee husks and cotton stalk etc. Sugarcane Trash or Baggase alone is reportedly estimated to be 40.92 million tones. Bhawalkars stated that most of it, is burnt creating pollution problems. However, Professors A.G. Gaur and K.V. Sadasivam stated that only a marginal part of agricultural waste is put to agricultural use (as soil amendments), but majority is used for cattle feed, fuel and other usage (hard board paper industry, etc.,). Most of these on appropriate utilizations in agricultural fields offer potentials of high level of plant nutrients.

Agricultural waste and bovine dung provide immense potentials in maintenance of agricultural as well environmental sustainability. Varied ways suggested by experts are use of agricultural wastes for mulching, conservation of nature, enhancing soil productivity by providing feed to micro-organisms exploiting beneficial aspects of soil organisms and cutting down chemical fertilizer inputs etc. However,

according to Professors A.G. Gaur and K.V. Sadasivam, efficient application methods have to be determined for various crops. Obviously simplest solution is composting of which vermicomposting is apparently safest and efficient.

List of recyclable wastes from agricultural related sources and others that can be utilized with Vermiculture is long. These comprise, poultry waste, food processing wastes, sugar mills and waste water etc. Amongst these technologies for recycling wastes of certain types of technologies are available but need further development, viz., with cost efficient and simple technologies like vermiculture and vermiicomposting, i.e., vermitechnology.

CHAPTER 8

VERMITECHNOLOGY

DEFINITION

Vermitechnology has been defined by Prof. B.K. Senapati, as a method of converting wastes into useful products through actions of earth-worms comprising three main component processes, (1) Vermiculture (2) Vermicomposting and (3) Vermi-conservation. These provide multiple benefits (many described in preceding pages) in various perspectives, namely, waste biomass management, animal protein production, pollution abatement, wasteland conservation, land reclamation, production of worm worked manure, soil fertility maintenance, enhancement of plant production. These in addition provide economic returns and generation of self-employment. These are essential component to development of any area, in particular for developing countries.

HISTORY

In terms of history of vermitechnology, development and start is marked with appreciation of role of earthworm in soil conditioning by earlier workers/ i.e., in 1BB1 by Charles Darwin with publication of his book the 'Formation of Vegetable Mould.' Concepts given therein were first ridiculed but Dr. O. Graff has made extensive tracing of history. From this it appears that J.C. Krunitz was the first to note in 1812 that earthworms have useful role for soil. Subsequently many German and Russian published several observations.

In beginning, Charles Darwin too is reported to wonder howlime and charcoal from soil surface gets into lower layers. It is only in 1837 that Darwin communicated his findings on earthworms to Geological Society of London that materials are taken from surface to lower layers by earthworms. By this time Darwin had already stated that formation of "vegetable mould" (= humified soil layer) is with activities of earthworms. His evaluations of role of biological agents (like earthworms) in formation of humified soil layer is first contribution on the subject. This was however, ridiculed as was un-imaginable on capability of earthworms merely on account and "...considering their weakness and their size the work they represented to have accomplished is stupendous, (Fish in Gardener Chronicle, 1869 as quoted by J.E. Satchell, 1983). Subsequently too and for many, even today, role of earthworms remains very poorly appreciated.

In context to early history from Charles Darwin onwards, V.V. Dokuchaev, a Russian soil scientist in 1883 appears to have indirectly accepted Darwin's views, but with considerable under estimations.

First person to give scientific credence to Darwin's views was G. Vysotskii, who in 1930 experimentally established main role of earthworms in high water-stable granular structures of soil in Russian Steppes.

In 1930, A.A. Yarilov referred Darwin as the founders of modern Pedology, but the father of biological soil science and of archaeological soil science". Interestingly, Yarilov had in his book title Charles Darwin the founder of Soil Science' cleared his dominant support to Darwin's concept on role of earthworms in humified soil formation.

IN OTHER COUNTRIES

Start of vermitechnology on modern lines is believed to have been around middle of 20th Century. Unfortunately not much is known on persons who were pioneers to commercialise the subject. However, name of Dr. George Oliver is known. He abandoned his flourishing medical practice to start Vermitechnology. Subsequently, T.J. Barrett of Boston in 1947, was first to produce earthworms on a tonnage level and obtained patent of the process. Subsequently commercialized vermitechnology started in several countries and according to Prof. B..K. Senapati, first earthworm production plants were set up in Holland Landing and Ontario. These gradually followed in America, Italy, Japan, France and Israel.

Presently in several parts of world, namely in U.S.A., Canada, U.K., Mexico and even Brazil, factory like processes have been developed for vermiculture and vermi-composting. Presently America is reported to have 90,000 earthworm Ranches and exports worms worth thousands of dollars, viz., to Japan. Developed countries like U.S.A. and U.K. are utilising vermiculture in stabilizing sewage sludge and potato waste. In Asian countries, like Phillippines, Taiwan, Malaysia, Indonesia and Hongkong, vermiculture is being variously used, viz., for Cassava waste composting. Phillippines is developing vermiculture (of Perionyx excavatus) to use as feed for Tilapia fish and Quail to cut down heavy bone and fish meal imports.

IN INDIA

India, too has developed technologies which are available from Pune, Bangalore, Bhubaneshwar and from Indian Agricultural Research Institute, Delhi. Unfortunately wider and general appreciations of values or importance of the subject as well its dimensions are lacking. It is, however, heartening that many voluntary organizations and few universities (Bangalore and Utkal) are working hard to popularise the subject. The Zoological Survey of India, provides know how on identification. Still it has not picked up the pace. One reason appears to be the wanting need of lucid but .scientific account of subject providing background information 6n all connected aspects. These in fact comprise main objectives of the present publication.

Needs of such scientific publication are obvious to develop full awareness. Here it deserves mention that nearly 907o zoologists world over have not seen earthworm cocoon. In schools, cocoon is not shown as it is not available. Simple solution is that schools, colleges and others should have their own vermiculture programs.

CHAPTER 9

ADVANTAGES OF VERMICULTURE

Numerous advantages can be derived from vermiculture in different perspectives. Some of these have been discussed in preceding pages, other important ones are enumerated below.

PRODUCTION OF CHEAP ANIMAL PROTEIN

By culturing earthworms, animal protein (Vermi-protein) can be produced at very low price from wastes. This protein can be variously used, viz., for sale as fish baits, fish culture feed (Japan imports for Eel fish culture), feeds for poultry, piggery and also for general fish farming, besides for educational and research purposes. Later would affect depletion of existing earthworm in nature for presently traders largely collect from wilds to sell in institutions.

Two food processing companies of California have developed Cookery Recipes for humans using earthworms and are named as Omelette Recipe and Cake Recipe.

Essential step in any feed preparation from earthworms is cleaning with rinsing and washing with clean flowing water. This follows removal of organic matter present within intestines of earthworms. For this live earthworms are fed on clean moist paper (like blotting paper). In America, live and cleaned earthworms are put on moist corn-meal for 24 hours. This removes all food present in guts due to purging action. Worms are then removed, cleansed with running water and only live ones are retained for further processing. So cleansed worms are boiled and used for dietary recipe. Cleansed earthworms can also be dried (at 95^0C for 15-30 minutes in an oven) and powdered for mixing in recipe. Both the recipes according to Kevin Arthur, in Handbook of Australia' are 'Good eating too'. However, in present day situations great caution is warranted due to existing pollution, pathogens and accumulation of pesticides, as well metals in earthworms from the substrate culture medium. Therefore, for human dietary requirements culture of earthworms should be in feed substrate medium that is not harbouring pollutants and pathogens. Professors B.K. Senapati, Radha D. Kale and Madhab C. Dash in 1985 have reported that in U.S.A. and U.K., earthworms are being reared on sterilized filter paper for human consumption. In Indian, as well in developing countries we have also to ensure safe 'seed culture, before starting culture on sterilized filter paper for consumption by humans. Acceptance of worms for human consumption however, may take years. However, there are reports that aborigines of Southern Australia and Maoris of New Zealand do take earthworms in their diets.

Earthworms for fish, poultry and animal feed are being widely used. This supplementation of earthworm protein to other protein sources leads economy. Philippines is developing its technology for reducing import of (£ 26 millions in 1978) fish meal and bone meal by commercialized culture of several species of earthworms. This is because earthworm proteins are perhaps more assimiable than animal proteins.

Nutritive values of living earthworms would obviously vary with several factors like feed and physiology etc. So does proteins and nutritive values of different species of earthworms would vary. In sewage worm, Eisenia foetida, proteins were reported by E. Schulz and O. Graff to comprise of 84% biological value, 79% net protein utilization and both factors were comparable to fish meal proteins. Indian scientists, B.K. Senapati, R.D. Kale and M.C. Dash in 1985 gave a generalised picture of earthworm tissue to contain 50-75% proteins, 7-10% fats, calcium, phosphorus and other minerals. According to them earthworm tissues on dry weight basis yields 4100 Cal/g, contain critical amino acids like Arginine, Tryptophan and Tryosine and showed better growth rates in crabs, fish, tadpoles and chicks. Several workers have shown better earthworm meal conversion in terms of weight gain etc. However, there is no relevance in popular belief that earthworm fed chickens lay eggs of low cholesterol. For poultry feed however possibility of transmission of Heterakis galliruarum has been reported. Therefore, feed substrate needs to be monitored.

In many types of animal researches on live carnivorous or insectivorous forms, feeding is difficult, viz., on insectivorous birds, fish, amphibians and even many reptiles. These can be easily maintained on earthworms from vermiculture.

VERMI CAST

In vermiculture, earthworms feed upon degradable and decomposable organic (and soil mineralised matter) like animal dung and plant wastes etc. Such matters after ingestion are digested, assimilated in intestines and left over are excreted as casts which are popularly referred as vermin cast. Thus there is slight difference between vermi cast and vermicompost. Vermi cast is generally more beaded, crisp having micronised, but binded soil particles containing several enzymes, micro organisms minerals and plant nutrients.

Shape of casts considerably vary from masses (heterogeneous to spheroidal) to oval individual pellets, small towers to coiled tubes, shaft, threads and beaded strings (reported by Dr. J.M. Jhulka). Some opine that these can be used to differentiate species while applied scientists differ on this criteria.

Cast production is direct outcome of earthworm activities commencing with burrowing. Therefore, it has many functions, namely, micronising soil particles to medium sized particles, re-distribution of nutrients, reduce run off of nutrients from soil surface (some authors differ for some situations), increasing availability of phosphorous, potassium and nitrogen to plants and increasing mixing of various nutrients.

SOIL, AND VERMI CAST

In nature, earthworm cast are important agents of pedogenesis and soil fertility. Therefore score of studies have been made from world over, starting from Charles Darwin to present. In India too, several top Agricultural scientists have at some stage worked on worms. Many studies are available linking cast production to soil turn over or soil amendments to plant productivity etc. There have been many studies indicating pedogenesis with earthworm casting activities for improving quality of soil. R.V. Reddy showed that in Nagaland soils with earthworm casts showed higher pH that soils without casts which had higher acidity.

Cast production in nature is in a way superior soil tillage. Many of us would not easily appreciate magnitude of casting in quantified terms. Dr. K.E. Lee has reported that at earthworm population of 202 to 400 individuals per mtr2, cast production would range from 21.7 to 27.8kg in about three months time. Drs. M.c. Dash and V.C. Patra have reported that during active phase, Pheretima hupiensis produced average 3.8 kg cast/m^2.

In Grasslands of Thailand, annual cast production is reported by H. watanabe and S. Ruaysoongnern to range 13.26 kg/m^2 to 22.48 kg/m^2 i.e., from May to November to a tune of 132.6 to 224.9 tones/ha and largest, cast mond of a Pheretima species was 5 cm in diameter and 35 cm in height. Casts of Notoscolex birmanicus is reported (Kale) weighing 1.6 kg.

In India, cast production in nature has been reported from Orissa by M. Dash and V.C. Patra to range from 1.4 to 77.8 tones /ha. For Africa famous British experts, Edwards and Lofty have reported cast production ranging from 2100 to 2600 tones/ha/year.

Interestingly, Charles Darwin in 1881, estimated that an average population of earthworms would produce casts ranging from 18 to 40 tones/ha. Unfortunately many ridiculcd Darwin and disbelieved his estimates.

In totality, earthworm cast productions brings about highly beneficial form of soil tillage with several amendments like addition of plant nutrients. It is reported by experts that soils with casts contain more nutrients, i.e., 5 times Nitrogen, 7 times phosphorous, 11 times Potassium, 2 times Magnesium, 2 times Calcium, 7-8 times Actinomycetes bacteria, than in soils without earthworm casts. Prof. R.D. Kale has pointed out other little known beneficial activities of earthworm casts. These are gibberellins, cytokinins and auxins released due to metabolisms in microbes present in cast. These substances in turn may increase germination and growth of plants.

In California, and san Diego, U.S.A. a firm markets earthworm casts at retail equivalent price of Rs. 4080 per ton ($ 120 at Rs. 34 per dollar conversion rate). All these do need awareness development. Prof. B.K. Senapati in 1985 has reported that increase with application of Vermicast in paddy, by 95% and straw and roots by 128 per cent. Prof. Radha D. Kale and her team also reported that vermi cast application in half the recommended doses of fertilizers showed significant increase of beneficial soil microbes in comparison to recommended doses of Farmyard Manure and chemical fertilizer in paddy fields.

From preceding points, one may wonder why not simply inoculate earthworms in agricultural fields and let earthworm perform all beneficial agronomical activities. Well, technically it is possible with introduction of right type of earthworm species in different soils. Limiting factors, however are varied, viz., time it would require in establishment of earthworm population at effective density, existing soil state and practices that limit population establishment. In fields under modern system of cultivation results of earthworm inoculation are expected to be available only after 70 years and at inoculation rate of approx. 12-20 tones/ha. These are obviously not presently at acceptable stage. In fact such studies are wanting to know impact on introduction.

EIARTH WORM INOCULATION IN SOIL

In America, in some areas an alternate approach to inoculation of live earthworms in agricultural fields is followed for faster results. This involves raising of ridges in, fallow fields which are then filled with agricultural wastes and animal dung. This bedding is then mulched and watered followed with introduction of live earthworms. Fields are left for earthworm activities for biological fertilizer supplementation. This form of earthworm activities utilization, is however, possible only by large land holdings and is apparently not possible in developing countries where ownership is of small holdings.

As yet, practically no information is available on benefits of introduction of earthworms and its casts on forestry plantations in India. These offer interesting future lines of researches.

Thus, simpler and quicker to introduction or inoculation of live earthworms for exploitation of beneficial activities is to utilize compost produced by earthworms.

DECOMPOSITION OF BIO-DEGRADABLE WASTES AND VERMICOMPOSTING

Earthworms have important functions by virtue of their feeding and general behavioural activities like, burrowing, feeding, micronising, digesting, excreting with decomposing micro-organisms and supporting further decomposition of bio-degradable matters. These decompose complex waste matters to simpler forms. The whole process is known as vermicomposting, i.e., composting in vermic ways (or through earthworms). Most of details on the aspect have already been described in preceding pages. Therefore are not being repeated.

Vermi-compost is therefore different than vermicast. However, vermi-compost contains casts also, so many workers do not differentiate between two terms.

In process of decomposition, presence of earthworms, i.e., their activities hasten decomposition by 2-5 times in comparison to decomposition in conventional manner.

Rate of decomposition in quantified terms through earthworm activities depends upon several factors like nature of material and species, and population density of species, besides several biological and ecological factors.

Numerous estimations are available from world over which with extrapolations provide information on decomposition or composting rates in quantified terms by various species. Most of these amply elucidate tremendous potentials of earthworms in composting. These deserve perusal as amply indicate commercialization scope of vermicomposting through vermiculture.

On average, 1000 live individuals (of Eisenia foetida, Eudrilus eugeniae and Perionyx excavatus) weigh 1 kg which can be housed in ½ m^2 space. These on provision of appropriate conditions would compost 5 kg/day. Thus 10,000 live worms, weighing 10 kg occupying composting area space of 5 m^2 would convert 1 tone/month.

With similar extrapolations from another estimate we find potentials of 1 million earthworms housed in composting space of 22.6 x 22.6 m on appropriate conditions may convert up to 120 tons/month. With extrapolations in monetary terms @ Rs. 2 per kg cost of vermicompost, this indicate possibilities of generating income upto Rs. 2,00,000 per month. Obviously in all biological productivity there are numerous factors on which biological activity is dependent. Thus, even if earthworm conversion rate is reduced by 507o, productivity potentials of 60 tones/month at estimated Rs. 1,20,000 p.m. appears significantly high. Therefore, process warrants appreciations and developmental impetus.

Perhaps due to above points, in several parts of America, mini factory type, semi-mechanised processes arc in use for vermicomposting of daily production of organic wastes. There are business houses that market such processes for daily composting of 50-500 lbs of organic wastes through vermiculture. However, essential manifest in all these, is obtaining of information on, collection and transportation of daily requirement of degradable organic waste. These follow up packaging and marketing of the compost.

Application rates of vermicompost to plants ranges from 30-40 parts vermicompost with 60-70 parts of soil. Variation, however, seldom makes difference as vermicompost is not at all phytotoxic. In potted plants it has been observed that two applications of vermicompost, 150 gm and 500 gm per 5 kg soil of potted plants (Kitchen gardens) at conventional intervals gave good results in most plant types, flowering plants to vegetables. In fact, vermicompost application rates (dosages etc.) warrants to be worked out for nutrients vary with feed substrates given to worms for vermicomposting. Other aspect warranting attention is to understand possibilities of supplementing nutrients in worm feed substrate for eventually having a so called tailor made compost, i.e., supplemented with macro or micro nutrients. All these are future lines of researches anyone can take up with nutrient testing from any test laboratory.

VERMICULTURE IN POLLUTION ABATEMENT

Various types of pollution is spreading all over world, posing various types of threats, viz., degradable organic wastes (sewage, animal dung, food plant, kitchen wastes etc.) and non degradable wastes, besides chemical wastes. Vermiculture provides us a tool for use in recycling degradable organic wastes into useful product, the compost.

Some experts have also expressed possibility of utilizing earthworms and their capability of accumulating materials/chemicals. Such reported chemicals are metals and agrochemicals. Several foreign experts have shown that earthworms have capabilities to accumulate lead, cadmium, chromium/ copper/ nickel, mercury and zinc etc. Earthworms have also been shown to develop more of metal binding proteins. Technically this is feasible but aspects warrants developmental researches.

Waste water pollution, viz., sewage, dairy, sugar mills/ paper mills, distillery wastes, and food processing units etc. pose major problems in disposal or treatment. U. & V. Bhawalkars have stated that with their process, using vermi filters such wastse waters can also be treated.

In pollution abatement and management, essential step is diagnosis of occurrence of pollution. Next step is to know extent. These follow other steps. Conventionally even first two steps comprise cumbersome steps. With appropriate research development possibility exists on using various earthworm species as biological indicator. These warrant development.

MISCELLANEOUS USAGES OF VERMICULTURE

Earthworm cultures can be used in numerous ways, most of those have already been described in preceding pages, viz., rise of cultured earthworms for class room study and in research as test animal.

Medical or Pharmaceutical usages of earthworms are varied. Prof. S. Jairajpuri has reported use of earthworms in Unani Medicine Systems for treating wounds, piles, chronic boils, sore throat, hernia etc. and with internal preparations for curing rheumatic pains, jaundice and respiratory ailments etc. Obvious present needs are scientific evaluations of these on modern testing procedures.

Two Americans (J.M. Reynolds and W.M. Reynolds) in 1972 have traced history of earthworm use in medicine to 1340 A.D. in various folk myths etc., from Pyorrhea to post partial weakness and rheumatism etc. Even on these, scientific confirmations are wanting.

In fact not much attention has yet been paid on study of medical usages if any of earthworms. This is despite the fact of consistent historical evidence reportedly exists on use of earthworms in treatment ol rheumatism. So far only a Japanese team in 1974 (M. Hori, K. Kondon, T. Yoshida, E. Konishi and S. Minani) have reported the presence of anti-pyretic agent (fever reducing) in a Japanese earthworm.

Earthworm usage, in confirmation of pregnancy with 95 per cent accuracy have also been reported. In fact there can be numerous usages of earthworm as test animal, viz., biological indicator of chemical pollutant. Subject needs development.

CHAPTER 10

HARMFUL OR NEGATIVE ROLES OF EARTHWORMS

NEGATIVE ROLES

Like all living creatures earthworms too are known to pose some problematic activities negative to our economic interests. It is reported that excessive accumulation of earthworms within potted plants disturbs root growth and nutrient supplies to plants. certain species in some situations according to Prof. s. Jairajpuri affect growing plants by pulling their leaves into burrow, extensive burrowing sometimes retards germination growth and development, also to some extent soil erosion.

According to Prof. S. Jairajpuri, some earthworm species have a role in spread, development of parasites and pathogens like Foot and Mouth disease; besides acting as intermediate hosts of protozoans, cestodes and helminths. Amongst these, noteworthy reported is in transmission of Heterakis gallirarum. opinion of experts, however, varies in transmission or spread by earthworms of two important parasitic nematodes, viz., Ascaridia galli in chickens and Ascaris suum in pigs.

Earthworms have also been reported spreading soil fungi and pathogens. Indian workers (Baweja, Khambata and Bhatt) have reported, earthworms spread Fusarium and Pythium.

In India, such aspects have remained poorly studied and with lack of awareness or perception emphasis has been to generalise selected examples overlooking aspects that can be exploited to tremendous benefits. To these some examples in problematic situations of agriculture deserve perusal.

Casts of Allolobophora spp. are compact, lump like and are reportedly problematic in potato cultivation. However, some Allolobophora species can be well utilised for vermicomposting. Presence of Allolobophoralonga is reported to promote hatching of cysts of Potato Earthworm.

Many experts from different parts of world have reported that usually surface dwelling earthworms have habits of pulling leaves and damage some plants like potted plants' In crops, tobacco crop is reportedly damaged in Bulgaria and India, rice is damaged in Philippines, China and Japan. Vegetables, particularly leafy vegetables like lettuce etc., in all parts of world are damaged to some extent. Prof. K. Gunathilagaraj (Tamil Nadu Agricultural University, India) has reported several species showing pestilence to cultivated plants, but does remarks that "...in the absence of organic materials, earthworms are known to attack cultivated crops as detailed below". The listed ones are, Betelvine (wilting due to excessive burrowing) by Metaphire elongata; Rice (damage to root system) by Malabarica paludicola, Aphanascus oryziuorus and Criodrihts spp.; Cardamom (burrowing into stem) by Perionyx spp.; Tobacco (cut at the ground level) by undetermined species and cotton (cut at ground level) by Perionyx excavatus.

Noted Indian expert, Prof. R.D. Kale in 1989 (Kale et al., 1989, Mysore J. Agric. Sci., 23) stated that Curgiona narayani Michaelson live individuals clinging to paddy roots don't adversely effects paddy, instead showed marked influence on Nitrogen fixing bacteria and fungi.

Problem of earthworm abundance in Grass turfs, Golf courses, Lawns and in Air Port shoulders (attract birds) are faced all over world. Basically on grass turf areas it is due to casts which are disturbing. In Air Fields earthworms attract all sorts of predatory complex that pose bird collision threats to air crafts. In such situations chemical control is invariably desired.

CONTROL OF EARTHWORMS IN PROBLEMATIC SITUATION

Aspects warrants very judicious judgment in all perspectives, ranging from essentiality, environmental consequences, residues, problems of secondary hazards to predators, pesticidal application precautions and implications to subsequent earthworm population etc. A very persistent chemical once used, will considerably inhibit normalization of population. It would also adversely affect eco-system and in particular predators.

In small areas, control, if desired had picking is best method. From garden pots, change of soil is other method. From house lawns, easiest and safest is to pour boiling water over casts" This kills earthworms but burns patches, wherein grass gradually regrows without permanently damaging earthworm population and disturbing whole eco-system.

In large Crass turfs, Golf courses and Air field environment, Carbaryl or Phorate dust between 6 to 12 kg per hectare have been suggested by experts. However, this measure has to be repeated after 1 to 2 months as these insecticides have less persistence.

There are ever reports (Stolte) that earthworms have affected man too, viz., reported in human body in a fistula (Microscolex modestus), urine (Eisenia foetida), human faeces (Lumbricus and Octolassion species) and in vagina.

Some workers from India have also observed that in some situations earthworm casts disturb drainage which hamper growth of certain plants. Others have also stated that excessive casting promotes soil erosion as casts largely comprise micro fine particles. Simple solution to check such erosion from slopes is seeding with soil binding grass wherein germination would be faster.

CHAPTER 11

VERMICULTURE

GENERAL AND PLANNING

Careful perusal of different aspects of earthworm activities in nature, and benefits that can be derived with mass culture, viz., for cast production, vermicomposting and commercializing live material, indicate needs of developing mass earthworm culture. This is popularly referred as 'vermiculture'.

Main benefits of vermiculture is that introduction of live earthworms is avoided in natural conditions or that only selected species can be introduced. Thus in reality chances of adverse effects, if any, possible due to introduction of live worms is overcome. Benefits with vermiculture are varied, namely, enable easy management, vermicomposting wastes at source or place where one wishes or has facilities, compost can be more profitably utilized and commercialization for economic gains is possible. Other benefits are that management of live population in field too first necessitates development of suitable conditions which are not easy due to modern agricultural practices. Even if these are made available, a large culture of suitable earthworm species, viz., approximately on tonnage level = about 1 million live individuals per hectare land are required. All such requirements necessitate development of earthworm culture (vermiculture).

Vermiculture, as a subject, involve background of various aspects on biology etc. of earthworm. All these are scattered in literature. Commercial establishments are spread all over world which in provision of know how, first look up their own economic gains. So preposition appears complex, cumbersome and uneconomical.

Vermiculture process is infact very simple and easy to follow with careful step wise programme. However, like all live animal or culture of any biological material, first step is to start purely as a test experiment on a small scale. This enables acquire personal experience(s) on various aspects. For beginners, hobbyist and farmers, simple procedure should be first to start on experimental scale and record every detail of steps followed and responses on earthworms, i.e., how these fair in particular medium with increase or decrease in their numbers, waste matter conversion, cast production and composting etc.

Keeping above points in view, we have attempted to simplify descriptions, so as to provide complete know how for any one who is interested in the subject.

Step-wise work at start of vermiculture, in particular for developing it eventually at Commercial level, necessitate appreciation of some points at planning level.

Points to be considered at planning level are : (1) site selection; (2) availability of decomposable organic waste, its daily quantity and quality, alternate organic material, transportation and stocking etc.; (3) marketable outlet and requirement with future scope; (4) collection and study of know how on earthworms to be cultured; (5) collection, procurement of suitable species; (6) testing of suitability of species on performance in available organic waste; (7) maintenance of seed culture for eventual large scale culture. In addition to these, numerous allied points like funding, availability of labour, quality of water and packaging etc. etc. are to be kept in mind. All such points comprise essential steps in any project formulation. Unfortunately, as yet, economists have not formulated any standard format for earthworm project formulation, its economic inputs and outputs. This appears to be due to lack of appreciations and awareness for want of consolidated literature.

In terms of wider utilization of vermiculture, first step is selection of suitable species for culture and eventual vermi-composting.

SELECTION OF SUITABLE SPECIES

Selection of suitable species for vermiculture is done according to requirement, viz., for composting, poultry and animal feed, marketing for fish or other forms of culture and sale for fish baits. As yet demands in India for fish bait is meagre and lack for wanting development of fresh water sport fisheries, including for selected fish species (like Eel Fish) culture and also large scale culture. For all culture feeds, care has to be taken that earthworm feed does not harbour parasites and pathogens (described in preceding pages).

In general, some species are 'vermicultured' that have other possible commercial utilizations, viz., *Eudrilus eugeniae.* In other words, species cultured are also used for vermicomposting and surplus are marketed for other utilizations, excepting for human consumption or for animal feed (biomass production). In later two cultures, parasites, pathogens and other pollutants should not be there.

Theoretical background of selection of suitable species is based on certain biological and ecological parameters. Technically these have been referred by M.B. Bouche in 1977, as habitat characteristics, distribution in soil or feed media and trophic functions. Based on these parameters, we find that there are three types of earthworms which can be used in vermiculture. These are : (1) Epiges; (2) Endoges; and (3) Aneciques.

1. Epiges. They are small sized, with uniform body colouration, live on surface litter or dung, tolerate disturbance, have active gizzard; but have limited period of activity. These are phytophagous. Most of these species are good bio-degradators,-so are good nutrient releasers, but do not re-distribute nutrients. Thus have insignificant role in humus formation and are not good for use in field conditions for soil reclamation, unless careful manipulations are done. These have short life cycle with high reproduction and regeneration rate.

2. Endoges. These are small or large sized worms with weak pigmentation, found in top soil layer of organic and mineralized matter. Burrow branchings are horizontal and worms moderately tolerate disturbance. According to one expert, these show some preference in selection of fced substrate (buffered and predictable) conditions. These are geophagous. Life cycle is of intermediate duration, but are potential in soil improvements due to high efficiency in energy utilization from poor soils. So can be used in field with some manipulation.

3. Aneciques. These are large sized worms with pigmentation only at anterior and posterior ends. In habits these are largely nocturnal, deep burrowing and pull leaves or litter matter into soil (burrows) and are phytogeophagous. Tolerance to disturbance is poor and reproduction rate as evidenced from cocoon production is low. May have useful role in mixing nutrients as from deep burrow come up to surface for casting. Prof. R.D. Kale has reported that some species for unknown factors get into seasonal diapause.

So far, in whole world, only few species have been studied for vermiculture and majority remain unstudied. Essential step is to initiate stepwise bio-ecological studies without overlooking any of the ethological and other parameters essential from view point of utilizations in vermiculture-vermicomposting.

These can be assessed by certain methods on distribution, adaptability, functional ability, life cycle strategy and tolerance to various factors etc. Such methods are complex and only trained biologists can take up differentiation or selection of species based on these methods. These are allometry, trophic study, niche segregation, selection pressure and "r & k selection" r-selected species have high metabolic rate, (so high conversion rates), small body size, high reproduction rate, so have high productivity and are early colonizers of new environments (thrive on high organic humus) viz., epigeic and endogeic earthworms, therefore are most suitable for vermicompostings. K, selected species have large body size, with long life span and low metabolic rates. These have lesser movements outside burrows viz., anecique worms.

BASIC CHARACTERISTICS OF SUITABLE SPECIES

From foregone descriptions, it is clear that selection of suitable species for vermiculture and consequential purpose/utilization is necessary. Farmers and those with little background of biology would want that organic waste is quickly converted to vermi-compost. Such worm species should be tolerant to disease and its culturing techniques should be simple enough to adopt. Simple characteristic features therefore should be known. These are as detailed below:

1. Worm should be efficient convertor of plant or animal bio-mass to body proteins, so that its Growth rates are high;
2. It should have high consumption, digestion and assimilation rate (composting qualities);
3. Worm should have wide adaptability (tolerance) to environmental factors (capability to live in varying temperature conditions);
4. It should have feeding preference and adaptability for wide range or organic material (high and rich organic matter),
5. Worm should produce large numbers of cocoons that should not have long hatching time, so

that multiplication and organic matter conversion is fast;

6. Growth rate, maturity from young one to adult stage should be fast;

7. Worm should have compatibility or tolerance with other worms (as with possibility of mixture of species by ameteurs) as would add to productivity of biomass (worms) and conversion rate at different strata (layers) of organic matter, i.e., faster composting. This feature, i.e., composting with different layer feeders have so far received very little attention;

B. Worms should be disease resistant;

9. Worms on introduction in substrate, should have least inactivity period (= vermistabilization period); and

10. Some experts opine that worms should feed near the surface of organic matter. This, however, deserves study as in vermicomposting conversion would depend on capability of earthworm and its activities in turn over. Therefore, points discussed at No. 7 too deserve study. Such points, however, should concern scientists and comprise future lines of researches.

DESCRIPTION OF SUITABLE SPECIES

Earthworm bio-diversity utilisations itr terms of vermicultural characteristics has not yet been fully studied. So far in whole world, only 3-4 species are in wide use. In India, according to experts like Professors B.K. Senapati, R.D. Kale and Dr. J.M. Jhulka, only two peregrine species are being extensively used for vermiculture namely *Eisenia foetida* and *Eudilus eugeniae*. Potential, however, exists for utilization of several species and deserves attention. This is on several reasons like inbuilt adaptability to climatic conditions per existing distributional range, local availability and in view of needs for better waste conversion rates etc. Such species for Indian sub-continent are as follows:

Family: LUMBRICIDAE

1. Bimastos parvus (= Allolobophora (Bimastos) parvus Eisen) F.B.I. p.506, No. 11)

Distribution, India : Kashmir (Gorai, Srinagar); Himachal pradesh (Kasauli, Barog, Simla, Chail, Narkanda, Kotkhai); Punjab (Ferozepur and other areas ?); Rajasthan (Pratapgarh); and Uttar Pradesh (Nainital and other areas ?).

Preliminary Differentiating Characters. Brownish red body with saddle shaped clitellum, dorsally covering 6 or more segments, from XXIV or XXV to XXX; length 25-40 mm; diameter 1-2 mm; total segments 85-111 usually 90. Other characters morphological and are differentiable by experts only for confirmation.

Note.

(i) Parthenogenetic bearing 1 to 6 individuals in a cocoon. Breeding biology warrants study.

(ii) In many temperate countries, allied species, namely, (1) *Allolobophora subrubricunda* and (2) *Allolobophora chloitica*, (3) *Dendrobaena rubida*, (4) *Eisenk hortensis* and *Lumbricus rubellus* are used in vermitechnology. All of these species, barring perhaps E. hortensis are more or less established in temperate regions of India. Obviously, in such regions, vermitechnology with these species deserves attention, as live individuals would be more readily available in nature and would be better suited to local conditions. Only one has to search and know local distribution or occurrence in different areas. Therefore, for convenience of users, distribution range is given herewith.

Distribution of temperate species. (1) *Allolobophora subrubricunda* Western Himalayas, viz., Simla (H.P.), Sandakphu and Phallut, Darjeeling species may be expected well established in most hilly areas where Britishers had settled and had imported plants for plantation.

(2) *Allolobophora chloritica*, can also be expected in areas Britishers had settled. Present status warrants to be ascertained with faunistic surveys.

(3) *Dendrobaena rubida* has been synomised to *Allolobophora rubida* f. typica Michaelsen by J. stephenson (1930 in Faun. Brit. India, p. 503) and reportedly distributed in Simla, but taxonomical technicalities have not yet been clarified by Indian taxonomists on taxonomic status and present distributional status of form reported occurring in India. It is apparent that the form has been a introduced one, by early British settlers. (4) *Lumbricus rubellus* Hoffmstr, reported from Nicobar Islands in 1930, its present distributional status warrants study as species is widely used in vermi-technology abroad.

2. Eisenia foetida (Sav.)

Distribution. India, almost throughout the country in sewage dumps, sludge, tanks and filters. Most commonly found naturally occurring at sewage filter mesh grills. Need is only to locate in different areas as around most cities the species is quite common. Further with recent awareness it has been widely used for vermitechnology.

In fact, many vermi culturists have been selling this worm only under different names like Red worm, Pink worm or Purple worm, Tiger worm, Brandling worm or even vermiculture or vermicomposting worm. In many technical papers, scientific name has been wrongly cited as *Eisenia fetida*. Such wrong citations are technically wrong. Most of us excepting in some remote areas/ can ourselves collect and raise it in culture for mass multiplication on techniques described in succeeding Pages.

Preliminary differentiating characters. when live, worms appears coloured (red, brown or purple or even darker)' With careful observations one may note dorsally coloured bands which are often two per segment. Ventrally body pale. On maturity, clitellum spreads over 7-9 segments in length over XXIV, XXV or XXVI to XXXII body segments. On these, ridges wall develop on maturity.

Note. *Eisenia foetida* is perhaps world's most widely used earthworm in vermitechnology for vermicomposting. The species has also been in wide usages for various studies as test earthworm. Some basic life features or characteristics of the species therefore deserves perusal.

Life worms are quite hardy and can tolerate wide fluctuations of temperature and humidity. Thus, culturing process of species is quite easy. Feeding adaptability or adjustment to organic matter is quite good on wide variety of degradable,/decomposable organic wastes. On these, an average conversion efficiency ranges upto 7 mg/ worm/ day. So growth rate is quite fast. Mature individuals can attain up to 1500 mg body weight. Mature adults attain body weight upto 1.5 gm and attain reproduction capability within 50-55 days of hatching from cocoon. Each mature worm on average produces one cocoon every third day and from each cocoon on hatching (within 23 days) emerge from 1 to 3 individuals. However, generally, survival of all emerged individuals is not seen. Still, on average, numbers can multiply or increase as high as 30 times. Duration of life is 70 days.

In general behaviour, live individuals do not show movement outside feed substrate (decomposing organic waste). On getting sufficient humidity in substrate, immediately on release at surface, live individuals quickly get into substrate. Humidity revel or moisture within substrate recommended by many experts is 40% which in practice is roughly estimable by inserting a round bamboo stick. This on insertion in substrate should hold some trickling or sticking mass. In practical usage, we found that climatic temperature toleration is good but in tropics, or India^ conditions ideal is a thatched roof protection over substrate medium.

Family: EUDRILIDAE

1. Eudrilus eugeniae (Kinb.)

Distribution. Originally distributed in Equatorial west Africa. Presently found distributed (may now be naturally occurring also) in most parts of the world having got introduced for various usages in vermi-technology. It is common in parts of even America and Europe. In parts of America, species is common and is popularly known as 'Night Crawler'.

In India, common in many vermiculture establishments, particularly in Southern India is recommended species for vermiculture. Since 1930's species is reportedly distributed in Travancore, Pune and North Konkan.

Preliminary differentiating characters. When live, worms appear "brown and red to dark violet" and general colouration is like animal flesh. Body length ranges from 32-140 mm, diameter is 5-8 mm and total body segments range 145-196. In mature adults, clitellum spreads over 5-6 segments numbering XIII or XIV to XVIII. Spermathecal and female pores are fused commencing after 1.3/14 body segments. Male pores commence before 17 /18 body segments.

Note. Species is perhaps fastest growing and second most widely used earthworm in vermitechnology for composting and for use as vermi-protein. Growth is fast (assimilation and conversion to biomass), better than other species and ranges upto 12 mg/ day. Maximum body weight attained ranges up to 4.3 mg/individual. Maturity is attained within 40 days, and a week later individuals commence cocoon laying, almost 1 cocoon/day or upto 4 cocoons /3 days for 46 days, depending upon appropriate conditions. Total life span in laboratory is estimated to range 1 to 3 years. Cocoon incubation period ranges 16-17 days with 2-3 individuals,/cocoon. Some opine that at times, number of individuals per cocoon may range 1-5. Low temperature tolerance is lower than *Eisenia foetida*, but high temperature tolerance is well over 48^{0}F in room conditions, i.e., under indirect sun exposure. On the whole under enclosed conditions survival without much disturbance to conversion capacity or limits is believed to range from 5^{0}F to 48^{0}F, with provision of appropriate, culture conditions.

Harvesting of the species from culture heaps is believed by many to be difficult. However, simple solution is to up turn the heap, leave it for 1-3 hours, all worms move to lower layer. From top lavers, compost can be collected and worms can be replaced in culture media or harvested for appropriate utilization.

Needs of harvesting worms arises as after second to third year, reproductive activity gradually decreases and so composting activity decreases. In such state is advisable to utilise worm for animal feed or just for burying in fields (a nitrogenous waste).

Nutritive values of cast of *Eudrilus eugeniae*, prepared on six different diets has been studied in detail and reported by Prof. Kubra Bano, R.D. Kale and G.N. Gajanan. Nutritive qualities ranged, (pH 6.65 to 7.20; EC (m.mhos/cm), 0.950 to 1.800); per cent OC, 3.84 to 5.04; per cent N, 0.455 to 0.560; per cent P2O5, 0.716 to 1.215 and per cent K_2O, 0.075 to 0.115. These values on comparison with other organic manures like decomposed FYM, organic matter, cow dung and pig manure showed higher per cent of N (0.52); P_2O_5 (0.94) and K_2O (0.999) excepting N in pig manure by only 0.03%. The Eudrilus cast has since then been released as Vee Camp E 83 UAS, by Karnataka.

Family : MEGASCOLECIDAE

Throughout world, so far only six species of this family are in use for vermitechnology work. These are *Amynthas diffrigens, Lampito mauritii, Metaphire anomala, Metaphire birmanica, Perionyx excavatus and Perionyx sansbaricus*. Of these, world over commonly used species is *Perionyx excavatus* which is endemic to India. Its establishment in other countries appears to be with introduction from India. In view of utilities of indigenous species, like adaptability to our conditions and distributional availability within our regions, it is desirable to know distribution of various species of India. For all taxonomic characteristics consultations with specialists is necessary for present taxonomic and distributional status are not known to many, primarily for want of updated documents on earthworm fauna. Such documentation involve, very cumbersome study. Therefore, present descriptions (basing J. Stephenson's, Fauna Brit. India) are being limited to selected species only.

1. Lampito mauritii (Kinb.)

Species is also referred in old documents as Megascolex mauritii (Kinb.).

Distribution. Throughout India, excepting Uttar Pradesh, wherein present distribution is not known. Elsewhere in India reported occurring in Kapurthala, Punjab, many areas of Bengal, Gujarat, Maharashtra. Gujarat, Madhya Pradesh, S. Rajasthan, Andhra Pradesh, Tamil Nadu, Goa, Kerala, Andaman Islands, Lakshdweep Island.

Species is reportedly common in many parts of South and South East Asia.

Preliminary differentiation characters. Body colouration dark yellow except at anterior end which has purplish tinge. Total body length 80-210 mm, diameter 3t-5 mm with 166-190 total body segments. Clitellum spread over to four body segments, on XIV to XVII and is ring shaped. Male pores on papillae, female pores near each other in pairs on XIV segment and spermathecal pores, in three pairs.

Note. Species has been suggested by Prof. B.K. Senapati and Dr. J. M. Jhulka for vermicomposting. Details on its performance in vermiculture warrant study.

2. Metaphire anomala Mich. (= Pheretima anomala)

Distribution. Reported from Sibpur, Calcutta. Present distributional status needs study (in view of utilities in vermiculture) and is excepted throughout Orissa, Bihar, South-East Madhya Pradesh, Andhra Pradesh, Tamil Nadu, Karnataka and Kerala, also in parts of Maharashtra.

Preliminary differentiation characters. Body colourations have not yet been studied. Total body length 80-90 mm, diameter 5 to 5.5 mm and total body segments 130 (variation range ?). Clitellum, ring shaped covering three body segments, i.e., XIII-XVI with XIV ventrally having setae. Spermathecae pores absent but copulatory papillae in pairs present.

Note. Details on performance of species in Vermiculture work are wanting. Likewise details are wanting on *Metaphire birmanica* (Rosa) which is reported from Bhamo, Burma but produces large casts in masses; up to 1.2 kg. This indicates possible usages in composting heaps.

3. Metaphire posthuma (= Pheretima posthuma)

This is perhaps most common species in India on which most exhaustive morphology and anatomical memoir by late Prof. K.N. Bhal is available since 1930. Most unfortunately other details on vermitechnological usages, if any, to-date remain to be studied.

4. Perionyx excavatus E. Perr.

Within India, Genus is reportedly believed to have spread from eastern or western Himalayas downwards in regions of heavy rainfall. Now perhaps, species are widely distributed and two exotic species, *Perionyx excavatus* and *Perionyx sansbaricus*, believed to have got introduced from Australia or New Zealand; but are presently established in India as peregrinus species. Only *P. excavator* is believed to be in use for vermitechnology in many parts of the world. Evaluation of other Perianyx species in vermitechnology largely remains wanting. Therefore, basic details of the species are being discussed.

Distribution. In India, species is reportedly as one of the commonest worms in Eastern Himalayas (Dibrugarh, Sadiya and Darjeeling), Western Himalayas (Kumaon Dist., Sahastradhara, Dehradun, Simla) Pilibhit, Bengal (Calcutta, Rajasthan, Sibpur), Maharashtra (Bombay) and Little Andaman Islands.

Outside India, Ceylon, Malay Archipelago, Siam, Cochin China, and Phillippines. Many parts of Europe and America as introduced species.

Preliminary differentiating characters. Body colouration on dorsal surface (upper party) deep purple to reddish brown and lower side pale. Total length 23 to 120 mm; diameter,2.5 mm; clitellum ring shaped, covering five or less segments on XIII or part, XIII to XVII. Male pores in a depression (line or area). Spermathecal pores in7/8 and 8/9, nearly at same distance as male pores.

Note. Species is amongst commonest in several parts of India. Presently with vermiculture, its distribution is getting extended rapidly. Species is highly adaptable, can tolerate varying degree of moisture and organic matter. So, from dead wood, plant stem, within leaves and flowing rivers, species has been reported. Allied species, *Perionyx sansbaricus* may be similarly found naturally occurring within sewage over flow or filter over flow drains. In fact, present habitat and habits of both species need re-appraisal. Prof. R.D. Kale and R.V. Krishnamoorthy reported species (*P. excavatus*) in Lakshmipura in high density of 3700/100 cft. Apparently it was dominant.

On breeding biology of *P. excavatus*, several workers have made various observations in different parts of world, primarily with objectives of utilizing species in vermitechnology. Some basic features reported (Prof. K. Gunathilagaraj of Tamil Nadu April. University) are as follows :

Life cycle duration is of $\pm$ 46 days, growth rate is 3.5 mg/day, body weight (max), 600 mg. Reproduction rate is fast. Maturity is attained within 21-22 days and reproduction (cocoon laying) commences by 24th day. Average cocoon production is 1.1 /worm/day. This is almost double reproduction rate of most commonly used worm in vermiculture, *Eisenia foetida*. Number of hatchings from each cocoon vary and different numbers have been reported on average it ranges between 1 to 3. Prof. R.D. Kale, K. Bahu and R.V. Krishnamoorthy have experimentally shown varied number of cocoon production in different organic mass with highest in sheep dung media and lower in cow dung media. Reproductive phase was however shorter in sheep dung media with reduced longevity than in cow dung media. Such points can be of wide utilizations in developmet1t of culture and easily be tested with regular observations in other species too.

Incubation period reportedly ranges to $\pm$ 18.7 days and mean number of hatchings is 1 to 3 per coccon.

Many opine that species is amongst the best suited for vermicomposting in tropical climates.

5. Perionyx sansbaricus Michaelson

Dishibution. Widely distributed in many parts of India. However, records are incomplete due to want of survey reports. Species is reported in natural environments of Gujarat (Baroda), Maharashtra (Igatpuri, Manmad, Wathur near Mahabaleshwar and Londa near Castle Rock); Madhya Pradesh (Khandwa and Kala Khund near Indore), South India (Coonoor and Kotagiri in Nilgiris, Kodaikanal) and North India (Delhi and vicinity area). species is expected to be distributed in several other areas, but surveys are wanting.

Preliminary differentiating characters. Dorsally body colouration is purple which is darker at anterior portion. On lower side (ventrally) body is pale. Body length :32-63 mm and diameter :2 ½ to 3 ½ mm. Total body segments range 84-108. Clitellum is ring shaped, extends on 5 segments, over XIII-XVII body segments. Area of male pores variable (XVIII). Spermathecal pores near the middle line 6/7, 7/8 and 8/9.

Other characters are morphological and possible with detailed studies or with help of diagnostic description.

Family: OCTOCHAETIDAE

Species of this family are reportedly distributed in all parts of India; but are more in tropical region (viz., Indian peninsula) and less frequently in temperate climates (viz., northern India). Outside India, species of this family are reportedly distributed in New Zealand and South Madagascar. Of several species under the family, six species are presumably promising for vermitechnology namęly, Dichogaster bolanui, Dichogaster curgensis, Dichogaster saliens, Dichognster nt't'inis, Raniella bisharubari, Hoplochaetella khandalensis, Hoplochaetella suctoria, and Octochaetonn surnensis. These have been suggested by Dr. J.M. Jhulka in 1993. However, from publication of Kubra Bano (1993 Nat. symposium, Bangalore), it appears that only Dichogaster curgensis and Octachaetus (Octachaetoides) surnensls Mich. (= Octochnelona surnensis) are under utilization in India for vermiculture. Therefore, presently relevant descriptions are being restricted to these two species only. On others, only introductory remarks are being made.

1. Octochaetus (Octochaetoides) surnensis Mich.

Species mentioned by Kubra Bano in 1991 (referred in above para) as Octochaetona surnensis is presumably Octochaetus (octochsetoides) surnensis Mich. (Stephenson, 1930, F.B.I., p. 394. Accordingly description is being dealt with.

Distribution. Barkul and Sur Lake, Orissa. Probably has wider distribution range in whole of Indian Peninsular.

Preliminary differentiating characters. Body grey coloured with dark tinge dorsally on anterior portion. Body segments number 113 (variation possible and needs verification). Total length, 75 mm and diameter 2 to 2.5 mm. Clitellum spread over 5 segments, namely XIII to XVIII. It is ring shaped. Male pores, on a square shaped area on body segment number XVII. Female pores paired and spermathecal pores on segment numbers VIII and IX but are inconspicuous.

2. Ramiella bishambari (Steph.)

Distribution. Reported from Saharanpur, Uttar Pradesh but presumably has wider distribution in most areas of Northern India.

Preliminary differentiating characters. Body form thin of grey colour. Body length 35 mm, diameter 1 mm and total body segments 85. Clitellum on narrow body portion, spread over to three segments, namely, XIV to XVI. Other character not easily differentiable by non biologists.

Sub-family : DIPLOCARDIINAE

Stephenson placed this sub-family under Megascolecidae and reunited two families into one on taxonomic conveniences. To avoid technicalities, for convenience of non-biologists species under Genus Dichogaster are being dealt with here.

Species of Genus Dichogaster are reported to have scattered distribution in West Coast, Rajasthan, Gangetic Delta and Darjeeling District. Obviously, species under the genus must be having more or less continuous distribution and warrants confirmation. So far only two species Dichogaster curgensis and D. travancorensis are considered endemic to India. Elsewhere numerous species are reportedly distributed in Tropical Africa, West Indies, Central America, Malay Archipelago and Polynesia.

Present descriptions are being restricted to those suggested for Indian conditions for Vermiculture work.

1. Dichogaster bolani (Mich.)

Distribution. Reported from South India (Ernakulum, Trivandrum and presumably whole of South India), West Bengal (Rangamati, Sibpur, Calcutta and many other areas), Gujarat (Kathiawar and Baroda), Maharashtra (Bombay) and Rajasthan (Bayana). Species should be expected naturally distributed in many areas of India and needs confirmation.

Outside India, species is reported from Tropical Africa, America (excepting east and west) and West Indies. Preliminary differentiating characters. Body colour unpigmented presumably it is flesh coloured which is somewhat pinkish brown. This, however, needs to be defined in technical terms. Body length, 20-40 mm and diameter, 1 1/3 to 1 ½ mm. Total body segments, 78-97. Clitellum is saddle shaped spread over to 5 to 8 segments, namely from either XIII or XIV to XVIII or XIX or XX. spermathecal pores two pairs and female pores single on a papillae. Prostatic pores on segment numbers XVII and XIX.

2. Dichogaster affinis (Mich.)

Disiribution. Reported from Gujarat (Baroda), Maharashtra (Bombay) and South India (Shasthancottah, Trivandrum, and Travancore). Species can be expected in many areas that needs confirmation.

Outside India, species is reported from Ceylon (Peradeniya and Anuradhapura), East Africa, Mozambique, Madagascar, Comora Islands, Siam, Cape Verde Islands and Colombia.

Preliminary differentiating characters. Body colouration not defined and reportedly 'Colourless', presumably it is "flesh coloured" or pinkish brown. This needs to be defined by taxonomists. Total body length, 30-32 mm and diameter, 1.2 to 1.5 mm. Total body segments 140. Clitellum saddle shaped covering 8-10 body segments, over XIII or XIV to XXI or XXII. Prostatic Pores, two pairs on XVII. spermathecal pores two pairs on 1-3 mid ventral papillae on 7/9-9/10 or 8/9 and 9 /10.

3. Dichogaster curgensis (Micha.)

Distribution. South India (Moowad and Bhagmanola, Coorg). Species is expected distributed in other areas of South India.

Preliminary differentiating characters. Body colouration 'even grey'. Total length, 65-75 mm; maximum diameter, Ca 2 mm and 90-110 total body segments. Clitellum ring shaped, pronounced dorsally but lesser ventrally; and at incomplete development appears saddle shaped. Clitellum covers 8 segments over XIII to XX segments. Male reproduction area appears depressed. Female pores on segment No. XIV. Spermathecal pores not well defined, two pairs in 7/8 and 8/9.

4. Dichogaster saliens (Bedd.)

Distribution. In India, distribution of species needs verification. Outside India, species is in Malay Peninsula and Archipelago-Penang, Singapore and Java.

Preliminary differentiating characters. Body colouration reportedly 'Un-pigmented', i.e., somewhat flesh coloured or pinkish. This needs to be defined by taxonomists. Total length: 25-40 mm, diameter, 1.5 mm and total body segments 96-120. Clitellum saddle shaped covering 7 segments over XIII to XIX. Prostatic pores, one pair on a half moon shaped papilla on segment number XVII. Spermathecal pores, inconspicuous two pairs on 7/8 and 8/9.

5. Ramiells bishambari (Steph.)

Distribution. Reported from Saharanpur, Uttar Pradesh, This endemic species is expected in many other area; and present distributional status warrants confirmation in view of its importance in vermi-technology.

Preliminary differentiating characters. Body colouration, 'indefinite grey colour'. This needs to be defined by taxonomists. Total body length, 35 mm, diameter, 1mm, total body segments, 85 and body appears thin. Clitellum covering 3 segments, numbering XIVXVI and body appears thin near posterior end of clitellum. Prostatic pores on segment numbers XVII and XIX. Preliminary differentiating characters need to be further defined for easier identification.

Note. Hoplochaetella khandalensis and **Haplochaetella suctorh** have also been suggested by few for utilizations in vermitechnology. However, present taxonomic status of these two species needs to be defined for enabling vermiculturists initiate further studies. On *Haplochaetella suctoria* some information is available from publication of J. Stephenson (1923, Fauna Brit. India, p. 464) who has synomised the species as *Erythraeodrilus suctorius* (Steph.), accordingly the species is being dealt with.

6. Erythrodraeodrilus suctorius (Steph.)

Distribution. "Sawvordem, Portuguese, India". Present distributional status needs to be defined with faunistic surveys in view of utilizations in vermitechnology; as also for knowing about the variety *affinis* reported from Marmugao, Goa.

Preliminary differentiating characters. Body colouration, dorsally light brown, ventrally pale with darker median stripe. Total length, 140 mm, diameter 6 mm and total body segments 145. Male field or portion differentiable in segment numbers XVII to XIX with two pairs of prostatic pores in a depression with three sucker like structures within an oval area. Spermathecal pores two pairs on body segment No. VIII.

E. suctorius variety *affinis* (Steph.) reportedly differs from characters of 'male area'. Male area in the variety, is within body segment numbers XVII, XVIII and XIX, but outer margin oval shaped spreads to XVI (on anterior side) and XX (on posterior side), the prostatic pores two pairs are XVII and XIX with two sucker like structures at anterior and posterior end only. Taxonomic studies on these two forms would be interesting from many angles, viz., distributional area (more or less same niche); but showing morphological variations that are quite pronounced. These studies are interesting future lines of researches for biologists.

7. Ocnerodrilus (Ocnerodrilus) occidentalis (Eisen.)

Distribution. India : Rajasthan (Kota) Maharashtra (Bombay), Karnataka (Nedumangad, Travancore) and Andaman Island. Obviously, species is expected to be distributed in many other areas too and distributional status needs to be re-defined.

Outside India, species is reported from Panadhure, Ceylon, North America, Africa, Cape Verde and Comoro Islands. The species has been referred as "widely peregrine species" (Stephenson). Obviously, species appears tolerant and adaptable to niche variations.

Preliminary differentiating characters. Body colour not defined and described by taxonomists. Total body length, 15-30 mm, and when alive extendable to 38 mm. Body diameter, 1 mm and total body segments, 70 clitellum ring shaped covering 6-8 segments from number XIII or XIV to XIX or XX. Male pores on a pappillae on segment number XVII.

Family : MONILIGASTRIDAE

1,. Moniligaster perrieri (Mich.)

Distribution. South India at Kodaikanal and Tiger Shola in Palni Hills, Ponmudi and Bonnaccord, Karnataka. Expected to be found in many other areas of South India. Present distributional range warrants to be worked out.

Preliminary distinguishing features. Body colouration, blackish grey which is darker above than on ventral side. Total body length 210 mm, and diameter up to 5 mm. Total number of body segments 175. Clitellum ring shaped, less pronounced at anterior and posterior ends, covering slightly more than 5 segments, over IX to XIV. Male pores on 10/11, 11/12 or 12/13, somewhat laterally located in a hexagonal depression. Female pores one pair, in 11 /12 or on XIII or XIV. Spermathecal pores in 7/8 or 8/9 in Cd.

Species by habit is a semi-aquatic dweller and can be expected in water also. This indicates its tolerance to heavy moisture.

2. Drswida willsi (Mich.)

Distribution. Madhya Pradesh (Bilaspur) and Andhra Pradesh. Present distributional range warrants study in view of utilities in vermiculture.

Preliminary differentiating characters. Nearly 48 species are reported to occur in India. So, far non-biologists it is difficult to differentiate. For others too, differentiation of species without taxonomic key is difficult. Characters dealt below are of *Drawida willsi* and are expected to enable differentiation up to generic level.

Body colouration generally bluish grey or reddish grey; but hues are variable. Total body length 55-60 mm, diameter up to 2.5 mm having 155-160 numbers of total body segments. Clitellum ring shaped covering 4 segments over X-XIL Male pores over a papillae in 'b' or in 9/10. Female pores in 'ab' with inconspicuous spermathecal pores.

Brief descriptions of species suggested to be utilizable in vermiculture and vermicomposting indicate numerous aspects on which information remain to be generated. Obvious necessity is that Indian Zoologists take up the task before it is too late. There is a need to modulate and modify our study curriculae and research programmes, so that gradually required information can be developed from all over country.

After selection of suitable species for vermiculture, it is necessary to initiate development of mass culture for composting (vermicomposting). This involves two steps, namely, (1) maintenance of base or seed culture or mother culture, and (2) multiplication for introduction in composting heaps or tanks or pits.

MAINTENANCE OF BASE CULTURE

Base or mother or seed culture is the material which is stepwise multiplied for large scale culture for utilization in various forms of vermitechnology. This has to be carefully maintained and checked for health of live individuals and condition of feed which should not have any chemical that is lethal to worms. This means procurement point of organic waste should also be checked for seepage and contamination of feed. For initial multiplication best feed substrate is cow dung manure which is more or less in advanced stage of decomposition spread it on ground to see if any parasite is there. The material is then given pre-treatment. This should be then stocked on any of the schemes shown in figures on succeeding pages and proceed for multiplication of culture for vermicomposting.

CHAPTER 12

VERMICOMPOSTING

GENERAL

Vermiculture and vermicomposting are two inter linked and inter dependent processes which when conjoined, can be referred as vermitechnology.

Vermiculture can only be done on compostable or decomposable organic matter. Composting is the outcome of earthworm activities. So both the processes can be brought about simultaneously. In other words we can multiply earthworms for various uses and can obtain vermicast or vermicompost at a faster pace, if we have higher numbers of earthworms.

Economic implications and importance of vermiculture for recycling decomposable organic wastes have already been described in preceding pages. However, certain points deserve reiteration.

ADVANTAGES OF VERMICOMPOSTING

1. Huge quantities of domestic, agricultural and rural industrial organic wastes can be recycled for various usages. This also reduces pollution.

2. Vermicompost substitution with fertilizer input will reduce economic input, viz., by substituting certain per cent of chemical fertilizer with bio-fertilizer, i.e. the vermicompost. Thus economic input would go down

3. Vermicompost can be produced nearest to the site of use. This has many advantages.

4. Extra production with or without worms can be marketed for generating extra income.

Marketing rates of worms and vermicompost vary from species to species in different areas within India. With upcoming trends, possibility exists of large scale market demands which however warrants to be developed. Likewise export potentialities have not yet been developed. These too need development for marketing surplus production.

5. Numerous miscellaneous usages of vermiculture and vermicomposting are possible and have been described in succeeding pages. All these necessitate a perusal of composting materials.

VERMICOMPOSTING MATERIALS

Almost all types of biologically degradable and decomposable organic wastes can be used in vermiculture and vermicomposting. However, constituents vary, viz., poultry droppings are rich in calcium, phosphates and other salts. This has to be diluted by mixing with leaf litter, soil and cow dung. Similarly all types of leaf litter is not preferred by all species of earthworms. All such materials can be put to preliminary testing discussed under maintenance of base culture.

Commonly used composting materials are listed below :

1. Animal dung. Like cattle dung, sheep dung, horse dung, goat dung and poultry dropping etc.

In use of animal dungs other than cattle dung, various preliminary testing and precautions for pathogens and responses to earthworms are necessary.

With use of horse dung, operators have to be extremely, cautions of Tetanus virus that is common in particular within horse dung and is lethal to human beings. In sheep dung immediate growth is poor.

2. Agricultural waste. These comprise all items discarded after harvesting and threshing of the produce. Thus stem, leaves, husk (excepting paddy husk), peels, vegetable waste, orchard leaf litter, processed food wastes/ sugarcane trash and baggase; and processing wastes.

3. Forestry wastes. These also comprise various types of plant products like wood shavings, peels, saw dust and pulp. All these besides various types of forest leaf litter can be used.

In fact its time that researches are promoted for utilization of unutilized Forest waste like leaf litter for vermicomposting. Such programs would provide enormous usages in Forestry programs, besides promoting rehabilitating and economic uplifting tribals or to other population dependent upon Forest produce.

4. City leaf litter. As yet no data is available on tonnage of leaf litter from avenue or residential areas that is burnt. All this can be converted into vermicompost. This would keep cities clean and would provide useful product the vermicompost.

On success of vermiculture on different types of leaf litter, some information is available" These are mango, guava, grasses and certain weeds. However, researches are wanting for generating more information.

5. Waste paper and cotton cloth etc. These are decomposable

organic waste. These if are not being recycled for other useful products, can be recycled with vermicomposting.

6. City refuge. City refuge or garbage on daily production basis comprise important items of city factors affecting pollution. Its management (collection and disposal) costs lot due to various factors. Composition of city refuge widely varies. Considerable portion of city refuge can be got sorted and recycled or composted. For composting however, essential requirement is that citizens avoid mixing of toxicants, i.e., sorting or separation commences right at generation or producer,s level. Simple solution is that more awareness is developed with appropriate development of disposal systems to check mixing of decomposable, recyclable, non-cyclable, and chemical contaminated city refuge including sewage.

Most of household as kitchen waste with little manipulation can be vermicomposted. The compost can be variably used. This concept if well practiced and managed would manifold reduce over all generation of city refuge.

It is high time that developed and developing countries start visualising importance of above stated points. Certain examples need reiteration. In some developed countries like U.S.A., Germany and Japan, many house hold articles have labels Recyclable or Non Recyclable or Green. Sewage systems are separately engineered to reduce or avoid contamination with chemicals. This is important as some newer or even old ones are now known to be problematic.

7. Biogas slurry. After recovery of biogas, if not required for agricultural use, viz., in conventional composting can be used for vermicomposting.

8. Industrial wastes. Some types of Industrial wastes, viz., waste from food processing, distillery etc. can also be used in vermiculture with some manipulations in regard to vermicompostable conditions.

PRELIMINARY TREATMENT OF COMPOSTING MATERIAL

Organic wastes that are decomposable are to be subjected to certain preliminary treatments. This is to enhance vermi-compostability and its efficiency.

First step is proper collection, sorting or separation of compos_ table, non-compostable and non-biodegradables like plastics, stone, glass, ceramics and metals. wastes heavily contaminated with chemicals should be separated as most would kill earthworms. Even in kitchen wastes, heavily spicy wastes should be got separated. Remaining matter selected for composting should be heaped and large lumps should be broken. At this stage little awareness of points on decomposition processes discussed in succeeding pages is desirable.

Separated matter, if possible be spread in a layer upto 1 foot and be exposed to sun for a day also. This kills many unwanted organisms. It also removes foul smell. This is always not possible in present day city living where open space is limiting factor. In such situations mixing of daily organic waste produce be done with somewhat pretreated leaf litter in approximate ratio ranging from 10 to 40% of the waste to be vermicomposted.

Pre-treatment of leaf litter and agricultural waste is also very simple. These should be got heaped on ground and exposed to sun. Heaps should then be beaten with some stick or bamboo to break into smaller pieces. Materials like crop plant stems and bagasse etc. are required to be cut into smaller pieces for enhancing decomposition and vermicomposting processes. Non-marketable vegetable produce, i.e., one infected with some insect pests, require some chemical treatment. This is because some insect pest life stages continue in wastes and hinder earthworm activities, i.e. vermicompostability. Such hindering insect activities are varied, viz., webbing, lumping and at times some insect larval stages due to unknown factors reduce feeding in earthworms. Common example to these is insect pest popularly known as Brinjal Borers which effect several vegetables.

For controlling insect pests of non-marketable vegetable wastes is to chop waste into smaller pieces up to 4" size and spread over ground. This layer be then sprayed with 47o aqueous solution of some Neem insecticidal formulation. This would gradually kill insect pests stages without making waste unfit for vermicomposting. Neem formulation can also be prepared by collecting Neem fruits, drying and taking out seed kernel as we take out almonds by removing hard outer covering. 20-25 gm Neem seed kernel be wrapped in a cloth over night and squeezed in half liter of water with repeated dipping and squeezing with turning movements. Solution so obtained is insufficient concentration to kill most insect pests stages.

For simplification we prefer to designate vermiculture and vermicomposting only with two names, small scale or indoor and large scale or outdoor vermicomposting.

SMALL SCALE OR INDOOR VERMICOMPOSTING

This is conducted in covered areas (with a shade). It is preferred and recommended for areas where protection from climatic adversaries like high rains, prolonged spells of high or low temperatures (from less than 10^0 F to more than 45^0F) and predators like ants, rodents and large insectivorous birds are abundant.

Indoor culture and composting can be practiced in abandoned cattle sheds, poultry sheds back yards or underneath temporary thatched sheds. Thatching material should be locally available material as drawn from agricultural wastes or material of non-marketable grade from Social Forestry programme, viz., stem straws from subabool plants and straw of harvested crop plants.

Small scale indoor vermiculture and composting is easy and can be adopted with any of the six diagrammatic illustrations and schemes described in succeeding pages.

LARGE SCALE OR OUTDOOR VEITMICOMPOSTING

Large scale vermicomposting is of two types, (1) simple promotion of vermic activity in fallow fields after harvesting crop(s), and (2) large scale commercialized vermicomposting in open heaps as shown in scheme 6. It is, therefore, not being described here.

Large or small quantities of plant wastes to be vermicomposted, after pre-treatment be heaped and mixed with small quantities of mature cow dung manure (FYM). Roughly 1/2 kg FYM for every 10-20 kg of plant waste is required. This is only to give bacterial inoculum for enhancing decomposition process and eventual faster vermi-composting. These heaps be sprinkled with little water (roughly 5 ltrs per 20 kg wastes) and covered with a hesian cloth or left on ground. Whole waste heap be kept moist for 3-7 days and periodically it is upturned and mixed. In fact only after 2-7 weeks heap comes in a stage that vermicomposting is fast. After such treatment waste is ready for vermicomposting. Waste heaps can be vermicomposted even without mixing of FYM but process would not be fast.

OTHER TYPES OF VERMICOMPOSTING

There can be several names designated to vermicomposting. Basically all are same but vary only with extent of waste mass to be vermicomposted and composting container(s). Some even tag with names of mechanical structures used as composting containers, viz., vermi-excelerator etc. This is common with some commercial establishments in U.S.A. and Europe.

In process of simple promotion of vermic activity, in fallow fields ridges are to be raised by 8-10" and whole area is divided into smaller plots in accordance with existing ground level. Partly digested(= decomposed) wastes, largely-comprising agricultural wastes are somewhat uniformly spread over plots. It is mulched, watered to keep moist and covered with other decomposable organic wastes like weeds and leaf litter etc. This helps conservation of moisture and promotes species of earthworms are introduced along with a thin layer of somewhat mature cow dung manure. The process is allowed to continue for 3-4 or more months, but periodic light irrigation or moistening is continued.

Prolonged 'vermic activity' on fallow fields made as above, gradually provides all natural benefits due to earthworms. Worm activities conditions soil, helps in formation of humus, improves soil aeration, percolation infiltration and nutrients etc. All these eventually promotes soil health management and yields of plants. Thus the process is important integral of organic farming. In fact process is important for soil reclamation etc., viz., under jhum or shifting cultivation.

In some parts of America, such natural vermicomposting, is practiced. In India, with average small land holdings, this may not be possible, but at community level, viz., for Panchayati Lands (Like Pastures), this is certainly possible. Likewise for Forestry plantation, it deserves trials.

REQUIREMENTS FOR VERMICOMPOSTING

As discussed in proceeding pages, there is no special material requirement(s) for vermiculture and vermicomposting. Still for planning any programme certain scientific points are required to be kept in mind for optimal result (composting). These have been termed here as 'requirements for vermicomposted and number of live earthworms we want to culture.

1. Container. Vermin-composting container can be of any shape or size and requirement depends upon quantity of waste to be composted and number of live earthworms we want to culture.

On average, 2000 adult earthworms can be maintained in containers of 1m^2 dimension. These with appropriate conditioning of composting material work would convert approximately 200 kgs wastes every month. Interestingly, roughly in a container of 2.23 x 2.23 mtr it is possible to maintain 10 kgs of earthworms to have an expected conversion rate of approximately 1 ton per month. However, to have optimal conversion normally only upper 9-12" layer is composted. This should be softly scrapped off.

2. Bedding material. This is the lower most layer of earthworm feed substrate that is required to be vermicomposted. For this any biodegradable matter is used like banana stem peels, coir pith, coconut leaves, sugarcane trash, stems of crops, grasses or husk. Waste or discarded cattle feed can also be used for bedding.

3. Moisture content. Moisture content during vermicomposting should be maintained between 3040 per cent. If moisture is high, dry cow dung manure or leaf litter should be mixed with substrate.

4. Temperature. Requirement for optimal results is 20-30^{0}C. However, survival of earthworms is even at lower temperatures and upto 48^{0}C air temperature. Obviously with little provision of shade, temperature within worm feed substrate (material to be vermicomposted) can be reduced. For this it is desirable that substrate should not be tightly packed in containers.

5. pH. pH of substrate should be between 6.8 to7.S. For nonscientists; measurement of pH, can be done with use of pH paper strips available from chemists. These pH indicator strips are dipped in soil solution (soil and distilled water), colour changes and which is matched with colour chart on cover of strip booklet. 7.0 pH indicates its neutral condition, less than 7 indicates its acidic nature and greater than 7 indicates alkaline condition of soil.

6. Cover of feed substrates. This is required for reducing moisture loss and also save worms from extra movements (outside substrate) or from predators like ants. Moist gunny bag covers also help in conservation of moisture.

7. Selection of right type of Worm species. This is important to have optimal results. Relevant points have already been discussed in preceding pages. Few basic points need reiteration. In general, species to be used for vermicomposting should have good survival in high organic matter, conversion rate should be high in terms of growth rate of earthworms (protein conversion), high temperature tolerance, and pressure/ as well have high reproduction rate.

FEED FOR EARTHWORMS

Earthworms are consumer of decomposing organic matter. So variety of matters as earthworm feed can be used. However, efficiency and survival would depend upon various points that have already been discussed at length in preceding pa8es. Broadly under mentioned combinations are good for most species of earthworms used in vermiculture and vermicomposting. However, exact proportions may have to be adjusted with little pre-testing.

1. Old cow dung (minimum 7 days);
2. Cow dung + sheep droppings + horse dung mixed in equal quantities;
3. Cow dung or mixed dung + Rice polish in ratio of 10 : 3;
4. Cow dung or mixed dung + wheat bran in ratio of 10 : 3;
5. Cow dung or mixed dung + Gram bran in ratio of 10 : 3;
6. Cow dung or mixed dung + Vegetable waste in ratio of 10 : 3;
7. Cow dung or mixed dung + Agricultural waste in ratio of 10:3;
8. Cow dung or mixed dung + Sewage sludge in ratio of 10 ; 3;

9. Cow dung or mixed dung + Kitchen wastes in ratio of 10 : 3;

10. cow dung or mixed dung + semi crushed leaf litter in above ratios;

11. Biogas slurry with some leaf litter and some soil sprinkled over;

12. only agricultural waste or sewage sludge or kitchen waste or leaf litter or their mixtures;

13. Standard diet given by Prof. R.D. Kale comprises cow dung or mixed dung + Gram bran + Wheat bran + Vegetable wastes in , ratios of 10 : 1 : 1 : 1 + Some powdered egg shell.

Any of the above material combinations can be taken up. These are thoroughly mixed with upturning with a spade to mix. Heaps are watered and kept in shade for partial digestion for 2 to 3 weeks. Then it is beaten to break lumps, i,e, to make it some-what powdery and used as feed for earthworms.

In addition to above numerous other combinations have been tried and or can be tried with care. For example de-oiled Neem kernel cake can also be used after it has been partially matured or decomposed. Fresh de-oiled Neem cake has been reported to reduce reproduction and so does sheep dung. Vermi-stabilization is also delayed in some combinations. For all such problems, best is to subject it to initial pretesting.

Some mushroom cultivators are vermicomposting "spent" or used substrates after mushroom harvest for vermicomposting. Treatments of this material too is same and is to be mixed with any of the feed materials.

VERMICOMPOSTING SCHEMES

Depending upon the availability of requirements any of the following six schemes can be adopted for vermicomposting. For the sake of convenience whole process is divided into two steps, namely,

(1) maintenance of vermicomposting bed, and (2) collection of vermicompost.

MAINTENANCE OF VERMICOMPOSTING BEDS

Preparation of vermicomposting beds after necessary pre-tests and selection of suitable species is done. This is in fact one of the most important aspects of whole programme. Steps for the described six schemes are as under :

1. Available container is to be selected, and cleaned for removing unwanted chemical or other material if any present. At bottom a 2 to 3 inches thick layer of any biodegradable matter is laid. Over this layer, 2 to 3" thick layer of partly digested and powdered cow dung is put. The whole material in bedding is sufficiently moistened (up to 40% moisture) and then live earthworms are gently released over it. A box of 1 m x 1 m x 0.5 m high can hold around i000 to 1500 worms which require about 30 to 40 kgs of whole organic matter. On top any of the earthworm feed matter is put in 7 to 9 inches thick layer and watered. Feed layer should be put in when previous layer disappears, i.e., is converted into vermi-

compost. (In fact vermi-compost should be periodically removed from top). Finally on top a moist gunny bag be spread.

2. Dung and other feed materials are thoroughly mixed, watered and is subjected to partial digestion for 2 to 3 weeks in layer of 30 cms thick. On this earthworms are released.

3. In container bottom, a 2 cm thick layer of fine sand is laid. over this a 2-3 inches thick layer of saw dust is laid which is covered with a thin layer of garden soil. Thickness of each layer can be 2 to 3 inches. Whole is watered and earthworms are released. The material is then covered with a moist gunny bag. This process for vermicomposting is slow as saw dust takes time to partly decompose. However, can be useful for areas saw dust is available.

Responses of various saw dusts have not yet been studied and comprise interesting lines of researches.

4. In case suitable container is not available, vermicomposting can be done on ground. For this ground is leveled, over this, soil free of stones, glass or any form of chemical contaminants is plastered and a manageable sized platform is made. Depending upon availability of space and compostable organic waste, the size of platform, is made. It could be 3 feet wide and 20-50 feet long. Over the platform a feed layer (9") partly digested feed is spread. After watering, live earthworms are introduced. Finally more layers of pre-treated waste matter can also be heaped. The whole is covered with a hesian cloth.

If platforms are already under thatched roof shade, heaps can also be covered with broad leaves locally available. These however have to be periodically replaced as are decomposed and eaten up by worms.

5. In another variation, heaps in semicircle can be made in same manner as in previous one. Composting can be done. Only advantage is that sufficiently moist dung does not spread if plastering with organic waste and cow dung has been done well.

6. Rectangular or circular pits of dimension per requirement can be made and vermicomposting process can be taken up by any of the described methods. In this, however, packing or layering of the material has to be loose and not compacted. To a certain extent common earthworm, Metaphire posthuma can also be used in this type of composting.

VERMICOMPOSTING EFFICIENCY

In general a bed of 1 m x 1 m x 0.3 m requires 30 to 40 kg of bedding and feed material. This can support 1000 to 1500 earthworms which would multiply and compost the matter from upper layers. So upper layers of organic matter should be periodically replenished. Many experts opine that from top layer, accumulating casts should be periodically removed as it reduces vermic activity or reproduction. Whole organic matter gradually gets decomposed with exhilirations by vermic activities and matter is converted into vermicompost. Vermicompost is reported to contain 5 times more nitrogen, seven times more phosphorus, 11 times more potassium,2 times more magnesium and calcium. These are in a form that is readily assimiable to plants.

It has already been discussed that decomposition of organic waste depends upon several factors. Earthworm activities like burrowing, feeding and defecating (casting) exhilirate process of decomposition. So larger the number of earthworms present in an appropriate medium and conditions, faster would be vermicomposting. Thus initially, i.e., immediately after introduction of worms, first lot of vermicompost is ready within 60-70 days. Gradually with bacterial decomposition leading to breaking of larger masses and increase in numbers of worms, vermicompost is ready in 30-40 days only. According to available extrapolative estimates, 1 kg of earthworms (i.e., nearly 1000 adult Eugenia species worms) would produce 10 kg casts in 60-20 days.

COLLECTION OF VERMICOMPOST

When vermicompost and vermicasting are ready for collection, top layers appear somewhat dark brown, granular as if used dry tea leaves have been spread over the layer. Watering should then be stopped for 2-3 days and gently-compost should be scrapped from top layers or to a depth, it appears vermi composted. This should then be removed to a side and left undisturbed for 6-24 hours. If there are adult worms present these would move down or away from the composted material.

The vermicompost should be stocked separately in bags. Some cocoons invariably go along with the compost and would lead to natural dispersal of earthworms. To some extent this amounts to a loss to vermiculturists as his worms pass to others without extra returns. For reducing this some persons sun-dry the vermicompost for killing freshly emerging cocoons. This, however, reduces nitrogen contents of compost and does not always kill all the emerging earthworms. Some commercial producers try to sieve out cocoons from the vermicompost. This too is always not sure method of removing cocoons. Suggested mesh size for removing cocoons in 2 mm galvanised mesh.

After collection of compost from top layers, feed material is again replenished and composting; process is rescheduled. After 2-3 months checking is made to see the condition of bedding material and growth rate of earthworms. Normally reproduction of earthworms goes on, but goes down after 9 months. Then mature or old worms should be removed.

From heaps, mature earthworms are easily removed by upturning the whole heap and leaving it for 6-12 hrs. All mature worms go down and organic waste is removed from top. So removed earthworms can be marketed to other vermiculturists or for animal feed preparation.

Collected vermicomposted and casts, if in bulk, can be stocked on ground under shade. For commercialization, vermicompost should be packed in plastic bags or hesian hags of marketable quantity, i.e., small or big packings.

Pricing of vermicompost can be done according to wages put in man hours n i.e., 8 hours per day, plus input costs; material, infrastructure, transportation and miscellaneous. Expenditures incurred on development of infra-structure has to be recovered, but it should be in manner that marketable cost remain competitive and does generates subsistence income to producer. Technically, as yet, Economists have not paid any attention to these aspects. Some prices have been indicated in preceding pages" In Delhi, price fluctuate @ Rs. 2 to 10 per kg of vermicompost and depends upon demand, marketing skill of producer and business area. The later, largely depends upon extent of awareness in masses. This means extension services too need development.

TRANSPORTATION OF LIVE WORMS

With gradual development and functioning of vermicomposting beds, or tanks, a stage is attained when surplus numbers of earthworms are produced. These can be sold to other vermiculturists and for various other usages like areas ranging from export potentials to local demands have already been indicated in preceding pages. In such situations, needs of transporting live earthworms arises.

Transportation of live earthworms is very simple and easy. Cocoons are to be hand picked with brush and collected in some container having same feed material with some moisture. Feed material should be approximately ½ gm per cocoon for every 24 hrs of transportation journey period. Cocoons can be gently packed in any clean perforated container, viz., softly put in muslin bag and which is put in any other plastic jar having perforated lid for aeration. Final postal packing or Air Freight Packing should also be perforated.

Live earthworms are also similarly packed with moist feed substrate in any plastic jar with perforated lid. Feed substrate quantity should be roughly 1.5 gm per individual per 24 hrs of transportation journey. Container space should be roughly ½ sq. inch per individuals. Roughly 1 ltr capacity jar is sufficient for approximately 200-500 live earthworms for short journeys. For local transportation, live earthworms with feed substrates can be put in clean empty bags and transported.

MARKETING OUTLETS

With increasing awareness" demands for live earthworms and vermicompost is developing fast. Demands are expected from hobbyist to Institutional levels, also from Horticulturists Agriculturists and from others like Industrial Establishments having large land holdings but generating decomposable organic waste. For all these producers have to find out demands if any. Unfortunately as yet no centralized or state level organization has been formulated to look into these aspects. These deserve attention from various angles.

APPLICATION OF VERMICOMPOST

Broadly vermicompost application is to be done in same manner as conventional Farm Yard Manure is applied. For various usages, vermicompost application can be done in undermentioned manner.

FLOWER OR GARDEN POTS

Make a 2-3" pit around plant ensuring that roots are not cut and fill vermicompost around it. Cover compost with ranked over soil and water.

For preparation of Garden pot soil, basic preparations are same. Only 10-40 parts vermicompost can be mixed in soil before filling pots for transplanting seedlings" Succeeding applications would be same as conventionally done. Some experts even opine that 20-30% recommended dose of chemical fertilizers be substituted with vermicompost.

Seed bed preparations can also be done with simple addition of vermicompost in conventional manner.

IN HORTICULTURE

In horticultural plants, vermicompost application is preferred and is applied by mixing equal quantity of cow dung manure. Application quantity depends upon age and size of plant. Method involves preparation of a ring around plant base of ½ to 1 feet depth and 1 to 2 feet wide. In this ring, mixture of vermicompost and Farm Yard or cow dung manure is filled. Over this a thin layer of soil is put and finally covered with organic matter comprising dry leaves, weeds (minus seeds), husk, coir or even old hessian. This process completes important step o('mulching' and then watering should be done. Generally application can be repeated every month or at conventional periodicity.

Above method can also be tried by hobbyists for kitchen or in "Terrace' Gardens for Vermicompost application around flower, fruit and vegetable plants in homes.

IN AGRICLTURE

Utilization of vermicompost in Agriculture has so far been limited due to low level production of ve4micompost" However, first application at seedling stage, mixed with FYM in equal proportion may be useful. Estimated dosage is around 5 tons/ha. Second application may be repeated after one month.

Though some experimental data of small plots has been reported, yet large scale trials are wanting

CONCLUSION

Vermitechnology utilization is simple, highly useful and economic in numerous perspectives.