2. Review of Literature

As India is an agriculture based country, farmers need adequate resources to replenish soil fertility and maintain the productivity of soil. Really, the green revolution has popularized the use of chemical fertilizers to achieve higher productivity. But due to continuous and indiscriminate use of fertilizers, the natural fertility of soil has been lost and this activity has contaminated our soil, water and food. Therefore farmers are in need of search of alternative to replace the chemical fertilizers. In recent years, the use of organic inputs like vermicompost, biofertilizers and biopesticides is becoming popular world over. There is a need of effective technology to deal with disposal of wastes which continues to be a challenge as population increases. Vermicomposting has been identified as one of the potential processes in managing waste, since it is a natural process, cost effective and required only shorter duration. The application of vermicompost helps in increasing the organic matter content of the soil, and maintaining its natural productivity (Sivagama Sundari and Gandhi, 2013).

Recently, Vermicomposting has emerged as an environment friendly technology that uses earthworms as versatile natural bioreactors for effective recycling of organic waste in the soils. It is thus an environmentally acceptable means of converting waste into nutritious comports for crop production (Jagannath Aryal and Anand Shova Tamrakar, 2013). Vermicomposting is a simple biotechnological process of composting in which certain species of earthworms are used to convert the biodegradable solid wastes or organic wastes into a nutrient-rich end product, vermicompost, which is used as a soil conditioner. Now a days, Vermicomposting has become better option of solid waste management among all options because it is a biological process, not associated with any kind of soil or groundwater pollution, no risk of gas leakage, cheaper method, less land requirements, resulting earthworm castings (worm manure) are rich in microbial activity and plant growth regulators, and fortified with pest repellence attributes as well. During Vermicomposting, the important plant nutrients such as N, P, K and Ca are converted into more soluble forms which are easily utilized by plants. Wastes are the misplaced valuable resources, which can be utilized by proper composting. The composted waste, the vertices which has higher
qualities of manure can be used to feed our ‘Nutrient-organic matter-hunger’ soils (Mehta and Karnwal, 2013).

2.1 Hazardous impacts of agrochemicals over environment, soil quality, biodiversity and human health

Agrochemicals which ushered the ‘green revolution’ in the 1950-60’s came as a ‘mixed blessing’ for mankind. It boosted food productivity, but at the cost of environment and society. It dramatically increased the ‘quantity’ of the food produced but decreased its ‘nutritional quality’ and also destroyed the ‘physical, chemical and the biological properties’ of soil over the years of use. It killed the beneficial soil organisms that help in renewing natural fertility. It also impaired the power of ‘biological resistance’ in crops making them more susceptible to pests and diseases. Over the years it has worked like a ‘slow poison’ for the farm soil and the society. The excessive use of ‘nitrogenous fertilizer’ (urea) has also led to increase the level of ‘inorganic nitrogen’ content in groundwater (through leaching effects) and in the human food with grave consequences of health hazards. Chemically grown foods have adversely affected human health all over the world. According to UNEP and WHO about 25 million farmers and agricultural workers are poisoned by pesticides every year and nearly 3 million people suffer from ‘acute pesticide poisoning’ and some 10 to 20 thousand people die every year from it in both the developed and the developing countries (UNEP Report, 2001).

Adverse effects of agro-chemicals on the health of farmers using them and the society consuming the chemically grown food have now started to become more evident all over the world. Farmers and agricultural labours complain of headaches, dizziness, vomiting, nausea, difficulty in breathing, sensitivity to light, nails turning black and dropping off and chronic itching. WHO classified the common Class I pesticides ‘methyl parathion’, ‘monocrotophos’ and ‘methamidophos’ as ‘extremely hazardous’. Millions of people suffer from ‘acute pesticide poisoning’ and thousands die every year from it in the developing countries. US scientists predict that up to 20,000 Americans die of cancer, each year, due to the low levels of ‘residual pesticides’ in the chemically grown food (UNEP Report, 1992).

Agricultural practices determine the level of food production and, to a great extent, the state of global environment (Tilman et al., 2002). About half of usable land is already in
pastoral or intensive agriculture (Tilman et al., 2001). In addition to causing loss of natural ecosystems, agriculture adds globally significant and environmentally detrimental amounts of nitrogen and phosphorus to terrestrial ecosystems (Vitousek et al., 1997; Carpenter et al., 1998) at rates that may triple if past practices are continued to achieve another doubling in food production (Cassman and Pingali, 1995; Tilman et al., 2001).

Modern agricultural systems rely upon the massive application of N fertilizers, which amounts to approximately 85 million metric tons per annum worldwide (Crawford and Glass, 1998). N and P leakage from agricultural systems causes major environmental problems (Vitousek et al., 1997; Carpenter et al., 1998). Today only 30 to 50% of applied nitrogenous fertilizer (Smil, 1999) and 45% of phosphorous fertilizer is taken up by crops (Smil, 1999). A large portion of inorganic phosphates used as fertilizers is immobilized after application and becomes unavailable to plants (Dey, 1988; Singh and Kapoor, 1994; Tilman et al., 2002) and moreover increased application of nitrogen and phosphorous fertilizers are unlikely to be effective at increasing yields because of diminishing returns (Tilman et al., 2002). Increase in N and P fertilizers could cause significant losses to biodiversity (Krebs et al., 1999), as well as marked changes in the composition and functioning of both terrestrial and aquatic ecosystems (Vitousek et al., 1997; Carpenter et al., 1998).

Developments in modern agriculture have led to doubts regarding the long-term viability of current production systems. These developments include heavy reliance on chemical fertilizers and pesticides, the destruction of wild life habitats, environmental pollution and risks to human health (Rigby et al., 2001; Bolan et al., 2004). During the first 35 years of the green revolution, global grain production doubled, greatly reducing food shortages, but at high environmental costs (Conway, 1997; Vitousek et al., 1997; Carpenter et al., 1998; Tilman 1999; Rigby et al., 2001). In addition to its effects on green house gases (Conway, 1997; Matson et al., 1997; Tilman et al., 2002), agriculture affects ecosystems by the use and release of limiting resources that influence ecosystem functioning (N, P and Water), release of pesticides and conversion of natural ecosystems to agriculture (Tilman et al., 2001). More serious matter is that the global cropland, which provides about 99.7% of
human food is shrinking by more than 10 million hectares (almost 37,000 square miles) a year due to soil erosion.

Prolonged exposures to these chemical fertilizers is linked with serious diseases and developmental disorders like Nervous System Disorders, Immune System Suppression, Breast and other Cancers, Reproductive Damages, Impairment of Brain Development in Children and Disruption of Hormonal Systems (Lloyd, 2011). Pesticides have also been considered as potential chemical mutagens as experimental data revealed that various agrochemical ingredients possess mutagenic properties inducing mutations, chromosomal alterations, or DNA damage (Bolognesi, 2003). There have been numerous attempts to predict the environmental impacts of pollutants of soil system, particularly the application of pesticides (Burrows and Edwards, 2002). A large number of studies confirm that pesticides affect the soil microbiota, both in laboratory (Domsch et al., 1980) and field conditions (Elmholt et al., 1989; Ekelund, 1999). Pesticides applied to agricultural lands also affect non-target organisms (Margni et al., 2002; Ibekwe, 2004; Tanu et al., 2004) and contaminate soil and water (Margni et al., 2002; Zhang et al., 2005).

Conventional farming systems are often associated with problems such as nitrate leaching and ground water pollution (Lee and Jose, 2005), degradation of soil structure (Jordahl and Karlen, 1993), decreased surface infiltration of water (Logsdon et al., 1993) and pesticide contamination (Poudel et al., 2002). In addition, these farming systems are also associated with decreased levels of total soil N (Wander et al., 1994; Drinkwater et al., 1998) and total soil C (Wander et al., 1994) overtime. In the highly productive Punjab region of India and Pakistan, the productivity of wheat-rice systems is declining because of declining concentrations of organic matter in the soil and increasing concentrations of salinity in the groundwater as a result of high inorganic fertilization (Murgai et al., 2001).

High concentrations of inorganic N in soil can inhibit N₂ fixation in cyanobacteria and *Azotobacter sp.*, while Gunadi et al. (2002) have shown that the application of inorganic fertilizer to tomato and pepper plots can decrease the numbers of trophic groups of soil arthropods (De Luca et al., 1996). Inadvertent fertilization can cause eutrophication, loss to diversity, dominance by weed species and increased nitrate leaching or NOx fluxes.
Nitrogen fertilization can increase emission of gases that have critical roles in tropospheric chemistry and air pollution (Bolan et al., 2004). Nitrogen oxides (NOx) emitted from agricultural soils and through combustion (Delmas et al., 1997), increase tropospheric ozone, a component of smog that impacts human health, agricultural crops, and natural ecosystems (Tilman et al., 2002). Nitrogen inputs to agricultural systems also contribute to emissions of the greenhouse gas nitrous oxide (Tilman et al., 2002; Bolan et al., 2004).

Studies indicate that there is significant amount of ‘residual pesticides’ contaminating our food stuff long after they are taken away from farms for human consumption. Vegetable samples were contaminated 100% with HCH and 50% with DDT. Bhatnager and Sharma (1993) reported pesticide residues in wheat flour samples. Contamination with HCH was 70%, Heptachlor 2 was 45%, Aldrin 45% and DDT 91%. 60% of water samples were found to be contaminated with Aldrin and 50% with DDT. They were all higher than permissible limits prescribed by WHO. A study made by the Society for Research and Initiative for Sustainable Technologies and Institutions (SRISTI), Ahmedabad, India, to analyse the residual pesticide in soils of croplands of Gujarat found that 41 out of 70 samples contained insecticidal residues of Phosphamidon, DDVP, Methyl parathion, Malathion, Chlorpyriphos and three different pyrethroids (Sinha et al., 2009c). Rao (1993) also reported residues of pesticides in meat, fish, eggs, butter, milk including in mother’s milk and human fat in India. The contamination was 100% with HCH, 69% with DDT and 43% with aldrin. In human fat DDT residue ranged from 1.8 ppm in Lucknow to 22.4 ppm in Ahmedabad; HCH ranged from 1.6 ppm in Bombay to 7 ppm in Bangalore.

2.2 Organic farming: A Boom to Mankind

The term organic farming was coined by Lord Northbourne in his book *Look to the Land*. From his conception of the farm as organism, he described a holistic, ecologically balanced approach to farming. The global movement for ‘Organic Farming’ is directed towards the production of biological based fertilizers (bio-fertilizers) and bio-control of pests and diseases (bio-pesticides) with restoration of biologically active ‘disease-suppressive’ fertile soils (with beneficial microbes and nematodes) that can also ‘protect plant health’ while promoting growth. To the maximum extent feasible, organic farming systems rely on
crop rotations, crop residues, animal manure, legumes, green manure, off-farm organic wastes, and measures of biological pest control to maintain soil productivity and tilth, to supply plant nutrients and to control insects, weeds and other pests. Therefore, organic farming is best defined by its principal ideological background based on the concept of the farm as an organism in which all components - soil, plant and animals - interact to maintain a stable whole (Lampkin et al., 1999).

Scofield (1986) stresses that organic farming does not simply refer to the use of living materials, but emphasizes the concept of wholeness, implying the systematic connexion or co-ordination of parts in one whole. As Scofield points out, the concerns that motivated the early exponents of organic farming are still very much part of the current debates over agricultural sustainability, including issues of soil health and structure, the exhaustible nature of artificial fertilizers and human health.

There are, as with sustainable agriculture, a variety of definitions of organic farming. Mannion (1995) refers to it as a holistic view of agriculture that aims to reflect the profound interrelationship that exists between farm biota, its production and the overall environment. Northbourne (1940), the person credited with first using the term organic farming, advocated a society made up of small, self-contained units, a view that has a strong role in modern environmental movements, where there is often a rejection of large impersonal units of production, where both people and nature are viewed as being subordinated to the machine or corporate identity. This rejection of the concentration of specialized production in fewer, larger units was most famously articulated in recent years by Schumacher (1973) and in Small is Beautiful (Scofield, 1986).

In 1980, the USDA released a landmark report of organic farming. The report defined organic farming as a production system, which avoids or largely excludes the use of synthetic organic fertilizers, pesticides, growth regulators and livestock feed additives. Organic farming systems largely depends on crop rotations, crop residues, animal manures, green manures, off-farm organic wastes, mechanical cultivation, mineral bearing rocks and aspects of biological control to maintain soil productivity, supply plant nutrients and to control insects, pathogens and weeds (Sharma, 2006).
Organic farming has given meaning promptly in recent years and is seen as a sustainable alternative to hazardous system of agriculture triggered over the last 50 years (Stockdale et al., 2001). The principles of organic agriculture are wide ranging which include concerns for safe food production in the environment (Browne et al., 2000; Williams and Hammit, 2001; Gosling and Shepherd, 2005), for animal welfare and for issues of social justice (Browne et al., 2000). Organic farming, avoiding the use of synthetic fertilizers and pesticides (Reganold, 1989; Poudel et al., 2002), has become a regular movement as manifested by a still increasing average of agricultural land managed according to national or international standards and regulations (Schjonning et al., 2002).

The disease suppressive soils were first described in the late 1800s (Huber and Schneider, 1982). The basic requirement in organic farming is to increase input use efficiency at each step of the farm operations. This is achieved partly through reducing losses and adoption of new technologies for enrichment of nutrient content in manure. Organic in agriculture is a labeling term that denotes products that have been produced in accordance with certain standards during food production, handling, processing and marketing stages, and certified by a duly constituted certification body.

The impact of organic culture on natural resources favors interactions within the agro-ecosystem, which are vital for both agricultural production and nature conservation. Ecological services derived include soil forming and conditioning, soil stabilization, waste recycling, carbon sequestration, nutrient cycling, predation, pollination and habitats (IFOAM, 1998). In recent years, there is a lot of debate between the proponents of organic farming and a section of the community who questioned the scientific validity and feasibility of organic farming (Chhokar, 2003).

Organic farming systems rely on the management of soil organic matter to enhance the chemical, biological and physical properties of soil. One of the basic principles of soil fertility management in organic systems is that plant nutrition depends on ‘biologically - derived nutrients instead of using readily soluble forms of nutrients; less available forms of nutrients such as those in bulky organic materials are used. This requires release of nutrients to the plant via the activity of soil microbes and soil animals. Improved
soil biological activity is known to play a key role in suppressing weeds, pests and diseases (IFOAM, 1998).

Organic farmers have long maintained that synthetic fertilizers and pesticides increase crop susceptibility to pests (Yepsen, 1976). Research substantiates some of these claims. Organic crops have been shown to be more tolerant as well as resistant to insect attack (Lotter et al., 1999). Soil-borne root diseases are generally less severe on organic farms than conventional farms, while there were no consistent differences in foliar diseases between the systems. The successful control of root diseases in organic systems is likely to be related to the use of long and diverse crop rotations, crop mixtures and regular applications of organic mixtures (Van Bruggen, 1995).

Organic plots showed a more efficient use of available resources by soil organisms as indicated by a lower metabolic quotient for CO₂ and a higher incorporation of ¹⁴C labelled plant material than conventional plots (Fliessbach, 1998; Fliessbach and Mader, 1998); Higher mycorrhization in soil under organic than conventional winter-wheat, cover crops and clover-grass (Mader, 1997; Mader et al., 1993). A higher level of mycorrhizal infection and spores in organic than in conventional grassland soils (Scott et al., 1996); and a higher number and abundance of saprophytic soil fungi with a higher potential of decomposition of organic material (Elmholt 1996; Elmholt and Kjoller, 1989). An improvement of microbial activity correlated with the period the soils were farmed organically; a 20-30% higher microbial biomass than in the conventional systems (Alfoldi, 1995, Mader et al., 1996); A 30-100% higher microbial activity observed in organic plots in comparison to conventional plots (Beck, 1991; Diez et al., 1985; Niederbudde and Flessa (1989) with a particularly positive impact of biodynamic treatments (Mader, 1997); Higher microbial diversity in organic plots than in conventional (Fliessbach, 1998; Fliessbach and Mader, 1997); A number of studies have shown that under drought conditions, crops in organic agriculture systems produce significantly higher yields than comparable agricultural crops (Stanhill, 1990 and Dormaar et al., 1988). As vermicompost conserve soil moisture it reduces the need for irrigation which is generally the source of most salts in soil.

Maidl et al. (1988) and Garcia et al. (1994b) found a higher aggregate stability in organic than in conventional soils. This is a result of more phases of soil recreation, rotations
including clover grass, application of organic manure and flat tillage. A higher percentage of coarse pores on organically farmed soil than in conventionally farmed soils were found by Niederbudde and Flessa (1989). Research results by Diez et al. (1991) showed that compared with conventionally managed soils, the air capacity in the topsoil of organic farms tended to be higher, while it was lower in the subsoil.

In organic farming systems, plant growth results from good rooting conditions, which in turn, depends on the spatial and chemical availability of nutrients resulting from microbial activity and the exchange of water and air. Thus, favorable soil structure is of higher importance in organic farming systems than in conventional ones. Soils with good fertility and good physical properties supporting root growth are essential for sustainable agriculture (Tilman et al., 2002). A fertile soil provides vital nutrients for crop growth, supports a diverse and active biotic community, exhibits a typical soil structure, and facilitates for an undisturbed continuous decomposition (Mader et al., 2002). In the development of sustainable agricultural systems maintenance of soil fertility as a part of “soil health” is a very important goal (Papendick and Parr, 1992; Doran and Safley, 1997). Soil health may be defined as the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environment (Pierzynski et al., 1994) and maintain plant, animal and human health (Haberen, 1992; Doran et al., 1996; Doran and Safely, 1997; Doran and Zeiss, 2000). Soil, water and land management practices are the primary determinants of soil quality and health (Doran, 2001).

Organic matter in soil plays a major role in the development and functioning of terrestrial ecosystems (Smith and Papendick, 1993) and in determining soil quality as it renovates the physical, chemical and biological properties of the soil (Accoe et al., 2004). Organic matter has a positive impact on soil quality, enhancing soil structure and fertility facilitating water infiltration and storage (Brady and Well, 1999). It is well-known that additions of organic matter (OM). Examples manures, composts, above-ground crop residues, or increases in soil organic matter can improve soil properties (Loveland and Webb, 2003). Water-holding capacity of soil can be increased by soil organic
matter (Tilman et al., 2002). Higher efficiency of organic carbon turnover in organic plots which was observed during cultivation with organic farming (Mader et al., 1995).

A study by Reganold et al. (2001) showed that the yield of apples under organic, integrated and conventional production systems was equal. In addition, lower negative environmental impact, higher profitability, and higher fruit quality were demonstrated in the organic farming systems. In another study, vegetable fields under organic production in California produced yields equal to those produced by chemical farming (Drinkwater et al., 1995; Stamatiadis et al., 1999). Drinkwater et al. (1998) have demonstrated that organic management systems, employing animal manure and legumes for nitrogen supply were equally as profitable comparing inputs in the chemical farming. Gosling and Shepherd (2005) from a 15 year study have shown no significant differences in the total soil organic matter or total nitrogen content or between the C: N ratio between the conventionally and organically managed soils.

Mader et al. (2002) after many decades of research have reported that organic farming systems not only enhance soil fertility but also show a higher biodiversity compared to conventional systems. In general, many studies have shown that soils with organically managed farming systems support a higher number of soil microarthropods than in soils from conventional farming systems (Hendrix et al., 1986; Doles et al., 2001; Mader et al., 2002). In addition, other researchers have shown that the detritus-based food web is enhanced by organic systems (Scow et al., 1994; Ferris et al., 1996; Gunapala and Scow, 1998).

Biofertilization, a new approach practiced in several tropical countries by adding organic manures and earthworms to soil have been tested (Ismail, 1997; Senapati et al., 1999; Ansari, 2002). In India, bio-fertilization techniques using tea pruning debris as the organic input increased tea production by more than 200% comparing to controls, and by 80% when compared to mixed organic and inorganic fertilization (Senapati et al., 1999).

In contrast to conventional farming, organic methods supply nitrogen in organic forms that release mineral nitrogen gradually, perhaps better synchronizing nutrient availability with plant needs (Tilman, 1998). In an experiment, at the Rothamsted experimental station in the United Kingdom, wheat yields have averaged 3.45 tons per
hectare on plots receiving complete nitrogen phosphorus and potassium (NPK) fertilizer (Johnson, 1994). Moreover soil organic matter and soil nitrogen levels are reported to have increased by about 120% over 150 years in the manure plots, whereas only 20% was recorded in the plots amended with NPK (Jenkinson et al., 1994; Powlson, 1994).

Many studies under laboratory and field conditions confirmed that plants have access to organic nitrogen sources (Nasholm et al., 2000; Persson and Nasholm, 2002; Jones et al., 2005a, b). Free amino acids represent a significant source of available nitrogen for some plants. Nasholm et al. (2000) and Jones et al. (2005a) suggested that capture of dissolved organic nitrogen by plants may primarily occur in organic rich patches in soil where the concentration levels of free amino acids are usually high. Uptake of free amino acids by the root directly from soil may be a mechanism of capturing nitrogen released from SOM, effectively short-circuiting the reliance of the microbial community to create inorganic nitrogen (Nasholm et al., 2000).

Organic management practices aids in soil health and support major strategies for agricultural sustainability of conserving organic matter (SOM), minimizing erosion, balancing production with environmental needs and making better use of the available renewable resources. Research has clearly demonstrated that initial yield reduction with organic management are more than offset by environmental benefits of soil organic matter buildup and synchronization of nitrogen availability with crop needs during the growing season (Doran, 2001).

Even in bird surveys conducted by the British Trust for Ornithology (BTO, 1995) and by Rhone-Poulenc Agriculture (Rhone-Poulenc, 1997) compared breeding and wintering of birds on 44 organic and conventional farms over a period of three years. The study concluded that breeding densities of sky larks as a key species were significantly higher on organic farms than on conventional ones (British Trust for Ornithology, 1995). This result was corroborated by an intensive follow-up study on a pair of organic and conventional farms over two years. Generally, higher densities of birds, especially in winter, were found on the organic farms (British Trust for Ornithology, 1995).

The environmental costs of conventional agriculture are substantial, and the evidence for significant environmental amelioration via conversion to organic agriculture is
overwhelming (Kler et al., 2001 and 2002). The replacement of external inputs by farm-derived resources normally leads to a reduction in variable input costs under organic management. Expenditure on fertilizers and sprays is substantially lower than in conventional systems in almost all the cases (Offermann and Nieberg, 1999 and Padel and Lampkin, 1994). The economics of organic cotton cultivation over a period of six years indicated that there is a reduction in cost of cultivation and increased gross and net returns comparing to that of conventional cotton cultivation in India (Rajendran et al., 2000). Pest control in organic farming begins by making sensible choices, such as growing crops that are naturally resistant to diseases and pests, or choosing sowing times that prevent pest and disease outbreaks. Careful management in both time and space of planting not only prevents pests, but also increases population of natural predators that can contribute to control of insects, diseases and weeds (FAO, 2003).

Considering the potential environmental benefits of organic production and its compatibility with integrated agricultural approaches to rural development, organic agriculture may be considered as a development vehicle for developing countries like India, in particular. In India only 30 % of total cultivable area is covered with fertilizers where irrigation facilities are available and in the remaining 70 % of arable land, which is mainly rain-fed, negligible amount of fertilizers is being used. Farmers in these areas often use organic manure as a source of nutrients that are readily available either in their own farm or in their locality. The northeastern region of India provides considerable opportunity for organic farming due to least utilization of chemical inputs. It is estimated that 18 million hectare of such land is available in the north east which can be exploited for organic production. India with its rich resources of agricultural knowledge have the potential to grow crops organically and emerge as a major supplier of organic products in the world’s organic market (Organic farming in India, Eximbank report, 2002).

Farmers at Phaltan in Satara district of Maharashtra, India, applied live earthworms to their sugarcane crop grown on saline soils irrigated by saline ground water. The yield was 125 tons/ha of sugarcane and there was marked improvement in soil chemistry. Within a year there was 37% more nitrogen, 66% more phosphates and 10% more potash. The chloride content was less by 46%. In another study there was good production of potato (Solanum
*tuberosum* by application of vermicompost in a reclaimed sodic soil in India. The sodicity (ESP) of the soil was also reduced from initial 96.74 to 73.68 in just about 12 weeks. The average available nitrogen (N) content of the soil increased from initial 336.00 kg/ha to 829.33 kg/ha (Sinha *et al*., 2009a).

There has been lot of debate in recent years about the feasibility of organic farming under Indian soils (Chhonkar *et al*., 2003 and Tiwari *et al*., 2005). The most debated questions related to organic farming include its production potential, economic feasibility and the possible environmental benefits like improved soil quality and health (Ramesh *et al*., 2005). Unlike Europe and USA, very few long-term organic farming experiments are available in India (these were initiated only recently by Indian Council of Agricultural Research (ICAR) in the last 4-5 years which could answer our question scientifically (Stanhill, 1990 and Watson *et al*., 2008). Application of organic manure is the only option to improve soil organic carbon for sustenance of soil quality and future agricultural productivity (Katyal, 2000). In general organic farming by use of composts has several virtues and values. Use of vermicompost still has greater significance as it is 5-7 times more powerful than all the conventionally produced composts. Moreover, its use in farm soil eventually leads to generation of huge population of ‘earthworms’ from their cocoons in the vermicompost. Earthworms are great soil and environmental managers and add further to the agronomic, social, economic and environmental values of organic farming (Sinha *et al*., 2011b).

### 2.3 Organic farming by vermicompost and chemical fertilizers

Chemical agriculture is proving destructive in every way agronomically, socially, economically and environmentally. Organic farming by vermiculture will be supportive in every way. Vermicompost works as a slow-release fertilizer whereas chemical fertilizers release their nutrients rather quickly in soil and soon get depleted. Significant amount of chemical nitrogen is lost from soil due to oxidation in sunlight. Suhane (2007) calculated that upon application of 100 kg urea (N) in farm soil, 40-50 kg gets oxidized and escapes as ammonia (NH₃) and nitrous oxides (N₂O) into the air, about 20-25 kg leaches underground polluting the groundwater, while only 20-25 kg is available to plants. N₂O is a powerful greenhouse gas nearly 312 times as compared to CO₂.
### 2.4 Need for waste management

The term waste is a misnomer to the material that is mismanaged and underutilized. Its importance is lost for not having the proper methodology for recycling. Organic decomposable material is one of the resources derived from agriculture, animal husbandry and agro-industries. The quantum of waste generated from these sources will contribute to about 60 to 70% of the total rejects produced from various other activities. Unscientific way of disposal of these materials leads to air and water pollution. These wastes being from plant and animal resources, they have the necessary macro and micro nutrients for plant growth and are the only source of organic carbon needed for microbial activity in soil. Composting of such material in a methodical manner will turn the organic waste into Bio-resource. There is a need for make use of environmental resources for development instead of creating pollution by their mismanagement (Prapirrna and Shashikanth, 2002). Macfadyen (1963) had referred to organisms including earthworms as decomposer industry that can be considered for treating large quantities of decomposable waste. These organisms can be made to work on farmyard wastes and organic rich industrial wastes (Lee, 1985).

With the progressive increase in the size of the world’s population and the adoption of intensive animal husbandry production, large volumes of organic wastes produced all over the world are creating a serious disposal problem and a major source of environmental pollution. These wastes require large quantities of land for disposal, release odor and ammonia into the air, could contaminate ground water with pollutants, and might present a healthy risk (Inbar et al., 1993). However some form of treatment of these wastes can make them suitable for land application and for safe disposal into the environment (Atiyeh et al., 2000a).

Solid waste management has become one of the major problems we are facing today. The rapid increase in the generation of huge quantity of waste is one aspect of the environmental crisis. This is accompanying with recent global development with respect to rapid urbanization and population growth which has resulted into generation of large quantity of organic solid waste.

On one hand tropical soils are deficient in all necessary plant nutrients and on the other hand large quantities of such nutrients contained in domestic wastes and agricultural
byproducts are wasted. It is estimated that in cities and rural areas of India nearly 700 million tons organic waste is generated annually which is either burned or land filled (Bhiday, 1994). Such large quantities of organic wastes generated also pose a problem for safe disposal. Most of these organic residues are burned currently or used as land fillings. In nature’s laboratory there are a number of organisms (micro and macro) that have the ability to convert organic waste into valuable resources containing plant nutrients and organic matter, which are critical for maintaining soil productivity. Microorganisms and earthworms are important biological organisms helping nature to maintain nutrient flows from one system to another and also minimize environmental degradation. The earthworm population is about 8-10 times higher in uncultivated area. This clearly indicates that earthworm population decreases with soil degradation and thus can be used as a sensitive indicator of soil degradation.

Animal manure is a valuable resource as a soil fertilizer because it provides large amounts of macro and micronutrients for crop growth and is a low-cost, environment-friendly alternative to mineral fertilizers. However, the use of manure in agriculture is being abandoned because of increasing transportation costs and environmental problems associated with the indiscriminate and inappropriately-timed application to agricultural fields (Hutchison et al., 2005). Processing of this waste material through controlled bio-oxidation processes, such as composting, reduces the environmental risk by transforming the material into a safer and more stable product suitable for application to soil (Lazcano et al., 2008) and also reduces the transportation costs because of the significant reduction in the water content of the raw organic matter. Composted materials are therefore gaining acceptance as organic fertilizers in sustainable agriculture, and there has been a considerable increase in research dedicated to the study of the effects of compost-like materials on soil properties and plant growth.

2.5 Earthworms - The soil engineer

Earthworm has always been a subject of interest for many ancient scientists, sages and poets have sung its praises. While the Tamil poet Manonmanian Sundaranar has extolled the earthworms as those who can remediate any type of difficult soil. Earthworm is nature's own litter, aerator, crusher, composter and master builder of the top soil (Talashilkar et al., 2003). Aristotle called worms the intestines of the earth and stated that there may not be any
other creature that has played so important a role in the history of life on earth. Charles Darwin (1881) pioneered the studies on the role of earthworms in soil fertility, followed by several researchers who studied the mechanisms of conversion of organic matter into humus through the action of earthworms and have highlighted their importance in the decomposition of organic wastes (Edward et al., 1985; Priya and Garg, 2003). Soil crust plays an important role in supporting nutrient cycling as well as creating and maintaining soil structure (Buck et al., 2000). Due to their vast presence in the soil and animal-biomass and its higher engineering rates of soil turnover, earthworms are considered as the special importance for soil fertility. Jimenez et al. (2004) and Salmon et al. (2005) designated earthworms as major soil ecosystem engineers because of their direct role of physical, chemical, and biological activity on soil.

Earthworms are called living ploughs by virtue of their excellent ability to loosen soil, improve soil aggregates stability, improve porosity, increase water infiltration, gather nutrients and enhance nutrients availability and thereby increasing fertility by their feeding and burrowing actions. In general the land ploughed by earthworms for 3 years will become high yielding farmland. Healthy soil is rich in minerals, soil microorganisms, earthworms and humus. Air and water can penetrate soil through earthworm tunnels. Earthworms climb up to the surface of soil to grab remnants of plants and feed in tunnels and thus fertilize all strata of soil. One square meter of healthy soil contains 1,000 earthworms. According to the estimate of an American researcher, 1,000,000 (one million) earthworms in a garden plot provide the same benefit as three gardeners working 8 hours in shifts all year round, and moreover having 10 tons of manure applied in the plot (Xu Kuiwu and Dai Xingting, 1998). Earthworms also encourage root growth and reduce incidence of root diseases, increase pasture and crop yields and increase grain quality in terms of protein content.

Guts of earthworms are factories and storehouse of beneficial soil microbes. Apparently, it is both the earthworms and its microbes that play a combined role in growth promotion and improves agricultural production. Worms and microbes secrete growth promoting plant hormones gibberlins, auxins and cytokinins which help mineralise the nutrients and make them bio-available to plant roots. Microbes also help in plant protection from diseases (Compant et al., 2005). In a glasshouse trial, Buckerfield et al. (1999) found
that the stimulatory effect of vermicompost on plant growth and protection was apparently destroyed when it was sterilized.

These Ecosystem engineers as they multiply the numbers and types of microbes in the soil by creating conditions under which these creatures can thrive and multiply. Utilization of such creature to break down organic wastes is gaining increasing popularity in different parts of the world. It is well established that earthworms have beneficial physical, biological and chemical effects on soils and can influence plant growth and crop yields in both natural and managed ecosystems (Edwards & Bohlen, 1996). The cultivation effect of earthworms is the combination of both the results of their burrowing activity and the consequence of their casting and mucus secretion (Lee, 1985; Buck et al., 2000). A positive harvest in agriculture can be achieved by earthworm activities, since humans in today’s world are mostly facing with the problems of soil degradation worldwide (Buck et al., 2000). Pattern of agriculture practice can disturb earthworm distribution, fecundity and soil microbial activity. Earthworms may be essential part of many agro ecosystems and may be useful indicators for sustainability (Lee, 1995; Jordan et al., 2004). Presence of earthworms in a soil directly influences on the various physico - chemical properties of the soil (Lee, 1985; Edwards and Bohlen, 1996).

2.6 Role of earthworms in the formation of soil structure
Earthworms are known to have a significant positive effect in the construction of soil structure and hydrology (Tomlin et al., 1995; Shuster et al., 2000), microbial community, dynamics of chemical processes (Lee, 1985; Edwards and Bohlen, 1996), nutrient availability and the rate of mineralization (Edwards et al., 1995). With their peculiar feeding, burrowing and casting activities, they contribute to the release of organic residues directly into the soil crust accelerating rate of decomposition and thereby facilitating the release of nutrients which can be easily assimilable by plants (Buck et al., 1999).

2.7 Influence of Environmental factors on Earthworms distribution
2.7.1 Temperature
Temperature influences the activity, metabolism, growth, respiration and reproduction of earthworms. Temperature and moisture are usually inversely related and high surface temperature and dry soils are much more limiting to earthworms than low temperature and
water logged soils (Nordstrom and Rundgren, 1974). Unfavorable temperatures reduce growth, development, reproduction and feeding activities (Daniel, 1991; Fayolle et al., 1997).

### 2.7.2 Moisture

Earthworms that live in compost and dung heaps tend to prefer moisture conditions than most species of soil dwelling earthworms. *P. excavatus* are reported to prefer a moisture content of about 80% in cattle manure at 25°C (Hallett et al., 1992) and 80-85% in other organic materials (Edwards and Fletcher, 1988).

Parmelee and Crossley (1988) and Edwards et al. (1995) suggested that cocoons may act as the main survival stage during drought for some earthworm species such as *Lumbricus rubellus* (Lavelle et al., 1974). Soil moisture and temperature can act synergistically to influence earthworm activity. These directly affect rates of cocoon production, incubation time and hatching rates of earthworms (Dash and Senapati, 1980; Ismail and Murthy, 1985).

Earthworms rely upon moisture of the soil to maintain high water content of their bodies (Ismail and Murthy, 1985; Ismail et al., 1990; Kretzschmar and Bruchou, 1991; Buckerfield and Webster, 1998; Muyima et al., 1994). Reduction in water content to facilitate accumulation of dry matter in the mature worms has also been reported (Dash and Patra, 1977; Alawdeen and Ismail, 1986). Earthworms are reported to withstand heavy loss of body water up to 75% (Schmidt, 1918; Roots, 1956; Baskaran et al., 1986). Prolonged drought decreases the number of earthworms markedly (Edwards and Bohlen, 1996). Earthworms go into dormancy and even die under extreme drought conditions (Edwards and Lofty, 1977; Ismail and Murthy, 1985).

### 2.7.3 pH

It has been demonstrated that earthworms are very sensitive to hydrogen ion concentration. It is not surprising that soil pH is sometimes a factor that limits the species number and distribution of earthworms that live in any particular soil. Several workers have stated that earthworms prefer soil with a neutral pH (Arrhenius, 1921; Petrov, 1946; Ismail and Murthy, 1985; Rivero-Hernandez, 1991). Reddy and Pasha (1993) reported significant
positive correlation between pH and the seasonal abundance of juvenile and young adult *Octochaetona phylloti* in semi and arid tropical grasslands in India.

**2.8 Classification of earthworms and species suited for vermicomposting**

Earthworms can be grouped into three ecological groups based on the types of different morphological and behavioral characteristics (Bouche, 1977; Lavelle, 1983; Ismail, 1997; Sims and Gerard, 1999) which is named as anecic (feed on litter that live in vertical burrows in the soil), endogeic (soil-feeding earthworms) and epigeic species (litter-feeding earthworms that live in the surface of soil) (Ismail, 1997, Sanchez-de Leon and Zou, 2004).

Six earthworm species have been identified as potentially the most useful species to break down organic wastes. These are *E. foetida* (and the closely-related *Eisenia andrei*), *Dendrobaena veneta*, and *Lumbricus rubellus* from temperature regions and *Eudrilus eugeniae, Perionyx excavatus* and *Perionyx hawayana* from the tropics. The optimum temperatures for growth and reproduction of *Eudrilus eugeniae* and *Perionyx excavatus* were about 25°C to 30°C, (Edwards, 2004).

*Perionyx excavatus* is an epigeic species of earthworm, which lives in organic waste and could be potentially used to convert organic waste into a valuable end product. *P. excavatus* is known to be good at converting organic waste into high-value vermicompost, which can be used as a medium for growing plants (Kale et al., 1982; Suthar 2006). Nevertheless, most of the vermiculture experiments using *P. excavatus* were done using animal dung e.g. cow dung (Kale et al., 1982; Reinecke et al., 1992; Edwards et al., 1998), sheep dung (Kale et al., 1982), biogas sludge (Kale et al., 1982; Edwards et al., 1998), poultry manure (Kale et al., 1982), pig solids (Edwards et al., 1998), horse solids (Edwards et al., 1998) and turkey waste (Edwards et al., 1998). The potential of *P. excavatus* for processing other wastes, namely vegetable waste (Singh et al., 2005) and water hyacinth (*Eichhornia crassipes*) (Gajalakshmi et al., 2001), has also been tested and proved for better yield.

**2.8.1 Diversity and species richness of earthworms in India**

Earthworms as major soil macro fauna, have gained importance as the modulators of the physicochemical properties of the soil. The country with its diversified geographical
regions, edaphic and climatic factors is characterized by species diversity and richness. Out of the different families of earthworms distributed in the world, the sub-continent has representative genera and species from nine families. *Lampto mauritii* is the widely distributed earthworm in India, reported from different agro-ecosystems. *Polypheretima elongata, Perionyx excavatus, Pontoscolex corethrurus* and *Dichogaster bolai* are the other earthworms having wider distribution in the country next to *L.mauritii*.

2.8.2 Earthworm burrows - The living habitat for earthworms

The crawling movement of earthworms results in the construction of tiny channels and pores throughout the soil crust (Jegou *et al.*, 2001). These channels allows the circulation of air and permit infiltration of water (Jegou *et al.*, 2001) and incorporation of organic matter into soil providing potential for enhanced plant growth (Butt and Lowe, 2004). The deep burrow wall zone, which is directly or indirectly influenced by the earthworm burrow activity, has been called zoosphere (Joffe, 1936), vermisphere (Hamilton and Dindal, 1983) or drilosphere (Bouche, 1975).

The microenvironment associated with the walls of earthworm burrows may be substantially different from soil only a few millimeters away (Parkin and Berry, 1999). Further secretion of mucus (cementing material during construction of burrows) is highly concentrated with organic nitrogen and ammonium (Needham, 1957) which acts as a substrate for the growth of beneficial fungal and bacterial loads (Edwards and Fletcher, 1988). The faecal castings that are dropped in the burrows are subsequently pressed onto the side walls of the burrow is rich in levels of nitrate and ammonium (Edwards and Lofty, 1980).

2.8.3 Earthworm burrows - Point of water and gaseous exchange

Earthworm channels facilitate gaseous exchange and water movement through the constructed burrows. Earthworm burrows have also been gained importance in the preferential flow of water and essential minerals (Ehlers, 1975; Zachmann *et al.*, 1987) and it has reported that the walls of earthworm burrows which is enriched with NO₃⁻ and labile - C (Syers and Springett, 1983; Parkin and Berry, 1999) may be transported by infiltrating water (Parkin and Berry, 1999). Many studies have confirmed the role of anecic earthworms on biogeochemical transformations within the soil resulting from the interaction of various
factors, including enhanced movement of gases and water within the soil profile via burrows (Devliegher and Verstraete, 1997), nutritional enrichment of burrows with detritus (Devliegher and Verstraete, 1995; Amador et al., 2003) and the release of nutrients by the microfauna and microflora in the drilosphere (Gorres et al., 1997; Parkin and Berry, 1999). Such process can influence the water table of soil either directly or indirectly. Amador et al. (2005) have concluded from his studies that the water content of the drilosphere created by the anecic earthworm Lumbricus terrestris alters both C and N dynamics and also influences the speciation of inorganic Nitrogen.

Ample amount of Carbon and Nitrogen are excreted via the body surface of earthworm into the burrow walls as cutaneous mucus and urine (Needham, 1957). In field and laboratory experiments, burrow walls of L. terrestris have been found to contain large amounts of lactate-extractable P (Graff, 1970), mineral N (Devliegher and Verstraete, 1997; Gorres et al., 1997) and water-soluble organic C (Stehouwer et al., 1993). Devliegher and Verstraete (1997) found an increased levels of total bacterial loads whereas it was not observed with the fungal loads in the borrow linings of L terrestris. Increased content of organic matter and nutrients in the drilosphere stimulates root development (Graff, 1971), further it influences the soil water holding and absorption capacity and the quality of infiltrating water (Stehouwer et al., 1993).

2.8.4 Earthworms and microbes - Natural mutualism

Earthworms are treasure-houses of micro-organisms (Ismail, 1997) acting as vectors of beneficial microorganisms promoting growth of microorganisms in their guts. Analysis of gut content of the earthworms has revealed the occurrence of different kinds of symbionts like microfungi, bacteria, protozoans, actinomycetes, etc. (Dash and Senapati, 1986). Earthworm guts provide congenial environmental condition for their proliferation, and hence, the total numbers of such microorganisms in earthworm intestines generally increase many folds as compared to their habitats (Ponomarera, 1962).

They effectively harness the beneficial soil microflora to convert organic wastes into humus through mutualistic associations, (Sosamma, 1998; Lalitha, 1999; Haynes et al., 1999) which is evident by the presence of microorganisms in their casts and gut (Edwards and Bohlen, 1996 and Nagarathnam et al., 2000).
The intestinal mucus in the earthworm gut stimulates microbial activity and its growth thereby increases the decomposition of organic matter. The passage of soil through the digestive tract is accompanied by qualitative and quantitative changes in the microflora are a well established fact (Edwards and Bohlen, 1996; Daniel and Karmegam, 1999).

### 2.8.5 Earthworms and organic matter

The distribution or organic matter in the soil influences the distribution of earthworms. Soils that are poor in organic matter do not usually count for larger populations of earthworms. Conversely, if there are few earthworms, the decaying organic matter usually lies in a pile on the soil surface (Ismail, 1983; Potter et al., 1990; Clements et al., 1991).

Hendrix et al., 1992 and Doube et al., 1997; have reported a positive correlation between earthworm population density and soil organic matter. Hay with cattle dung acts as good supportive medium for the multiplication of *L.mauritii* and *P.excavatus* as explained by Ismail (1997). A study of ecological interactions (Anne Grace and Ismail, 1994) reveals that *L.mauritii* increases both in biomass and population density when cultured in sand with suitable organic amendments. Earthworms can have an enormous influence on the dynamic and decomposition of organic matter in an ecosystem. Decaying leaves are a source of organic matter favoring earthworm’s multiplication (Edwards and Bohlen, 1996).

### 2.8.6 Earthworm and chemical balance on soil

Earthworms affect the physico-chemical properties of soil and are also responsible for distribution and transport of plant nutrients because they consume large quantities of surface litter and organic material. Earthworm casts usually have a higher pH, higher base exchange co-factor, more total nitrate nitrogen, organic matter, total and exchangeable magnesium, potassium, manganese and phosphorus. Lee (1983) summarized the influence of earthworms over soil nitrogen cycling. According to him nitrogenous products of earthworm are returned back to the soil through casts, urine, muco-proteins and dead tissues of earthworms.

### 2.8.7 Earthworm and plant growth

It is well endorsed that earthworms have a direct beneficial role on physical, chemical and biological effects on soils and several researchers too authenticated that these effects can increase plant growth and crop yields in both natural and managed ecosystems (Edwards and Bohlen, 1996; Edwards, 1998). These beneficial effects have virtue to
improvements in soil properties and structure (Kahnsnitz, 1992), to greater availability of mineral nutrients to plants (Gilot, 1997), and to an increased microbial populations and biologically active metabolities such as plant growth regulators (Tomati and Galli, 1995; Doube et al., 1997).

Many field studies have shown positive indication of Carbon and Nitrogen mineralization mediated by earthworms as well as their beneficial effects over the physical and biological properties of soil (Lee, 1985) and marked up plant growth in agricultural settings (Lee, 1985; Devliegher and Verstraete, 1997; Doube et al., 1997). A case study by Topoliantz et al. (2002) have reported about pod formation of Vigna unguiculata sesquipedalis which was reputed positively in plots with a high soil Nitrogen content by the positive effects of Pontoscolex corethrurus on Nitrogen mineralization. Another study with saw dust inoculated earthworm has doubled tomato production compared to non-amended soil and reaching the same as inorganic fertilizers in Peru (Senapati et al., 1999).

Studies of Welke and Parkinson (2003) enlightens us the effect of the endogenic species, Aporrectodea trapezoids on the growth and yield of Douglas-fir seedlings and confirms that the height of seedlings, shoot and root biomass was higher in worm-worked soils comparing to control soils. They also concluded that the average bacterial activity, substrate richness and diversity were consistently higher in worm-worked soils comparing to controls. In another study Kreuzer et al. (2004) have reported that earthworm species, A.caliginosa and Octolasion tyrtaeum increased shoot biomass of Lolium perenne (grass) and Trifolium repens (legume). Pashanasi et al., (1996) in his studies on maize, rice and cow-peas observed for a taller morphology in a short duration of time and came to a conclusion that the worm activity by endogenic P. corethrusus was responsible for such change in a shorter period of time comparing controls. Stephens et al., (1994) observed an increased root dry weight of crop plants in worm-worked soil while Doube et al. (1997) observed significant increase in root and shoot weight in barely and increase in shoot weight for wheat grown in the presence of earthworms. Haimi et al., (1992) identified significant increase in biomass for birch seedlings grown in the presence of L. rubellus, while Tuffen et al. (2002) concluded that presence of earthworms generally increased the growth of both shoot and root of Allium porrum.
2.8.8 Earthworm casts - A treasure house of nutrients

Earthworm casts have been identified to contain elevated amounts of C, NH$_4^+$, NO$_3^-$, P, K and Mg relative to surroundings soil (Jimenez et al., 2003; Zhang et al., 2003; Jimenez and Decaens, 2004). Studies on worm casts have brought vision that the amount of organic matter (Lal and De Vleeschauwer, 1982) and organic carbon (Zhang et al., 2003) are higher in casts comparing to surroundings soil. Bossuyt et al. (2005) have reported that the macro aggregates within casts contained more C and 13 C compared to bulk soil.

Experiments of Mulongony and Bedoret (1989) and Flegel et al. (1998) revealed that earthworm castings turned out to be the power house for nitrogen accumulation. Metabolic secretions like intestinal mucus, urine and mucopolysaccharides secreted from skin surface, create an atmosphere rich in nitrogen in the drilospheres. Earthworms are known to excrete ammonial compounds including NH$_4^+$, urea, allantoin uric acid (Lee, 1985). Nutrient in casts vary with the age of cast. The dominant inorganic form of N fresh casts is NH$_4^+$ and as casts age there is NO$_3^-$ and consequent decrease in NH$_4^+$ (Lavelle et al., 1992).

Earthworm casts are rich in nitrogen content, which suggests that they can be used as good source of plant nitrogen (Parmelee and Crossley, 1988; Ruz-Jerez et al., 1998; Jimenez and Decaens, 2004). In addition to increased nitrogen availability, C, P, K, Ca and Mg availability in the casts is also greater than in the intitial feed material (Lavelle et al., 1992; Orozco et al., 1996). Some studies have revealed that the levels of available phosphorous (assimilable by plants) is higher in earthworm casts than in the control soil (Guggenberger et al., 1996; Jimenez et al., 2003).

Nutrients that are required for plant growth are generally rich in worm casts than in the parent soil (Mulogony and Bedoret, 1989). After decades of research, worm castings have been described as microhabitats which contain higher microbial products of excretion such as ammonia, urea and body tissues that are rapidly mineralized. Thus, earthworm castings represent a potentially significant source of readily available nutrients for the plant growth (Curry and Byme, 1992).

2.8.9 Microbes in vermicasts

Since the intestines of the earthworms harbor high concentrations of various kinds of microorganisms (Wallwork, 1984), these vermicasts exhibit rich population of
microrganisms (Atlavinyte and Vanagas, 1982). Therefore the earthworm casts with rich microbial content would contribute more enzymes to the field soil.

2.8.10 Enzymes in vermicasts

Many scientists have investigated and elucidated the structural, physical, chemical and enzymatic properties of casts (Bussinelli et al., 1984; Shipitalo and Protz, 1989; Tiwari, et al., 1989; Schrader and Zhang, 1997). Jegou et al., (2001) with his studies authenticated that the enzymatic activities and carbon and nitrogen content in the walls of the burrows and casts were found to be enriched comparing to the parent material. Higher values of alkaline phosphatase activity was observed in worm casts than in the control soil, Satchell and Martin (1984), Flegel et al. (1998) and Buck et al. (2000). Enzyme phosphatases which catalyze the release of inorganic phosphate (orthophosphate) from organically bound phosphate and high contents of inorganic phosphate are the results of high phosphatase activity (Buck et al., 1999), which results in an increase in the activity of acid and alkaline phosphatases of both casts and the burrow walls of L.terrestris incubated in small microcosms with litter (Le Bayon and Binet, 1999).

2.8.11 Earthworms and Humic substances

During the last decade, the biological role of humic substances, particularly those isolated from earthworm faeces, have begun to be investigated (Dell’Agnola and Nardi, 1987; Muscolo et al., 1999). Dell’Agnola and Nardi (1987) authenticated for the presence of hormone-like or plant-growth regulator effects, of depolyycondensed humic fractions obtained from the faeces of the earthworms Aporrectodea rosea and Aporrectodea caliginosa on plants. Nardi et al., (1988) reported that humic materials purified from the faeces of A. rosea and A. caliginosa exhibited auxin-gibberellin, and cytokinin-like activities. Treating carrot cells with humic substances obtained from the faeces of the earthworm A. rosea, increased their growth and induced morphological changes similar to those produced by auxins (Muscolo et al., 1999).

2.8.12 Plant growth promoting substances of earthworm casts

A number of references in the literature show that plant growth regulators, such as indole acetic acids (auxins), gibberellins and cytokinins, are produced by microorganisms and there have been positive suggestions that the promotion of microbial activity in organic
matter by earthworms would result in production of significant quantities of plant growth regulators (Tomati et al., 1990; Krishnamoorthy and Vajranabhaiah, 1986; Edwards, 1998; Tomati and Galli, 1995; Welke and Parkins counselor, 2003).

2.8.13 Effect of earthworm casts on plant growth

Plants supplemented with earthworms cast have been found to show an increased plant dry weight (Edwards, 1995) and plant N uptake (Tomati et al., 1994). The beneficial effect of earthworm casts has been observed in both horticultural plants (Saciragic and Dzelilovic, 1986; Tomati et al., 1987) and in agronomic crops (Pashanasi et al., 1996). Further maize grown with amendments of worm casts have shown significantly higher plant height, stem diameter, dry weight and also showed higher nutrient uptake (Materechera, 2002). Earthworms are important in the process of humogenesis because their faeces contain rich quantities of humic substances that can directly influence plant growth through physiological effects. Humic substances in the casts of A. caliginosa positively influenced the growth of carrots (Muscolo et al., 1999). Similarly, Nardi et al. (1994) extracted a humic substance from the casts of A. caliginosa that had effects similar to auxin in increasing the root development and stem length of Nicotiana plumbaginifolia.

Earthworm cast and compost amendment significantly increased P and K uptake in wheat compared to mineral fertilizer treatment or non-amended control and their results also show that casts are an efficient source of plant nutrients (Chaoui et al., 2003). Edwards (1995) reported that in a Rothamsted study with 25 types of vegetables, fruit or ornamentals, earthworm casts performed better than compost or commercial potting mixture amendments. It was suggested that the higher crop performance of the cast treatment was due to better soil physical structure; presence of plant growth hormones; higher levels of soil enzymes and greater microbial populations.

2.9 Sustainable agriculture

In recent years, increasing consumer concern about issues such as food quality, environmental safety and soil conservation has lead to a substantial increase in the use of sustainable agricultural practices. Sustainable agriculture can be defined as a set of practices that conserve resources and the environment without compromising human needs, and the use of organic fertilizers such as animal manure has been indicated as one of its main pillars.
(Tilman et al., 2002). Normally using organic fertilizers is advantageous in that it involves nutrient recycling which is becoming an increasingly important element of environmentally sound sustainable agriculture.

A basic requirement for human survival is the sustainability of agriculture. The word sustainable is derived from the Latin, sustinere, meaning to keep in existence, implying permanence or long-term support. The concept of sustainable agriculture has been discussed for several decades and has resulted in certain consent about four general aims: sufficient food and fibre production, environmental stewardship, economic viability and social justice (Kirchmann and Thorvaldsson, 2000).

Pretty (2002) states that sustainable agriculture seeks to make the best use of nature’s goods and services, of the knowledge and skills of farmers, and people’s collective capacity to work together to solve common management problems. Such systems are improving soil health, increasing water efficiency and reducing dependency on pesticides. On a global scale, food production needs to be increased and at the same time the quality of agricultural soils and of the surrounding environment should be taken into account (Kirchmann and Thorvaldsson, 2000). To be sustainable, a farm must produce high quality and adequate yields, profitable, protective, conserve resources and be socially responsible for a long run (Reganold et al., 1990).

Sustainable agriculture is concerned with the ability of agroecosystems to remain productive for a long term (Van der Werf and Petit, 2002). The world-wide focus on sustainability in human interaction with nature has gained an interest in alternative agricultural systems (Hatfield and Karlen, 1994). When environment related problems in agriculture came into vision, further decades were quickly presented as a solution for most of the problems that agriculture is facing in today’s world (Kirchmann and Thorvaldsson, 2000).

Sustainable cropping systems rely on a minimum of external inputs with maximum yield. In these systems, nitrogen (De Luca et al., 1996) and phosphorous (Ohno et al., 2005) are largely acquired from animal manures and leguminous green manures (De Luca et al., 1996; Ohno, et al., 2004). One of the principal aims of alternative cropping systems is to minimize excessive loss of N while maximizing N use efficiency and meeting crop N
requirements. Many such cropping systems substitute intensive application of synthetic fertilizer with organic inputs, such as N₂ fixing legumes (Kramer et al., 2002).

2.10. Vermicomposting

Vermicomposting is a simple biotechnological process of composting, in which certain species earthworms are used to enhance the process of waste conversion and produce a better end product. Vermicomposting differs from composting in several ways (Gandhi et al., 1997). It is a mesophilic process, utilizing microorganisms and earthworms that are active at 10-32°C (not ambient temperature but temperature within the pile of moist organic material). The process is faster than composting; because the material passes through the earthworm gut, a significant but not yet fully understood transformation takes place, whereby the resulting earthworm castings (worm manure) are rich in microbial activity and plant growth regulators, and fortified with pest repellence attributes as well! In short, earthworms, through a type of biological alchemy, are capable of transforming garbage into gold (Vermi, 2001; Tara Crescent, 2003).

In the process of feeding of organic wastes, earthworms fragment the waste, enhance microbial activity and accelerate rates of decomposition leading to a humification effect through which the unstable organic matter is oxidized and stabilized, as in composting, but by a non thermophilic process (Inbar et al., 1993). The end product termed vermicompost is quite different from the parent waste material in that they contain nutrients in forms that are readily taken up by plants such as nitrates, exchangeable phosphorus, and soluble potassium, calcium and magnesium (Edwards et al., 1988; Orozco et al., 1996).

Wooden boxes, cemented tanks, earthen pots, earthen pits lined with either stones or plastics can be used for vermiculturing. Humid and slightly dark places, 40-50% moisture in beds, 20-30°C temperature, pH of 7 and partially decomposed organic matter rich in nitrogen help earthworms to grow faster and produce more cocoons (Kale, 1995).

2.10.1 Feed materials as substrates for vermicomposting

Agricultural waste, horticultural waste, animal waste, silkworm litter, plant biomass (leaf litter), weeds, kitchen waste abiding, foul, acidic, spicy and spoilt food, city refuse after removing non-degradable waste material such as glass, plastic, strong rubber and metal can be vermicomposted (Kale, 1995). Numerous organic materials have been evaluated for
growth and reproduction of earthworms as these materials directly affect the efficacy of vermicompost. Nogales et al., (1999) evaluated the suitability of dry olive cake, municipal biosolids and cattle manure as substrates for vermicomposting. They reported that larger weights of newly hatched earthworms were obtained in substrate containing dry olive cake. In another study, maize straw was found to be the most suitable feed material compared to soybean (Glycine max) straw, wheat straw, chickpea (Cicer arietinum) straw and city refuse for the tropical epigeic earthworm, Perionyx excavatus (Manna et al., 1997).

2.10.2 Vermicompost - Organic gold

Vermicompost is finely divided peat-like material with high porosity, aeration, drainage, water-holding capacity, and low C:N ratio produced from organic wastes stabilized by interactions between earthworms and microorganisms, under aerobic conditions (Edwards, 1998). Vermicompost is a nutrient-rich, microbiologically-active organic amendment that results from the interactions between earthworms and microorganisms during the breakdown of organic matter. The nutrient status of vermicompost produced with different organic waste is; organic carbon 9.15 to 17.98 %, total nitrogen 0.5 to 1.5 %, available phosphorus 0.1 to 0.3 %, available potassium 0.15, calcium and magnesium 22.70 to 70 mg/100g, copper 2 to 9.3 ppm, zinc 5.7 to 11.5 ppm and available sulphur,128 to 548 ppm (Kale, 1995). It is a stabilized, finely divided peat-like material with a low C:N ratio, high porosity and high water-holding capacity in which most nutrients are present in forms that are readily taken up by plants (Dominguez, 2004). Study showed that soil amended with vermicompost had significantly greater soil bulk density and hence porous and lighter and never compacted. Significantly, vermicompost works as a soil conditioner and its continued application over the years lead to total improvement in the quality of soil and farmland, even the degraded and sodic soils (Nelson and Rangarajan, 2010).

Vermicomposts also have a very large surface area, providing strong capacity to hold and retain nutrients. Compared to their parent materials, vermicomposts have less soluble salts, greater cation exchange capacity and increased total humic acid contents (Albanell et al., 1988). In various sources of organic matter, vermicomposts have been recognized as having considerable potential as soil amendments (Norman et al., 2005).

2.10.3 Vermicompost and beneficial microbes
Parle (1963b) reported bacterial count of 32 million per gram in fresh vermicast compared to 6-9 million per gram in the surrounding soil. Scheu (1987) reported an increase of 90% in respiration rate in fresh vermicast indicating corresponding increase in the microbial population. Suhane (2007) found that the total bacterial count was more than $10^{10}$ per gram of vermicompost. It included Actinomycetes, Azotobacter, Rhizobium, Nitrobacter and phosphate solubilizing bacteria which ranged from $10^2-10^6$ per gm of vermicompost. The PSB has very significant role in making the essential nutrient phosphorus (P) available for plant growth promotion. Although phosphates are available in soils in rock forms but are not available to plant roots unless solubilized.

Pramanik et al. (2007) studied the microbial population in vermicompost prepared from cow dung and municipal solid wastes (MSW) as substrates (raw materials) and found that it was in highest abundance in cow dung vermicompost. The total bacterial count was $73 \times 10^8$, the cellulolytic fungi were $59 \times 10^6$ and the nitrogen-fixing bacteria were $18 \times 10^3$. It was least in vermicompost obtained from MSW. The total bacterial count was $16 \times 10^8$, the cellulolytic fungi were $21 \times 10^6$ and the nitrogen-fixing bacteria were $5 \times 10^3$. Application of lime in the substrate enhanced the population of all above mentioned microbes irrespective of the substrates used for vermicomposting.

Plant growth promoting bacteria (PGPB) directly stimulates growth by nitrogen (N) fixation, solubilization of nutrients, production of growth hormones such as 1-aminocyclopropane-1-carboxylate (ACC) deaminase and indirectly by antagonizing pathogenic fungi by production of siderophores, chitinase, β-1,3-glucanase, antibiotics, fluorescent pigments and cyanide. There is also substantial body of evidence to demonstrate that microbes, including bacteria, fungi, actinomycetes, yeasts and algae, also produce plant growth regulators (PGRs) such as auxins, gibberellins, cytokinins, ethylene and ascorbic acids in appreciable quantities and as their population is significantly boosted by earthworms large quantities of PGRs are available in vermicompost (Sinha and Valani, 2011b).

2.10.4 Vermicompost and Plant growth

Vermicompost is a nutritive organic fertilizer rich in NKP (nitrogen 2-3%, potassium 1.85-2.25% and phosphorus 1.55-2.25%), micronutrients, beneficial soil microbes like nitrogen fixing bacteria and mycorrhizal fungi and are scientifically proving as miracle
growth promoters and protectors with significantly higher agronomic impacts (5-7 times) over the conventional composts discussed above. Kale and Bano (1986) reports as high as 7.37% nitrogen (N) and 19.58% phosphorus as P$_2$O$_5$ in worm vermicast. Suhane (2007) showed that exchangeable potassium (K) was over 95% higher in vermicompost. There are also good amount of calcium, magnesium, zinc and manganese. Additionally, vermicompost contain enzymes like amylase, lipase, cellulase and chitinase, which continue to break down organic matter in the soil (to release the nutrients and make it available to the plant roots) even after they have been excreted. Annual application of adequate amount of vermicompost also lead to significant increase in soil enzyme activities such as urease, phosphomonoesterase, phosphodiesterase and arylsulphatase and the soil has significantly more electrical conductivity (EC) and near neutral pH (Tiwari et al., 1989).

Vermicompost may influence plant growth directly via the supply of plant growth regulating substances (PGRs). This was first proposed by Tomati et al. (1988), Tomati et al. (1990); Grappelli et al. (1987) and Tomati and Galli (1995). In these experiments the authors compared the effects of different vermicompost extracts on the growth of Begonia, Petunia and Coleus with the effects produced by auxins, gibberellins and cytokinins, and concluded that there was a strong evidence of hormonal activity caused by the earthworms. It was further reconfirmed by Neilson (1965) and Tomati et al. (1987) who reported that vermicompost contained growth promoting hormone auxins, cytokinins and flowering hormone gibberellins secreted by earthworms. It was demonstrated by Grappelli et al. (1985) that the growth of ornamental plants after adding aqueous extracts from vermicompost showed similar growth patterns as with the addition of auxins, gibberellins and cytokinins through the soil.

Hormonal activity has also been associated with the humic substances present in vermicompost. Canellas et al. (2002) and Zandonadi et al. (2006) reported that the humic substances extracted from earthworm compost were capable of inducing lateral root growth in maize plants by stimulation of the plasma membrane H$^+$-ATPase activity, thus producing similar effects such as the exogenous application of indole-3-acetic acid (IAA).

(2005) reported that vermicomposts contain biologically active substance like plant growth hormones and these may have a significantly positive effects on the overall plant growth. Atiyeh et al. (2002b) have extracted plant growth regulators in aqueous solutions and demonstrated that these can have significant effects of plant growth.

2.10.5 Vermicompost and humic acid

Earthworm activity accelerates the humification of organic matter, and their influence in increasing microbial populations enhances the presence of auxins and gibberellin-like substances as well as humic acids (Casenave de Sanfilippo et al., 1990). In recent years, humic substances have been shown to increase yields of corn and oats, tobacco roots, soybeans, peanuts, clover, chicory, tropical and other crops. More recently, workers have reported increase in the growth of crops grown in planting media amended with humic acids that were extracted from vermicompost.

Atiyeh et al. (2002b) speculates that the growth responses of plants from vermicompost appears more like ‘hormone-induced activity’ associated with the high levels of humic acids and humates in vermicompost rather than boosted by high levels of plant-available nutrients. Humic acid is secreted by earthworms in its excreta. Without humus plants cannot grow and survive. This was also indicated by Canellas et al. (2002) who found that humic acids isolated from vermicompost enhanced root elongation and formation of lateral roots in maize. Pramanik et al., (2007) reported that humic acids enhanced nutrient uptake by the plants by increasing the permeability of root cell membrane, stimulating root growth and increasing proliferation of root hairs.

Studies of the positive effects of these humic substances on plant growth, when full requirements for mineral nutrition, have resulted in consistently positive effects on growth independent of nutrition (Chen and Aviad, 1990). For instance, in controlled experiments, humic substances increased dry matter yields of corn and oat seedlings (Lee and Bartlett, 1976; Albuzio et al., 1994); numbers and lengths of tobacco roots (Mylonas and Mccants, 1980); dry weights of shoots, roots, and nodules of soybean, peanut, and clover plants (Tan and Tantiwiramanond, 1983); vegetative growth of chicory plants (Valdrighi et al., 1996) and induced shoot and root formation in tropical crops grown in tissue culture (Goenadi and Sudharama, 1995). More recently, workers have reported
increases in the growth of crops grown in planting media amended with humic acids that were extracted from vermicompost. Moreover, humic acids have also been shown to stimulate plant growth in auxin, gibberellin and cytokinin bioassays (Phuong and Tichy, 1976).

Other mechanisms which have been suggested to account for promotion of plant growth by humic substances include enhanced uptake of metallic ions and increases in cell permeability (Chen and Aviad, 1990). Vermicomposts originating from animal manures, sewage sludges or paper-mill sludges have been shown to contain large amounts of humic substances (Albanell et al., 1988; Petrussi et al., 1988; Hervas et al., 1989; Senesi et al., 1992; Garcia et al., 1995; Masciandaro et al., 1997; Elvira et al., 1998).

2.10.6 Vermicompost and enzymes

Enzyme activities are widely used as an index of soil fertility since they are involved in the biological transformations of native and foreign compounds in soils (Tate, 2000). The enzyme activities largely reflected the diversity of the microbial population and in turn reflect the composting process. The enzymes viz., Indole acetic acid, dehydrogenase, acid phosphatase, alkaline phosphatase, urease, catalase were recognized as very important enzymes involved in the mineralization of nutrients. Characterizing and quantifying the enzymatic activities during composting process reflected the dynamics of the composting process in terms of decomposition of organic matter and nitrogen transformations and provided us information about the maturity of final product (Tiquia, 2002). In addition, on the basis of the well demonstrated relationship between enzymatic activity, quantity and quality of organic matter, compost stability (Garica et al., 1993) which was defined as the degree of decomposition of the readily bio-degradable organic matter can also be assessed.

Abundant enzyme activities in vermicompost might be due to the decomposition process by the presence of earthworms and aerobic heterotrophic microbial population. Especially during the middle stage of vermicomposting, in correlation with the introduced enzyme activity the microbial numbers reached the maximum of $126 \times 10^6$, $28 \times 10^4$ and $93 \times 10^5$ CFU of bacteria and fungi g$^{-1}$ samples respectively. Availability of half digested nutrient rich organic wastes by earthworm activity contributed for the proliferation of aerobic decomposing heterotrophic microbes. These results are in conformity with the results of
earlier work of Kale et al. (1988). The increase of microbial population may be due to the congenial condition for the growth of microbes within the digestive tracts and by the ingestion of nutrient rich organic wastes which provide energy and also act as a substrate for the growth of microbes as stated by Tiwari et al. (1989).

Vermicompost also increases the levels of soil enzymes like dehydrogenase, acid and alkaline phosphatases and urease. Use of vermicompost over the years build up the soil’s physical, chemical and biological properties restoring its natural fertility. Vermiculture biotechnology will bring in economic prosperity to the farmers, ecological security for the farms and food security for the people.

2.10.7 Disease suppressing properties of vermicompost

Vermicompost has also been found to have a wide range of indirect effects on plant growth such as the mitigation or suppression of plant diseases. Suppression of plant diseases has been extensively investigated in other organic amendments such as manure and compost (Noble and Coventry, 2005; Termorshuizen et al., 2006; Trillas et al., 2006). Likewise, some studies have shown that vermicompost can suppress a wide range of microbial diseases, insect pests and plant parasitic nematodes.

As regards the suppression of fungal diseases, Orlikowski (1999) observed that the addition of vermicompost extracts to three ornamental plant species significantly reduced sporulation of the pathogen Phytophthora cryptogea. Similarly Nakasone et al. (1999) observed that aqueous extracts of vermicompost were capable of reducing the growth of pathogenic fungi such as Botrytis cinerea, Sclerotinia sclerotiorum, Corticium rolfsii, Rhizoctonia solani and Fusarium oxysporum. The addition of solid vermicompost to tomato seeds significantly reduced infection caused by Fusarium lycopersici (Szczech, 1999) and Phytophthora nicotianae (Szczech and Smolinska, 2001).

Edwards et al. (2006) observed that the suppressive effect exerted by several types of vermicompost on several plant pathogens such as Pythium, Rhizoctonia, Verticillium, and Plectosporium, disappeared after sterilization of the vermicompost, and concluded that disease suppression may be related to the presence of biological suppressive agents in vermicompost. As regards the effects of vermicompost on insect pests and mites, field studies have shown that the addition of vermicompost to soil significantly reduces the
incidence of the psyllid *Heteropsylla cubana* (Biradar et al., 1998), the sucking insect *Aproaerema modicella* (Ramesh, 2000), jassids, aphids, beetles, and spider mites (Rao, 2002).

Furthermore, some studies show that vermicompost reduces not only the degree of plant infestation, but also the populations of plant parasitic insects in soils. This has been reported by Arancon et al. (2005), who showed that vermicompost produced, from food waste significantly reduced the populations of two species of beetles in soil (*Acalymma vittatum, Diabotrica undecimpunctata*) in comparison with inorganic fertigation. Similarly Yardim et al. (2006) observed a significant decrease in the larvae of the worm *Manduca quinquemaculata* after addition of vermicompost to a cucumber crop. Arancon et al. (2007) observed a significant reduction in the populations of spider mites (*Tetranychus urticae*), mealy bugs (*Pseudococcus* sp) and aphids (*Myzus persicae*) after the addition of food waste vermicompost to several vegetable crops (tomatoes, cucumber, cabbage, bush beans and eggplants).

Vermicompost may also have significant effects on both the incidence and abundance of plant-parasitic nematodes in soil. This was first reported by Swathi et al. (1998), who found that addition of vermicompost to soil at a rate of 1kg m\(^{-2}\) significantly inhibited the incidence of the parasite nematode *Meloidogyne incognita* in tobacco plants. Similar reductions in the degree of plant infestation by *Meloidogyne incognita* were observed by Morra et al. (1998), while Ribeiro et al. (1998) reported a significant decrease in the egg mass of *Meloidogyne javanica* after the application vermicompost to the growth medium. Arancon et al. (2003a) indicated significant reductions in the abundance of plant-parasitic nematodes in soil plots amended with different doses of two types of vermicompost in comparison with the effects of inorganic fertilizers.

According to the mechanisms proposed for compost (Hointink and Bohem, 1999; Noble and Coventry, 2005), disease suppression by vermicompost may be attributed to either direct suppression of pathogens or to the induction of systemic resistance in the plant. Direct suppression of the pathogen by the vermicompost-associated microflora and microfauna may be general or specific, depending on the existence of a single suppressive agent or the joint action of several agents. In both cases, the proposed mechanisms are competition, antibiosis
and parasitism. The mechanisms responsible for disease suppression by vermicompost are not yet well known, and the effects of bio-pesticides are usually attributed to general suppressive effects. Vermicompost increases microbial biomass in soil and changes the diversity and abundance of soil fauna (Gunadi et al., 2002; Arancon et al., 2006), and thus a broader range of organisms may act as biocontrol agents. Furthermore, there is recent evidence showing that the use of vermicompost extracts as foliar sprays in different crop plants effectively reduces the incidence of fungal diseases such as *Phytophthora infestans* (Zaller, 2006), *Erysiphe pisi* and *Erysiphe cichoracearum* (Singh et al., 2003). Reductions in disease incidence are sometimes accompanied by an increase in the production of defence substances by the plant (Singh et al., 2003), thus suggesting the induction of plant systemic resistance by vermicompost.

In light of this evidence, it is clear that vermicompost constitutes a promising alternative to inorganic fertilizers in promoting plant growth. However, further research into the exact mechanisms and circumstances that stimulate plant growth by this organic substrate is necessary in order to maintain consumer confidence in this type of fertilizer.

### 2.10.8 Vermicompost is free of pathogens and toxic chemicals

Study indicates that vermicomposting leads to greater reduction of pathogens after three months upon storage. Whereas, the samples which are subjected to only thermophilic composting, retains higher levels of pathogens even after three months. Earthworms selectively kills all the harmful microbes including *Salmonella* and *Escherichia coli* either by devouring upon them or by secretion of ‘anti-pathogenic ceolomic fluids’ in the medium in which they inhabit (Sinha and Valani, 2011b). Several studies have found that earthworms effectively bio-accumulate or biodegrade several organic and inorganic chemicals including heavy metals, organochlorine pesticide and polycyclic aromatic hydrocarbons (PAHs) residues in the medium in which it inhabits (Sinha and Valani, 2011b).

### 2.10.9 Vermicompost and soil microbes

All composts are rich in beneficial soil microbes. Vermicompost is especially rich in microbial diversity. Earthworms further proliferates useful microbes in billions and trillions in soil. Earthworms can modify soil microbial community structure depending on the type of organic matter present in soil (Jack, 2010). Soil organic matter (SOM) is also the food source
of beneficial soil microbes and helps in improving microbial population and diversity. Microbes are responsible for transforming, releasing and cycling of nutrients and essential elements. Microbes are also essential for converting nutrients into their plant available forms and also for facilitating nutrients uptake by plants. Soil microbes also create the glue that sticks soil particles together, creating soil crumbs and pore spaces that make good soil structure decreasing soil hardness.

Some of the indirect effects of vermicompost have been related to the change in the microbiological properties of the soil or the potting media. Processing by earthworms during vermicomposting has a strong effect on the microbial community of the initial waste (Dominguez et al., 2010). Vermicompost therefore has a rather different microbial community structure than the parent waste, with lower biomass and activity but enhanced metabolic diversity (Lores et al., 2006; Aira et al., 2007a). Application of such a microbiologically active organic substrate may have important effects on the microbial properties of soil or greenhouse potting media thereby influencing plant growth. However, information regarding the impacts of vermicompost on soil microbial properties is still limited. A single application of vermicompost to a strawberry crop has been shown to produce a significantly higher increase in soil microbial biomass than application of an inorganic fertilizer, independently of the dose used (Arancon et al., 2006).

As well as increasing microbial biomass, vermicompost increases microbial activity (Ferreras et al., 2006) promotes the establishment of a specific microbial community in the rhizosphere different from that of plants supplemented with mineral fertilizers or other type of organic fertilizers such as manure (Aira et al., 2010). Kale et al. (1992) observed that the application of vermicompost may produce significantly greater increases in the abundance of N-fixers, actinomycetes and spore formers than in soil supplemented with inorganic fertilizers. Soil enzyme activity is also significantly increased by vermicompost addition as compared to equivalent rates of mineral fertilizers (Marinari et al., 2000; Arancon et al., 2006, Saha et al., 2008).

In addition to the changes exerted on the chemical and physical properties, composted materials have a clear impact on soil biological properties, such as increases in microbial biomass and activity (Knapp et al., 2010), as well as changes in the activity of soil enzymes
(Garcia-Gil et al., 2000, Ros et al., 2006) and in the structure of the soil microbial community (Ros et al., 2006).

2.10.10 Improves cation exchange capacity

Vermicompost application also increases the cation exchange capacity (CEC) of soil. An increase in soil CEC leads to higher soil adsorption of positively charged cations such as calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na). The increase in cations translates into nutrients being held in the soil and made progressively available for plants uptake. This also leads to reduced acidity and higher soil pH (Compost Australia, 2011).

2.10.11 Reduces bulk density of soil, prevents soil compaction and erosion

All composts including vermicompost reduce the bulk density of the soil, preventing compaction and improving potential root growth, drainage and infiltration. This also reduces surface crusting and sealing and allows better infiltration of rainfall and irrigation. Even a thin seal or crust, often just formed by raindrops on bare soil can reduce infiltration rates and increase run-off and erosion. Earthworms from vermicompost keep the soil more softly by their burrowing and aerating actions. They have been called as nature’s ploughman.

2.10.12 Removes soil sodicity and salinity

Farmers at Phaltan in Satara district of Maharashtra, India, applied live earthworms to their sugarcane crop grown on saline soils irrigated by saline ground water. The yield was 125 tons/ha of sugarcane and there was marked improvement in soil chemistry. Within a year there was 37% more nitrogen, 66% more phosphates and 10% more potash. The chloride content was less by 46%. In another study there was good production of potato (Solanum tuberosum) by application of vermicompost in a reclaimed sodic soil in India. The sodicity (ESP) of the soil was also reduced from initial 96.74 to 73.68 in just about 12 weeks. The average available nitrogen (N) content of the soil increased from initial 336.00 kg/ha to 829.33 kg/ha (Sinha et al., 2009b).

As all composts (much so vermicompost) conserve soil moisture it reduces the need for irrigation which is generally the source of most salts in soil. Vermicompost also increase the rate of water infiltration and reduces evaporation, which means that less salt accumulates at the surface and the top soil is less saline. High soil salinity can also increase susceptibility
to disease and nullify the natural disease suppressive effects of composts (Compost Australia, 2011).

2.10.13 Increases the ‘soil organic matter’ (soil carbon) and soil structure which is vital for crop growth

Application of all composts increase the soil organic matter (SOM) i.e. soil carbon to more sustainable levels, above 3-5 % and improve fertility. In loamy soil, compost applied @16 tons /acre (35 tons/ha), SOM increased from 1.1 % to 2.5 %. Organic carbon in soil plays a central and fundamental role in soil structure, quality and fertility. SOM acts as a glue to bind soil particles into aggregates thus improving soil structure, infiltration, air porosity, water and nutrient holding capacity. Soil erosion and compaction are exacerbated when soils are depleted in organic matter. Soil quality and fertility reduces over time as carbon is continually removed from farm soil through grain harvesting, cutting of hay and stubble fed to cattle and also through oxidation as greenhouse gas carbon dioxide. Soil carbon in farms is not being replaced in natural way. Application of vermicomposts replenishes the SOM adds the lost soil carbon and helps to sustain the soil quality and fertility and maximize production over time (Compost Australia, 2011).

2.10.14 Maintains optimal pH value of soil

Most compost have a neutralizing value of 5% calcium carbonate equivalent in the dry matter (3 % in fresh compost) compared with 50 % for ground limestone. The neutralizing value of 30 tons of fresh compost is roughly equivalent to 2 tons of limestone. With repeated application at this rate, soil would either maintain or slightly increase in pH over time.In loamy soil, compost applied @16 tons/acre (35 tons/ha raised pH from 6.8 to 7.1 (Compost Australia, 2011).

2.10.15 Increases water holding capacity of soil

Addition of vermicompost to soils increases water holding capacity, maintain evaporation losses to a minimum and works as a good absorbant of atmospheric moisture due to the presence of colloidal materials – the earthworm mucus. The worm vermicast works as micro-dams storing hygroscopic and gravitational water. The water stable aggregates of polysaccharide gums produced by the bacteria inhabiting in the intestine of earthworms increases the general entry of water into the soil and infiltration due to construction of
cemented macro-pores (Bhandari *et al.*, 1967; Munnoli *et al.*, 2002; Munnoli and Saroj, 2011). Increasing water holding capacity of soils prevents soil erosion and improves productivity.

### 2.11 Vermicompost and plant growth

As regards the direct effects on plant growth, vermicompost constitutes a source of plant macro- and micronutrients. Although some of these nutrients are present in inorganic forms and are readily available to plants, most are released gradually through mineralization of the organic matter, thus constituting a slow-release fertilizer that supplies the plant with a gradual and constant source of nutrients (Chaoui *et al.*, 2003). In addition to increasing plant growth and productivity, vermicompost may also increase the nutritional quality of some vegetable crops such as tomatoes (Gutierrez-Miceli *et al.*, 2007), Chinese cabbage (Wang *et al.*, 2010a), spinach (Peyvast *et al.*, 2008), strawberries (Singh *et al.*, 2008), lettuce (Coria-Cayupan *et al.*, 2009) and sweet corn (Lazcano *et al.*, 2011).

Research studies have confirmed that vermicomposts have beneficial effects on growth of a variety of crops including cereals and legumes, vegetables, ornamental and flowering plants and field crops (Edwards and Burrows, 1988; Gajalakshmi and Abbasi, 2004).

Vermicompost significantly stimulates the growth of a wide range of plant species including several ornamental plants such as geranium (Chand *et al.*, 2007), marigolds (Atiyeh *et al.*, 2002a), petunia (Arancon *et al.*, 2008), chrysanthemum (Hidalgo and Harkess 2002a) and poinsettia (Hidalgo y harkess, 2002b). Vermicompost has also been shown to stimulate plant flowering, increasing the number and biomass of the flowers produced (Atiyeh *et al.*, 2002; Arancon *et al.*, 2008). These investigators have demonstrated consistently that vermicoposted organic wastes have beneficial effects on plant growth which is independent of nutritional transformations and availability.

The variability in the effects of vermicompost may depend on the cultivation system into which it is incorporated, as well as on the physical, chemical and biological characteristics of vermicompost, which vary widely depending on the original feedstock, the earthworm species used, the production process, and the age of vermicompost (Roddia *et al.*, 2006, Roberts *et al.*, 2007).
Vermicompost has been found to have beneficial effects when used as a total or partial substitute for mineral fertilizer in peat-based artificial greenhouse potting media and as soil amendments in field studies. Likewise, some studies show that vermicomposting leachates or vermicompost water-extracts, used as substrate amendments or foliar sprays, also promote the growth of tomato plants (Tejada et al., 2008), sorghum (Gutierrez-Miceli et al., 2008) and strawberries (Singh et al., 2010).

2.11.1 Role of vermicompost in field soils

From earlier studies it is evident that vermicompost provides all nutrients in readily available form and also enhances uptake of nutrients by plants. Ferreras et al., (2006) observed that addition of 20 tons ha\(^{-1}\) of vermicompost to an agricultural soil in two consecutive years significantly improved soil porosity and aggregate stability. The number of large, elongated soil macropores increased significantly after a single application of a dose of vermicompost equivalent to 200 kg ha\(^{-1}\) of N to a corn field (Marinari et al., 2000). Similarly, Gopinath et al. (2008) reported a significant decrease in soil bulk density and a significant increase in soil pH and total organic carbon after application of vermicompost in two consecutive growing seasons, at a rate equivalent to 60 kg ha\(^{-1}\) of N. Together these changes in soil properties improve the availability of air and water, thus encouraging seedling emergence and root growth.

Many results of several long-term studies have shown that the addition of compost improves soil physical properties by decreasing bulk density and increasing the soil water holding capacity (Weber et al., 2007). Moreover, in comparison with mineral fertilizers, compost produces significantly greater increases in soil organic carbon and some plant nutrients (Garcia-Gil et al., 2000, Bulluck et al., 2002, Nardi et al., 2004, Weber et al., 2007).

Sreenivas et al. (2000) studied the integrated effect of application of fertilizer and vermicompost on soil available nitroen (N) and uptake of ridge gourd (Luffa acutangula) at Rajendranagar, Andhra Pradesh, India. Soil available N increased significantly with increasing levels of vermicompost and highest N uptake was obtained at 50% of the recommended fertilizer rate plus 10 tons ha\(^{-1}\) vermicompost. Similarly, the uptake of N,
phosphorus (P), potassium (K) and magnesium (Mg) by rice (*Oryza sativa*) plant was highest when fertilizer was applied in combination with vermicompost (Jadhav *et al*., 1997).

### 2.11.2 Vermicompost as biopesticides

There has been considerable reports and evidences in recent years regarding the ability of earthworms and vermicompost to protect plants against various pests and diseases either by suppressing or repelling them or by inducing biological resistance in plants to fight them or by killing them through pesticidal action (Anonymous, 2001; Arancon *et al*., 2002; Chaoui *et al*., 2002; Arancon *et al*., 2005; Compant *et al*., 2005; Wang *et al*., 2007; Elmer, 2009 and Jack, 2010). Plants grown with vermicompost which contain balanced nutrients and greater microbial and faunal diversity compared to chemical fertilizers are less susceptible to a number of arthropod pests and sustain significantly lower pest populations. The mechanisms leading to vermicompost-mediated plant defenses against insect pests has not been deciphered but it may be due to the antagonistic microbes found in vermicompost. (Hu *et al*., 2003).

All composts have been found to suppress high levels of soil-borne disease. Vermicompost is much more efficient. Ayres (2007) reported that mean root disease was reduced from 82% to 18% in tomato and from 98% to 26% in capsicum in soils amended with compost. Naturally-occurring microbes (bacteria and fungi) can suppress organisms that cause diseases. Important plant diseases suppressed by composts are wilt caused by *Fusarium* spp.; damping off caused by *Fusarium*, *Pythium*, *Rhizoctonia* and *Sclerotium* spp.; stem and root rot caused by *Fusarium*, *Rhizoctonia*, *Pythium*, *Phytophthora*, *Sclerotium* and *Aphanomyces* spp. Woody materials in composts that degrade slowly can provide long lasting disease suppression for more than three years as they release nitrogen, potassium and phosphorus slowly into the soil. Nitrogen (N) is a key nutrient in disease suppression and nitrogen deficiencies in soil can make plants more susceptible to diseases. There are several ways to show how the composts suppress crop diseases. These are by competition, secretion of antibodies and hormones, predation and parasitism, induction of systemic defences in plants against diseases and by boosting immune systems (Magdoff, 2004 and Hoitink, 2008).

### 2.11.3 Biological resistance in plants by vermicompost
Vermicompost contains some antibiotics and actinomycetes which help in increasing the power of biological resistance among the crop plants against pest and diseases. Pesticide spray was significantly reduced where earthworms and vermicompost were used in agriculture (Sinha and Valani, 2011b). Vermicomposts are consistently capable of conferring or inducing plant resistance in economically important plants. It has been shown to increase resistance in host plants against pests, pathogens, plant parasitic nematodes and a large number of arthropods including jassids (Empoasca kerri), aphids (Myzus persicae & Aphiscraccivora), spider mites (Tetranychus urticae), mealy bugs (Planococcus citri) and caterpillars (Pieris rapae) (Chaoui et al., 2002; Arancon et al., 2002, 2005 and 2007).

Vermicompost amendments as low as 20% have been shown to decrease leaf consumption by caterpillars and population growth of aphids on cabbage (Arancon et al., 2005). Yasmin (2011) found that vermicompost was very effective in causing Arabidopsis plants to become resistant to the generalist herbivore Helicoverpa zea. Vermicompost causes plants to have non-preference and toxic effects on insects. This resistance adversely affects insect development and survival on plants grown in vermicompost-amended soil. This resistance is possibly due to the interactions between the diverse microbial communities in vermicompost with plant roots, as is evident from the sterilization assays of vermicompost.

Earthworms gut acts as a microbial factory and it proliferates the microbial community and diversity in millions and trillions in soils in short time (Binet et al., 1998). Increasing the population of mixed species of earthworms in soil can proliferate the population and distribution of these bio-control microbial agents in farm soil in billions and trillions. This may become the future safe and non-chemical biological based strategies for crop disease control and protection, completely eliminating the destructive chemical based control (Jack, 2010).

2.12 Microbes and plant growth

Plant productivity is governed by the supply of nutrients from the soil, which in turn is dependent on the activity of soil microorganisms. Soil is the natural habitat for countless of microorganisms and other living forms of numerous genera and species (Bugmann, 1996). Microorganisms in soil function within communities composed of a number of different
species and are influenced by the biological, physical and chemical properties of their immediate surroundings (Burns and Stach, 2002). Microbial loads in soil plays a key role in agro ecosystems through regulating the dynamics of organic matter decomposition and plant nutrient availability (Clegg et al., 2003). The microbial communities associated to the root system are key factors in the chapter of sustainable systems since they regulate the availability of plant nutrient (Medina et al., 2003).

Soil quality can be evaluated by the integration of biological, chemical and physical properties (Martin and Johnson, 1995; Franzluebbers et al., 1999; Ashton and Macintosh, 2002; Dominy and Haynes, 2002; Spaccini et al., 2002). Though soil organic matter (SOM) may be the most important parameter in describing soil quality, microbial activity is a potential indicator of soil quality and has the ability to predict changes in soil properties (Ruark and Zarnoch, 1992; Barrett and Burke, 2000; Ibekwe, 2004) as plants rely on microorganisms to mineralize organic nutrient for growth and development (Chen et al., 2003).

2.12.1 Role of microbes in carbon and nitrogen fixation

They play an active role in increasing soil fertility as a result of their involvement in the nutrient cycling of carbon and nitrogen (McLean and Parkinson, 1997; Katterer and Anderen, 2001; Delgado and Follett, 2002; Dominy and Haynes, 2002). Soil microorganisms are potential in transforming inorganic and organic C and N into SOM that can be potentially utilized for the plant growth. Soil microorganisms fix carbon and nitrogen by forming new biomass using the energy gained from oxidation of the carbon sources through respiration or inorganic chemical reactions (Sokatch, 1969).

2.12.2 Microbes and plant growth promotors

It has been shown that microorganisms can produce materials that may affect plant growth such as substances acting as plant hormone analogues or growth regulators (Frankenberger and Arshad, 1995). There is a concrete evidence demonstrating that microorganisms, including bacteria, fungi, yeasts, Actinomycetes and algae, are capable of producing plant growth regulators (PGRs) such as auxins, gibberellins, cytokinins, ethylene and abscisic acid in considerable amounts (Frankenberger and Arshad, 1995).

2.13 Biological assay
Phytochemicals (from the Greek word phyto, meaning plant) are biologically active, naturally occurring chemical compounds found in plants, which provide health benefits for humans further than those attributed to macronutrients and micronutrients (Hasler and Blumberg, 1999). They protect plants from disease and damage and contribute to the plant’s color, aroma and flavor. In general, the plant chemicals that protect plant cells from environmental hazards such as pollution, stress, drought, UV exposure and pathogenic attack are called as phytochemicals (Gibson et al., 1998; Mathai, 2000). Recently, it is clearly known that they have roles in the protection of human health, when their dietary intake is significant. More than 4,000 phytochemicals have been cataloged (American Cancer Society, 2000) and are classified by protective function, physical characteristics and chemical characteristics (Meagher and Thomson, 1999) and about 150 phytochemicals have been studied in detail (Mathai, 2000).

These compounds are known as secondary plant metabolites and have biological properties such as antioxidant activity, antimicrobial effect, modulation of detoxification enzymes, stimulation of the immune system, decrease of platelet aggregation and modulation of hormone metabolism and anticancer property. There are more than thousand known and many unknown phytochemicals. It is well-known that plants produce these chemicals to protect themselves, but recent researches demonstrate that many phytochemicals can also protect human against diseases which are yet to be identified (Narasinga Rao, 2003).

2.14 Antimicrobial activity

An antimicrobial substance is one that kills or inhibits the growth of microbes such as bacteria and fungi. The antimicrobial drug should either kill microbe (microbicidal) or prevent the growth of microbes (bacteriostatic). According to WHO the mortality due to infectious diseases has become more prevalent due to the emergence of the antibiotic resistant strains of microbes. Microbes are part of the universe really challenging for the researchers in controlling their pathogenicity to the human life. The microbe that acquires the resistance to the new drug is a challenging task for the pharmacologist involved in novel drug design. To overcome the alarming problem of microbial resistance to antibiotics and the discovery of novel active compounds against new target is a matter of urgency.
According to Bandow et al. (2003) the clinical efficiency of the present available antibiotics are threatened by the emergence of the multi-drug resistance pathogens. The potential for developing antimicrobial from higher plants appears rewarding as it will lead to the development of a phytomedicine to act against microbes. The plant-based antimicrobials have enormous therapeutic potential as they can serve the purpose with lesser side effects that are often associated with synthetic antimicrobials (Iwu et al., 1999). According to Colombo and Bosisio (1996) the increasing failure of the chemotherapeutics had led to the screening of the several medicinal plants for their potential antimicrobial activity.

2.14.1 Plants and dermatophytes

Skin, hair, nail, and subcutaneous tissues in human and animal are subjected to infection by several organisms, mainly fungi named dermatophytes and cause dermatophytoses (Valeria et al., 1996; Amer et al., 2006). Dermatophytoses are one of the most frequent skin diseases of human, pets and livestock (Tsang et al., 1996). The disease is widely distributed all over the world with various degrees and more common in men than in women. There are three genera of mould that cause dermatophytosis. These are *Epidermophyton*, *Trichophyton* and *Microsporum*. Contagiousness among animal communities, high cost of treatment, difficulty of control and the public health consequences explain their great importance (Chermette et al., 2008).

The use of systemic drugs is limited to treat man or animal due to their high toxicity and problems of residues in products intended for human consumption (Araujo et al., 2009). Different treatments have been recommended to control dermatophytes. In general, pharmacological treatment option includes antifungal agents (Aly, 1997 and Agwa et al., 2000), but recently the use of some natural plant products has been emerged to inhibit the causative organisms. They are safe to human and the ecosystem than the chemical antifungal compounds, and can easily be used by the public who used them for thousands of years to enhance flavor and aroma of foods as well as its economic value (Shelef et al., 1980; Shelef, 1983).

A number of reports are available *in vitro* and *in vivo* efficacy of plant extract against plant and human pathogens causing fungal infections (Natarajan et al., 2003). The activity of plant extract against dermatophytosis i.e. the superficial infections of skin or keratinised
tissue of man and animals can be very well visualized from the reports of Venugopal and Venugopal (1995). They reported the activity of plant extracts against 88 clinical isolates of dermatophytes which includes *Microsporum cannis*, *Microsporum audouinii*, *Trichophyton rubrum*, *Trichophyton mentagrophytes*, *Trichophyton violaccum*, *Trichophyton simi*, *Trichophyton verrucosum*, *Trichophyton erinacci* and *Epidermophyton floccosum* by agar dilution technique.

**2.15 Antioxidant activity**

Aging is an universal biological phenomenon associated with histological, biochemical and functional alternation. It is generally accepted that free radicals play an important role in the progress of aging (Ashok and Ali, 1999). About 3,50,000 species of plants are available in the universe. Plants were used as medicines to cure injuries and deadly diseases in different combination prepared with the lot of care by the practitioners from time immemorial in India. The age old pharmacological practices are still in use all over the country owing to lesser cost and side effects.

The presence of antioxidants in plants or the plant products has a main role of eradicating the free radicals from our body that makes people healthy and beautiful without much cost but with much care. The antioxidants of the plants may be present in any part of the plant like stem, leaf, flower or seed. The secondary or the phytochemicals present in the plant parts are responsible for the property of the antioxidants present in them. The use of antioxidants has a varied role in the treatment of many diseases.

The antioxidants also have the effect of maintaining health and glowing of the skin of the human body by preventing or slowing down the process of ageing. The plants and animals maintain inbuilt complex systems of multiple types of antioxidants, such as glutathione, vitamin C and vitamin E as well as enzymes such a catalase, superoxide dismutase, glutathione and virus peroxidases. According to Larson (1988) there is a growing interest towards natural antioxidants of herbal resources. Antioxidants are substances or nutrients in our food which can prevent or slow the oxidative damage to our body. Antioxidants are a molecule that is capable of inhibiting the oxidation of other molecules.
Antioxidants act free radical scavengers and hence prevent and repair damage done by these free radicals.

The recent work of Ng et al. (2004) linked the antioxidant activity in an aqueous extract of rose flowers (*Rosa rugosa*), primarily with the presence of a phenolic compound identified as a gallic acid derivative. Antioxidants of a polysaccharide structure were also found by Vander Jagt and others (2002) but exhibited lower activity. Phenolic compounds were associated with radical scavenging activity in flower extracts of *R. rugosa* and *R. davurica* (Cho et al., 2003). In addition to antioxidant activity, water extracts of rose flowers were reported to possess anti-inflammatory and analgesic properties (Choi and Hwang, 2003).

**2.15.1 Production of free radicals**

Oxygen is essential for the existence of life of the higher organisms. Usually the oxygen taken up by the organisms are converted into water by the process of reduction during metabolism. But this is not the fate always for oxygen. Sometimes it may not be completely reduced to water instead they may be converted into the free radicals that cause destruction of the cells. The free radicals are produced as the by-product of cellular metabolism in the cells or due to environmental effects. They exist as the independent molecules or atoms that contain one or more unpaired electrons that are highly reactive. These species are also called as reactive oxygen species (ROS). It is estimated that about 1-4% of the oxygen taken up by the body is converted to free radicals. It is also formed by the action of enzymes such as cytochrome P450 reductase and xanthine oxidase. The free radical produces the chain reaction in the body. The above way specifies the endogenous method of the free radical production while the exogenous sources of the radicals include tobacco smoke, ionizing, pollutants, organic solvents and pesticides (Robinson *et al.*, 1997).

The chemical compounds that are capable of generating potential toxic oxygen species are referred to as the pro-oxidants. The compounds that oppose these reactions that scavenge or suppress these molecules are termed as the antioxidants. The oxidative stress can be overcome by the inbuilt antioxidant system available in the body or by the use of the antioxidants. They may include GSH, NADPH, ascorbic acid and vitamin E.
In normal cell there exists a balance of the pro-oxidant and the antioxidant species. This balance can sometimes be shifted towards the pro-oxidant when the production of the oxygen species is increased greatly by ingestion of chemicals and by the diminishing of antioxidant and also by inactivation of enzymes responsible for disposal of oxygen free radicals in the system. The stress created in body is termed as the oxidative stress. They may structurally alter the cell and may affect the function of the cell thereby causing the tissue damage. Though the oxidation reaction is crucial for the existence of life they also can cause damage.

2.15.2 The harmful effects of the free radicals

The free radicals are highly reactive and are capable of damaging all the biomolecules. The free radical begets free radical, i.e. generate free radicals from normal compounds that continue as a chain reaction. In proteins the free radicals can cause the oxidation of the sulfhydryl groups and modification of certain aminoacids like methionine, histidine, tryptophan etc. they may damage proteins by fragmentation, cross-linking and aggregation thereby the loss of the biological activity of proteins. The poly unsaturated fatty acids (PUFA) are highly susceptible to free radical damage. The hydroxyl radical removes the hydrogen atom from the PUFA.

The antioxidant potential of leaves, stems, roots, flowers, fruits of many plants was evaluated in vitro using a most convincing spectrophotometric method based on measuring the radical scavenging effect of 2,2-diphenyl-1-picrylhydrazyl (DPPH) radicals and iron chelating activity by FRAP assay (Nowaka and Gawlik-Dzikib, 2007).

2.16 Cytotoxicity studies

Cancer is a disease of erroneous cells that have high potential of abundant proliferation without any physiological demand from the organ involved. According to the National Cancer Control Programme in India, cancer was becoming one of the ten leading diseases that cause death. There are 11.4 million people in the world who have been diagnosed with cancer in 2004 (WHO). There are different methods to combat cancer in which the development of cytotoxic drugs against cancer cells is gaining momentum the drug design is the major pharmacological challenge for the researchers as the drug should target only cancer cells which are the transformed normal cells. The trend is the use of multi target
drug in favor of mono drug therapy to enhance the protective in spite of attacking the target cells with phyto-pharmaceuticals (Wagner, 2006). The phytomedicine provides multiple chemical structures which are bioactive compounds. The drugs are designed in such a way that they are combinations of drugs with multiple functions like prevention, protection and repair mechanisms (Wagner, 2006).

According to the Breast Cancer Facts by the American Cancer Society for World Health Organization, it is stated that the leading death cases in both developing and developed country was affected by breast cancer among women. Breast cancer can be treated by different methods including surgery (mastectomy), radiation therapy, systemic therapy, targeted therapy and hormone therapy. The hormonal and chemotherapeutic approaches are slowly becoming unresponsive in cancer patients.

2.16.1 Phytomedicine for cancer

According to the World Cancer Research Fund and the American Institute of Cancer Research, in which 30-40% of the cases are curable by appropriate diet, physical activities and maintenance of appropriate body weight. The drug resistance by cancer cells is evident due to the cellular resistance developed by tumor cells (Longley and Jhonston, 2005).

Herbal medicines are now widely being accepted as importance as complementary and alternative medicine throughout the world (Shoeb, 2006). The herbal remedies having antiviral and anticancer activities are good candidates for the treatment of HCC (Thyagarajan, 2002). A high number of new drugs derived from plant secondary metabolites have been applied towards the treatment of cancer (Balunas and Kinghorn, 2005; Newman et al., 2003). Natural products are gaining prominence due to the recognition of diverse chemical structures available and their biological significance (Qurishi et al., 2010). Several studies have demonstrated that extracts from several herbal medicines mixtures had an anticancer potential in vitro or in vivo.

2.17 Essential Oils

The fragrant mixture of liquids, obtained through distillation of aromatic plant materials, is known as an essential oil (Burt, 2004). Essential oils are mixtures of fragrant substances or mixtures of fragrant and odorless substances. A fragrant substance is a
chemically pure compound, which is volatile under normal conditions and which owing to its odour can be useful for the society (Gunther, 1952).

**2.17.1 Sources of Essential Oils**

The occurrence of essential oils is restricted to over 2000 plant species from about 60 different families, however only about 100 species are the basis for the economically important production of essential oils in the world (Baylac and Racine, 2003; Delamare et al., 2007).

Essential oils are isolated from various parts of the plant, such as leaves (basil, patchouli, cedar), fruits (mandarin, fennel), bark (cinnamon), root (ginger), grass (citronella), gum (myrrh and balsam oils), berries (pimenta), seed (caraway), flowers (rose and jasmine), twigs (clove stem), wood (amyris), heartwood (cedar), and saw dust (cedar oil); Burt, 2004; Sood et al., 2006; Hussain et al., 2008). Essential oils from different plants have gained much interest due to their antioxidant, antitumor, antibacterial, antifungal and insecticidal properties (Burt, 2004). Factors that determine the composition and yield of the essential oil obtained are numerous. In some instances it is difficult to segregate these factors from each other, since many are interdependent and influence one another (Terblanche, 2000). These variables may include seasonal and maturity variation, geographical origin, genetic variation, growth stages, part of plant utilized and postharvest drying and storage (Marotti et al., 1994; Hussain et al., 2008; Anwar et al., 2009).

There are many reports in literature regarding the variation in the chemical profile of essential oils from various plants collected during different seasons (Kofidis et al., 2004; Celiktas et al., 2007; Van Vuuren et al., 2007 and Hussain et al., 2008). Pala-Paul et al. (2001) reported month-to-month variations in the essential oil composition and yield of Santolina rosmarinifolia, which could be attributed to precipitation and temperature. Results obtained by Badi et al. (2004) for Thymus vulgaris (thyme), also indicated that timing of harvest is critical to both yield and oil composition.

Many reports are available in the literatures regarding the variation in the yield and quality of essential oils with respect to maturity stages (Marotti et al., 1994; Skoula and Harborne, 2002; Yildirim et al., 2004; Anwar et al., 2009). Chalchat et al. (1995) reported
that the oil yield of young *Tagetes minuta* plants, before flowering, was high, compared to that of plants in early or full flowering stages.

There are many reports in the literature showing the variation in the yield and chemical composition of the essential oil with respect to geographical regions (Uribe-Hernandez *et al*., 1992; Souto-Bachiller *et al*., 1997; Celiktas *et al*., 2007; Van Vuuren *et al*., 2007). Such differences could be linked to the varied soil textures and possible adaption response of different populations, resulting in different chemical products being formed, without morphological differences being observed in the plants (Hussain *et al*., 2008). Altitude seems to be another important environmental factor influencing the essential oil content and chemical composition (Vokou *et al*., 1993). Moreover, the preference of the plant for these conditions suggest that genetic make-up of the plant, rather than the soil-type in which it is growing, should have a greater influence on the chemical profile of the oil produced (Graven *et al*., 1990; Terblanche, 2000; Milos *et al*., 2001).

Other factors which affect the growing plants thus leading to variations in oil yield and composition, include part of plant used (Chalchat *et al*., 1995; Santos-Gomes and Fernandes-Ferreira, 2001); post harvest drying (Skoula and Harborne, 2002); length of exposure to sunlight (Burbott and Loomis, 1957; Clark and Menary, 1979), availability of water, height above sea level (Galambosi and Peura, 1996), plant density (Graven *et al*., 1990; Clark and Menary, 1979), time of sowing (Galambosi and Peura, 1996) and the presence of fungal diseases and insects (Graven *et al*., 1990). The oil composition and yield may also change as a result of the harvesting used (Bonnardeaux, 1992), the isolation techniques employed (Weston, 1984; Charles and Simon, 1990; Moates and Reynolds, 1991), the moisture content of the plants at the time of harvest (Burbott and Loomis, 1957) and the prevailing steam distillation conditions. Methods to isolate essential oils may be categorized into enfleurage, steam distillation, solvent extraction, hydrodistillation, and supercritical fluid extraction. Hydrodistillation or steam distillation is the most widely utilized physical method for isolating essential oils from the botanical material (Whish, 1996 and Masango, 2004). Although steam distillation is much popular for the isolation of essential oils on commercial scale and 93% of the oils are produced by this process, but it is
not a preferred method in research laboratories (Masango, 2004). This is probably due to unavailability of steam generators and suitable distillation vessels. Most studies which focus on the essential oil of herbs have made use of hydrodistillation in Clevenger-type apparatus (Kulisic et al., 2004; Sokovic and Griensven, 2006; Hussain et al., 2008).

Essential oils are made up of three elements almost exclusively carbon, hydrogen and oxygen. By far the most common component class is the terpenes. Terpenes are made from combinations of several 5-carbon- base (C5) units called isoprene (Gunther, 1952). Terpenes can form building blocks by joining together in a head-to-tail configuration to form monoterpene, sesquiterpenes, diterpene and larger sequences (Pinder, 1960). There is plenty of literature on the characterization of essential oils. Capillary gas chromatography (GC) with flame ionisation detection (FID), are, in most cases, the method of choice for quantitative determinations. Many researchers make use of mass spectrometers (MS), coupled with GC, to determine the identities of components (Salzer, 1977).

At present different extraction techniques like distillation, effleurage, CO₂ extraction, expression and solvent extraction are applied for oil extraction from rose. But commonly steam distillation and solvent extraction methods are used (Boutekedjiret et al., 2003). Rose essential oil comprises a number of different types of complex constituents. So their separation and analysis is performed by gas chromatography. During the last few years, gas chromatography has been established as a fast efficient and relatively simple technique for separation and analysis of mixture of volatile substances and is being extensively used by the perfumers (Lin et al., 2003). Gas chromatography–mass spectrometry (GC-MS) is one of the most promising techniques for determination of the components of essential oil (Tabanca et al., 2005). The rose essential oil comprises of a number of different type of complex constituents. These constituents can be analyzed by adopting extraction techniques like, using solvent hexane (Reverchon, 1997).

2.17.2 GC-MS

Gas chromatographic analysis (Sood et al., 1994) is most advanced, fast and relatively simple technique for separation of different aroma constituents by the perfumer. Moreover, the chances of interaction between the components are greatly reduced. GC-MS is a combination of two different analytical techniques, Gas Chromatography (GC) and Mass
Spectrometry (MS). GC is recognized as the most important and suitable technique to discover the compounds present in the active plant extracts. When the technique is coupled with MS, additional information about each separated compound, its molecular weight, functional group, quantity of the compound and molecular geometry are available. Compounds present in the plant extracts are separated in the Chromatogram as a result of their distribution between a mobile and a stationary phase. GC coupled with MS is a powerful combination results from the union of high resolution capacity of GC with identification capacity of MS. Two fundamental strategies are employed in GC-MS for compound identification, (i) consists of comparing unknown substances chromatographic (retention indices) and spectroscopic (mass spectra) data against the standard substances. However in the field of natural products research, many standards are not available as more and more compounds are in the process of discovery, (ii) strategy includes several approaches (a) retention index (b) experimental mass spectra are combined with (c) published data compiled in databases. Identification of individual compounds of plant extracts are always not possible by comparing to standard MS (Sheille et al., 2002). GC-MS, with the use of internal standards, provides a multidimensional drug identification and quantification procedure, leading towards a confirmation method for forensic drug testing and evaluation of compounds present in the medicinal plants. GC-MS analysis in plant extracts is a main research tool employed for determining the composition of compounds present in the complex mixtures.