CHAPTER – 1
INTRODUCTION
1. INTRODUCTION

Energy transformations in the living systems can be ascertained at diverse levels; namely, molecular, cellular, organismic and ecosystem/population levels Muthukrishnan and Pandian (1987). In reality, the bioenergetic subject involves basic thermodynamic laws (Haynie, 2001) i.e., energy can neither be created nor destroyed, although it may be inter converted between different forms (Frayn, 1996) and the energy transformations cannot occur spontaneously unless there is degradation of energy from a nonrandom to a random form (Phillipson, 1966).

The study of bioenergetics is relevant for both basic sciences as well as applied fields and also to assess the environmental impact on the biological organisms. Hence the field of "Bioenergetics and Growth" presents an interaction of research on the energetic efficiencies of animals with its habit and habitat as ecological energetics and their reliance in animal husbandry, aquaculture, apiculture, sericulture etc as applied biological components.

A treatise on "Animal Energetics" by Pandian and Vernberg (1987), have explicitly written on consumption, digestion,
egestion, excretion, metabolism, respiration, production and growth aspects in different animal phyla pertaining to energy allocations. The manner, in which an animal allocates its energy to various activities, depicts its chances of survival in its habitat. When more resource is allocated to production of an organism, it is likely to increase its capability for survival under unfavorable circumstances, which, is likely to increase its competitive ability.

Information on bioenergetics exist on free-living and parasitic nematodes including bio-chemical pathways of aerobic and anaerobic metabolism (Brand, 1974). The significance of energy flow and nutrient recycling in benthic ecosystems has been well documented for terrestrial, marine and limnic soils (Yeats, 1979; Platt and Warwick, 1980; Prejs, 1977).

Little information is available on the energetics of individual and populations of polychaetes (Knox, 1977 and Humphreys, 1979) though they account for the majority of metazoan biomes in many benthic ecosystems. From the limited data (Calow, 1979b), it appears that although assimilation efficiency and gross growth efficiency ($K_1$) are generally lower for deposit feeders than for suspension feeders or carnivores; net growth efficiency ($K_2$) is similar for all three feeding types. Average net growth efficiency is 47% for carnivores and 32% for deposit
feeders, somewhat lower than average values for other invertebrates.

Oligochaetes are earthworms that live in soil, including superficial litter layers, and in some cases above ground habitats especially in decaying logs, moss chimps and variety of arboreal habitats (Lee, 1983). They find in their habitat the energy, nutrient resources, water and buffered climatic conditions that they need (Lavelle, 1988).

Feeding constraints faced by earthworms are very much dependent on external abiotic parameters and relatively poor nutritive resources in the soil systems, movements in compact soil strata and also unfavorable climatic conditions and ultimately determined by their internal digestive capacity (Lofty, 1974). Satchell (1967) calculated that *Lumbricus terrestris* individuals consume 10% to 30% of their live weight (or about 100 to 120mg) of plant litter per day, which compares with Needham's (1957) figure of 80mg of *Ulmus* leaves per gram fresh weight of the species (8% of life weight) per day.

Many of the smaller species like *Aprrectodesa caliginosa*, *A. rosea* can consume, weight for weight, similar quantities of litter material (Rhee, 1963). The amount of food ingested by the oligochaetes depend on the rate of movement of material
through the alimentary canal under different conditions and the duration of these conditions (Dash et al., 1986). Assimilation rates and assimilation efficiencies are higher for tropical earthworms than temperate species.

Studies on crustaceans have been dealt with a specific component of the total energy budget for an organism i.e., ingestion or respiration. Energy budgets were calculated for the myrid shrimp *Metamysis lepida elongata* using laboratory studies as well as field based data to examine net and gross ecological efficiencies (Clutter and Theilacker, 1971). The energy budgets for individual organisms, different stages and their population studies have been well documented (Vernberg, and Vernberg, 1972; 1975; Wu et al., 1977).

A great deal of work has been carried out in insects. This is due to the impact of useful and harmful insects on man, his crops, and domestic animals. Studies on herbivorous insects (Price, 1975; Schoonhoven, 1977, 1981), carnivorous insects (Molles and Pietruszka, 1983; Malmquist and Sjostrom, 1980), and sanguivorous insects (Friend and Smith, 1977; Langley, 1977) have proved the climatological and physiological dependence of energy budgets. A good amount of information on food and water utilization budgets of the silkworms *Bombyx mori* (Radhakrishna and Delvi, 1987; Hanumanthappa and Delvi,
1989) and on *Philosoma ricae* (Pasha and Delvi, 1989; Radhakrishna et al., 1988) has been provided. Further work by the same team of workers on effect of insecticides (Permethrin, sumithion and tasethion), temperature regimes, water utilization and photo and scot0 periods have been greatly depicted in their complete bioenergetic charts over normal bioenergetic conditions (Delvi, 1983; Naik and Delvi, 1984; 1997; Radhakrishna and Delvi, 1988; Hanumanthappa and Delvi, 1989; Nuzhat and Delvi, 1998a; 1998b; 1999).

Surprisingly, much information is not available on the energetics of individual oligochaete species except for limited studies in population/ecological energetics of the soil inhabitants of the temperate regions (Boltsom and Phillipson, 1976; Lavelle, 1974; Coleman et al., 1976; Coleman and Sasson, 1978; Bouche, 1982; Persson and Lohm, 1977) and tropical ecosystems (Thambi and Dash, 1973; Dash et al., 1974; Dash and Patra, 1977; Dash et al., 1979b; Dash, 1981; 1983; Senapati and Dash, 1981; Bhadauria and Ramakrishnan, 1989; Reddy and Alfred, 1978).

Previous workers have collected bioenergetic data to assess the ecological energetics subjecting the abundantly found soil feeding earthworms and litter feeders during their active periods i.e., mainly during rainy seasons. Most of these categories of
earthworms undergo quiescence/diapause/aestivation under unfavorable conditions namely; dry spell and/or snow fall. The data under such circumstance have not been recorded. Most of the works show incomplete bioenergetic data on life-cycle, feeding regimes, selection of feed during different climatological seasons, effect of seasonal fluctuations (Chauhan, 1980) on feeding patterns, growth and reproduction.

The aim of the present work is to study the energy budget from long time laboratory experiments carried out during rainy, winter and summer seasons on the peregrine (widely distributed) tropical earthworm *Eudrilus eugeniae* (Kinb). The data were recorded from hatchling to extended post reproductive periods on exposure to an agro-industrial refuse, pressmud (from sugar factory) and activated sewage sludge (from urban treatment plant) as modulated feed and on cattle dung as natural diet.

Lee (1985) has summarized the ecological energetics of earthworms under temperate ecosystems and tropical regions based on field observations of soil inhabiting earthworms. However, the existing ecological energetic data cannot be taken as proof to interpret laboratory studies on detritivore/humus forming/organic waste feeding earthworms due to wide variation on their type of habit, habitat and feeding modules. There is a
wide gap that exist between soil feeding (with minimum organic matter content) earthworms and organic waste material feeding (with enriched nitrogenous content) earthworms in their morphological, physiological and behavioral aspects.

Since none of the literatures shows a complete bioenergetic chart for the earthworm, the present work is compared to the basic patterns followed by the insect bioenergetic workers. Extensive research work in different organisms by Kinne (1960) have revealed that conversion of food into body substance and into biologically useful energy as additional, sensitive, parameter for assessing rates and efficiencies of metabolic processes.

Paloheimo and Dickie (1966) have shown that the feeding rates and conversion efficiency estimates are better parameters of metabolic rates. Continuous research work by Delvi and Naik, (1984); Naik and Delvi, (1984); Delvi, (1987); Radhakrishna and Delvi, (1987); Muthukrishnan and Pandian, (1987); Hanumanthappa, (1988); Hanumanthappa and Delvi, (1989); Nuzhat and Delvi, (1998); Pasha and Delvi, (1989), have shown complete bioenergetic data and have compartmentalized assimilation, assimilation rate, assimilation efficiency and growth. Conversion i.e., food converted into body substance, conversion rate, conversion efficiency, gross conversion
efficiency ($K_1$), net conversion efficiency ($K_2$) and metabolism. This data were obtained based on repeated observations on one and the same experimental animal over periods of time. The present research data will be compared with the insect bioenergetics especially of *D. mort* and *P. rictint* (economically important insects).

The study of bioenergetics of compost earthworm *E. eugantae* reared under laboratory conditions will be helpful to understand its contributions at different climatological conditions. This leads to study of metabolic rate for safer conversion of "nature's refuse to natural riches - the vermicompost, earthworms' feces.

1.1. ORIGIN, COMPOSITION & NUTRIENT STATUS OF FEED:

Darwin (1881) showed that earthworms could distinguish readily between different food substances. Worms react to a wide range of chemical stimuli, like alkaloids, polyphenols, phosphoric acid, tartaric acid, oxalic acid and malic acid found in plant materials (Mangold, 1953). Acid sensitive organs that are distributed all over the worm's body are responsible for such reactions (Laverack, 1961) and these organs do not react to sodium chloride, quinine, sucrose, glucose or saccharose.
The feeding habits of different earthworm species influence their effects on litter fragmentation and incorporation into soil. Anecic species such as *Lumbricus terrestris*, incorporate large amounts of organic matter into soil, and are capable of breaking down and feeding on large litter fragments by stripping off smaller particles with their mouthparts. Epigeic species, that reside in surface litter, consume large amounts of litters, but do not incorporate much of it into the mineral soil layers. Endogeic species feed mainly on fragmented organic matter, mixing it thoroughly with mineral soil (Edwards and Bohlen, 1996).

Stabilization of organic wastes from domestic, agricultural and industrial sources through organic waste converting through earthworms' is the best ways and means to abate pollution. Such wastes that were successfully converted include:

Sewage sludge and solids from waste water (Neuhauser et al., 1988); materials from the Brewery (Butt, 1993), distillery sludge (Seenappa et al, 1995), herbal and flower waste from perfume industries (Sunitha and Kale, 1995), processed potato waste (Edwards, 1983a) and paper industries (Butt, 1993; Elvira et al., 1966); Wastes from super markets (Shanthi et al, 1993), municipal wastes (Ferreira and Cruz, 1992; Kale and Sunitha, 1993); wastes from poultry, pigs, cattle, sheep,
goats, horses (Edwards et al., 1985; Edwards, 1988; Murry and Hinckley, 1992; Wong and Griffiths, 1991; Dominguez and Edwards, 1997; Abe et al., 1978; Kale et al., 1982; Hendriksen, 1991, 1995 and 1997; Rodriguez et al., 1996), oil sludges (Loehr et al., 1992; Murgesan and Sukumaran, 1994), small domestic animals such as abbits (Allevi et al., 1987); as well as agricultural (Mba, 1996; Manna et al., 1997 and Cothrel et al., 1997), horticultural residues from dead plants and the mushroom industry, coffee pulp (Edwards, 1988; Orozco et al., 1996).

1.1.1. CATTLE DUNG:

Cattle void about 48% of their food as solid and liquid excreta. The dung is more watery compared to pig/sheep/horse dung, thus require more time for fermentation process. Earthworms, notably detritivores species, play a very important role in the disappearance of organic matter from dung pats (Holter, 1983; Holter and Hendriksen, 1988). The dung contains, as a result of chewing and mastication during digestion, organic particles of many different materials including bacterial cell walls and some bacteria (Soest, 1982).
By the earthworm's intensive activity, the cattle manure decreases to 30% over its initial volume and the produced vermicompost, will have neutral pH, reduction in electrical conductivity, large increases in oxidation potential and significant reduction in water-soluble chemical substances that constitute possible environmental contaminants (Mitchell, 1997). The growth rates of earthworms increase by 148% over 119% by anaerobic biogas slurry (Balasubramanian and Bai, 1995).


Hence, in the present research work, cattle dung was used as the control feed over other experimental feed. Freshly produced, urine free cattle dung manure proved an excellent food source provided it was added in such a way as to prevent the development of anaerobic conditions. Moreover on regular feeding with cattle dung give high growth and reproduction rates (Reinecke and Viljoen, 1990).
According to Kale and Bano (1984), the prevailing temperature conditions in South India remains ideal during most of the year, for the continual activity of *E. eugeniae*. When they were maintained on cattle dung the worms reached sexual maturity between three and seven months with breaks in cocoon production. The reproductive phase lasted longer and there were no mortality observed for one year (Kale et al., 1982). Their age specific survivability, reproductive potentiality and reproductive trend have been well established by Bano and Kale (1987), based on cattle dung diet.

Vermicomposted cattle dung (Sunitha et al, 2001), reveals the following chemical nutrient properties (the values in the bracket represent cattle dung prior to vermi composting):

- **Total Nitrogen** (%) - 2.22 (1.50); **Organic matter** (%) - 57.0 (61.0);
- carbon to nitrogen (C:N ratio) - 14:1 (23:1); **Iron oxide** (ppm) - 595 (458);
- **Calcium oxide** (%) - 2.06 (2.06); **Magnesium oxide** (%) - 1.75 (0.94);
- **Phosphorus pentoxide** - 0.83 (0.81); **Potassium oxide** (%) - 0.83 (0.78) and **sodium** (%) - 0.66 (0.48).
1.1.2. ACTIVATED SEWAGE SLUDGE (DOMESTIC SLUDGE):

Concern about environmental degradation has intensified the search for environmentally acceptable and cost-effective sewage disposal techniques. If sewage water is continually applied to the same soil, the soil at first derives corresponding benefit from the valuable fertilizing ingredients; but after sometime becomes 'sewage sick'. The pores of the soil become choked up by the slimy suspended matter present in sewage. Thus eventually the land rapidly deteriorates (Aikman, 1970).

The solids in sewage constitute one of its major, environmentally damaging ingredients. A large portion of these solids is removed in wastewater treatment and becomes sludge. The disposal or application of raw sludge offers peculiar health and aesthetic problems. This material is odorous, highly biodegradable and bears an array of pathogenic microbes typical of human excreta. The costs of disposal like, trenching, landfill and incineration are exorbitantly high (Colacicco et al., 1978).

Sludge from the treatment of municipal sewage is dried at the treatment plant to yield a material for land disposal that is solid in nature. Typically, this material is the result of both
primary and secondary sewage treatment processes in which the sewage is first settled and then subjected to aerobic biological treatment. Solids from these tow operations are then combined and subjected to aerobic biological treatment. Then, subjected to anaerobic digestion for about 30 to 60 days. After digestion, the sludge is frequently discharged to sand drying beds for de-watering. After drying, the sludge is suitable for land application (Lochs, 1974) which will have little odor and is called as 'activated sewage sludge'.

Research into the use of earthworms to manage sewage sludge began at the state University of New York, Syracuse (Hartenstein, 1978). In this program, Mitchell (1978) demonstrated that aerobic sewage sludge that is ingested and egested as casts by the earthworms is decomposed, and thus stabilized (i.e. render innocuous) about three times as fast as non-ingested sludge; apparently, because of the enhancement of microbial decomposition in the feces. He found that, relative to non-ingested sludge, objectionable odors disappeared much more quickly and there was a marked reduction in populations of the pathogenic bacteria typical of human excreta.

Kaplan (1978) suggested that, mixing sewage sludge and other materials, e.g. Garden wastes, paper pulp sludge or other lignin-rich wastes, and composting the mixture with earthworms might
accelerate their decomposition due to maceration and mixing of such materials into earthworm feces. Neuhauser et al., (1979) called the use of earthworms in sludge management vermicomposting/ vermistabilization (Loehr et al., 1984).

Preliminary studies carried out by Sunitha et al., (1999), has shown that cocopith in different proportion with sewage sludge enhanced the growth and reproduction of the worms *E. eugeniae*. Increased proportion of sewage i.e., time taken for worm cast production increased to 10, 20, 36 and 48 days in the sewage sludge and cocopith feed mixes of 5:1, 15:1, 30:1 and 50:1 respectively. However, increased conversion time enhanced the worms' growth and biomass as well as percent hatchlings.

Neuhauser et al., (1980) has reported the reaching of carrying capacity for compost earthworms to differ in different feed media in the given space. It ranged between 0.02 and 0.09g/cc, when horse manure was used as feed and the value was much higher for activated sewage sludge.

Vermicomposted sewage sludge reveals (Sunitha et al, 2001), the following chemical nutrient properties (the values in the bracket represent sewage sludge prior to vermicomposting):
Total Nitrogen(%) - 1.68 (2.18); Total organic matter(%) - 34.5 (57.0); C:N ratio - 12:1 (15:1); Iron oxide (ppm) - 857 (714); P₂O₅(%) - 0.63 (1.29); Calcium oxide - 6.96 (13.91); Magnesium oxide - 0.28 (0.85); Potassium oxide - 0.34 (1.28); and Sodium(%) - 1.22 (1.75).

1.1.3. SUGAR FACTORY PRESSMUD (AGRO-INDUSTRIAL):

Pressmud is the organic residue from sugarcane, obtained in the sugar factories. It has been used as an organic amendment to improve the soil texture and nutrient status. Pressmud is available in plenty in different sugar mills in the country. Annually, about 12 million tons of pressmud is generated. For every ton of sugarcane crushed, between 30 to 40Kgs of pressmud is generated (Sunitha et al, 2001).

The interaction between the beneficial microbes and the earthworms contribute to breaking the complex organic forms of pressmud into simpler inorganic forms that are easily absorbed by the plants with high percentages of nitrogen, phosphorus, potash, calcium, magnesium, manganese, zinc and iron. The carbon to nitrogen ratio is narrowed down from 25:1 to 11:1,
thereby, facilitating easy nitrogen availability to plants (Sunitha et al, 2001).

Surprisingly, non-of the literature survey reveals the work pertained to pressamud. However, *E. eugonina* feeds, grows and multiplies very well either fed alone with pressamud or in combination with other organic wastes. Vermicomposted pressamud (Sunitha et al, 2001), has the following chemical nutrient properties (the values in the bracket represents pressamud prior to vermicomposting):

- **Total nitrogen(%)** - 3.15 (3.43)
- **Phosphorus oxide (%)** - 0.97 (1.10)
- **Potassium oxide (%)** - 0.81 (0.75)
- **Calcium oxide (%)** - 3.06 (3.66)
- **Magnesium Oxide (%)** - 0.40 (0.43)
- **Sulfur(%)** - 0.57 (0.69)
- **Iron(ppm)** - 978 (964)
- **Manganese (ppm)** - 1021 (1988)
- **Zinc(ppm)** - 157 (151)
- **Copper(ppm)** - 122 (112)

In earthworms the digestible portion of the consumed food (C) undergoes digestion in the long intestine, the remainder being passed out as feces (F). The digested material, here considered as absorbed material, enters the circulatory system and is then distributed to the body activities. Some portion of the absorbed nitrogenous material is not metabolized is passed on and is lost through excretory organs, the nephredial, as urine (U) consisting mainly of ammonia and urea, through the
nephridiopores on the body surface. The remaining energy is here considered as assimilated material (A) and may be equivalent to the "metabolizable energy" (= net energy, see Klieber, 1961). The coelom of earthworms is a fluid-filled cavity that lies between the intestine and the muscular body wall, and which runs the complete length of the body. At each body segment it opens to exterior by a sphinctered dorsal pore. The coelom acts as a hydraulic skeleton (Cooper and Stain, 1981).

Major part of the absorbed material is exuded or ejected or secreted by the earthworm through dorsal pores as coelomic fluid or mucus, in response to mechanical or chemical irritation, or when subjected to extreme of heat or cold. Its other major contribution is to prevent the animal from desiccation, promoting cutaneous respiration and locomotion. Tropical earthworms respire at a faster rate than those of temperate regions because of higher temperature (Pomerat and Zarrow, 1936).

In the current study, too *E. eugeniae* has been shown to spend more energy for respiration. Since, energy lost for the production of coelomic fluid, urine excretion etc. cannot be separated henceforth it will be pooled together as respiration (R) in the energy budget. While the rest is accumulated and thus growth is resulted (P). A considerable portion of this
accumulated energy is channeled for the production of cocoons/egg cases (P₁). What is left behind in the earthworm, when it dies due to senescence, may be regarded as net growth (P₂). This scheme of energy balance is shown in chart 1. The IBP terminology (Petrusewicz and Macfadyen, 1970) may be written with reference to the earthworm in the following equation:

\[ C = A + Fu, \quad A = P + R, \quad P = E + \Delta B, \]

where,

- \( Fu \) = egesta, feces and urine
- \( A \) = assimilation
- \( \Delta B \) = change in biomass (growth and reproduction)
- \( E \) = elimination (the biomass of individuals that have died or been killed)
- \( R \) = respiration.

To understand growth, one must know the fate of the energy and material in the food it consumes. Thus, growth becomes one of the outcome of the integrated activities of the whole individual; which is dependent on the metabolic state of the individual and on energy expended in maintenance and behavior (Alexander, 1999) as well as on the quantity and quality of the organic waste consumed. Study of h worms' bioenergetics leads to the understanding of how environmental factors and feed habitats affect growth through influences on utilization of food energy.
CHART 1: CATEGORIES OF LOSSES AND USES OF ENERGY OF CONSUMED FOOD MATERIALS.

Food Energy (C)

|feces energy
energy + nephredial excretion
(Pn)

| assimilated
| (A)

| net energy

| respiration (R)
locomotion
mucus or coelomic fluid

| growth (P)

| energy in cocoon production (P₁)
energy at production (P₁)

| energy at death (P₂)

and material in their body. This, being much more than the study of growth, it permits us to evaluate the cost of life under different environmental conditions.

A favorable environment need to be created to permit this balance - a balance maintained under different conditions in different ways. Such studies need to be effectively pursued in the laboratory, to show several touchstones in nature for the biologist with a bioenergetic point of view.

Thus the present work deals with the bioenergetic studies of the tropical, epigeic, compost earthworm *E. eugeniae* from hatchling to the post - reproductive (active) stages. This study has been carried out using agro-industrial refuse - sugar factory pressmud and urban waste - activated sewage sludge; for the maximum utilization of these species for the safer conversion at industrial level through the studies on rates of feeding, assimilation, and conversion, efficiencies of assimilation and conversions as functions of growth and the patterns of energy partitioning.