An Effective Organic Waste Recycling Through Vermicompost Technology for Soil Health Restoration

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Abstract

Globally the increase in food productivity was the major concern during the last century that started with green revolution with the use of chemical fertilizers and pesticides to grow the different crops for feeding millions of growing population. Seventy-five percent of agriculture sector is dependent on chemical fertilizers during the last 20 years for the production of agricultural produce. This had positive effects initially for many years, but during the last decade, the negative impacts of excessive usage have resulted in low crop productivity, increased infestation of pests and diseases, soil degradation, and consequently the adverse effect on the environmental parameters. This has led the advent of use of organic agriculture by using different organic amendments, biopesticides, and biocontrol measures by researchers and farmers in many different countries. This has created selective markets for organic produce as well. This is also substantiated by increased solid waste produced at various levels that mainly includes organic waste to the tune of 46% globally which is incorporated in the soil and water causing pollution. These organic wastes can be recycled by processes like vermicomposting which can produce nutrient-rich organic fertilizers which are enriched source of beneficial microbes. The large-scale vermicomposting is being practiced in many countries like India, Canada, Italy, Japan, Malaysia, the Philippines, the USA, and Nepal. Vermicomposting is an efficient way of using organic waste materials like various plant litter matter, manure, and other solid

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wastes to convert through epigeic and anecic species of earthworms into useful organic fertilizer vermicompost which when applied to soil ecosystem can enhance plant growth productivity and ameliorate soils. Such technologies can be economically sustainable and viable. Vermicompost contains micronutrients; microbes from diverse groups like bacteria, fungi, and actinomycetes; phytohormones; soil enzymes; and humic acids and is free of pest/pesticides and diseases. The nutrient quality of vermicompost varies and depends on the substrates used (moisture %, 60–70; aeration, 50%; temperature, 18–35° C; pH, 6.5–7.5; nitrogen %, 0.8–3.0; phosphate %, 0.5–1.7; and potassium %, 0.5–1.6). The application of vermicompost in cultivation of crops is beneficial not only in terms of yield but plays an important role in soil amelioration in terms of structure and nutrient management. The researchers, farmers, industries, and practitioners across many countries have reported success and recorded numerous benefits with the use organic inputs like vermicompost to cultivate various crops like paddy, wheat, eggplant, okra, and tomatoes.

Keywords
Earthworms · Organic agriculture · Organic input · Plant productivity · Vermicomposting

Abbreviations

%	Percentage
C: N	Carbon: nitrogen
Ca	Calcium
Cu	Copper
EC	Electrical conductivity
ESP	Exchangeable sodium percentage
Fe	Ferrous
Kg/m2	Kilogram/meter2
Mg	Magnesium
Mg	Milligram
Mn	Manganese
NPK	Nitrogen, phosphorus, potassium
Zn	Zinc

3.1 Introduction

Plants on earth have been providing food, promoting health, and supporting the ecosystem. The soil is critical for plant growth that harbors important organisms (Ismail 2005). Soil microorganisms influence ecosystem by contributing to plant nutrition, plant health, and soil structure and soil fertility. Soil microorganisms are integral part of biogeochemical cycles (Kirk et al. 2004; Meena and Meena 2017). Microbes stimulate plant growth by increasing nutrient availability (Ismail 2005).

Modern agriculture is based on chemical fertilizers and pesticides which is not sustainable in long terms and causes irreversible damages to the soil ecological balances across the globe. The excessive and indiscriminate usage has resulted in contamination of groundwater and atmospheric pollution. High levels of nitrate residues leach into the soil and find its way into groundwater. It has also adversely affected the crop productivity in terms of quantity and quality (persistence of pesticide residues), thereby causing reduction by 15–18% (Swietlik 1992; IFDC 2013; Asma et al. 2016). There is also increase in cost of production by 33% and increase in greenhouse gases by 60% (Swietlik 1992; IFDC 2013; Asma et al. 2016; Rahman and Zang 2018; Ashoka et al. 2017). Overuse of chemical fertilizers and pesticides in agricultural lands over long period of time has resulted in poor soil health with combined effect on crop production and increase incidences of pests and diseases. The global usage of nitrogen and phosphorus fertilizers as recorded by Lu and Tian (2017) in 2013 is as follows:

Nitrogen fertilizers: China (31%), India (15%), the USA (11%), Brazil (3%), Pakistan (2%), and others (37%)

Phosphorus fertilizers: China (27%), India (13%), Brazil (11%), the USA (10%), Canada (2%), and others (37%)

These concerns have led to greater economic impact on farmers (Swietlik 1992; IFDC 2013; Asma et al. 2016; Rahman and Zang 2018). Over the last few years, the problems associated with food security have led to thinking and application of technologies for organic agriculture by soil management techniques and microbial innovations (use of biofertilizers, biopesticides, and organic fertilizers). The soil stability is maintained by formation of aggregate particles with humification and aeration process through integrated soil management. The practice of adding organic input into soil is essential to achieve stable soil structures (Asma et al. 2016; Rahman and Zang 2018; Meena et al. 2017b).

Biofertilizers are essential component of organic farming that facilitate soil microorganisms in increasing the availability and uptake of mineral nutrients, thereby increasing the nutrient status (Ismail 2005; Kumar et al. 2017b). Application of vermicompost assists in increasing microbial activity, enzymes, and humic acids which helps to increase the aggregation and stability of soils causing improvement in aeration. It is prepared through the inoculation of earthworms to organic waste materials. The vermicomposted material has excellent biochemical properties that improve the soil qualities in terms of porosity, aeration, and nutrient availability (Ansari 2008).

Biofertilizers like vermicompost increase useful microorganisms that recycle the organic substances in the soil and release the available nutrients slowly to the plants (Kirk et al. 2004; Ismail 2005; Ansari 2008; Meena et al. 2018b). The process of composting consists of two phases – breakdown and building up phase. Breakdown involves decomposition of biodegradable substances (organic waste) into degraded substances into simpler form like amino acids and subsequently into nitrates and nitrites. Building up phase consists of formation of complex humic acids and finally transforms to fine humus substance in composting material at the final stages. The processes are carried out by aerobic microflora like *actinomycetes*, *Azotobacter*, and *Nitrosomonas.*

Vermicomposting is an efficient process as it is faster than the conventional composting methods that take longer time (about 3 months). Conversion of organic waste results in superior quality of end material (vermicompost) which contains earthworm cast and available nutrients encapsulated in mucus formed through the processing of composting material mixed with fine soil particles when processed through the earthworm gut systems. The plants are able to absorb the macro- and micronutrients easily slowly from soil results in optimum quantity (Kale 1998; Ansari and Ismail 2001; Meena et al. 2015d). These nutrients from organic source result in effective growth of plant productivity.

Use of organic inputs has become an essential component of organic agriculture. Vermicomposting plays important role in realizing the agriculture without the use of chemical fertilizers. Vermicomposting is a simple process and has excellent properties without causing any damage to the plants. The process comprises the use of earthworms for the degradation of organic waste through vermin, stabilizing it in association with microorganisms. Organic waste is processed by aerobic microorganisms and is consumed by earthworms which pass through gut where it is mixed with coelomic fluid and mucus. It is also processed through microflora in the gut that also enhances the antibacterial properties. The vermicast is mixed with the composted material that is free of any pathogens. There is also a process of thermophilic digestion in the initial phase of composting that utilizes the thermophilic microorganisms. The diversity of useful microorganisms increases in the vermicompost (Ansari 2008, 2012; Meena et al. 2017c; Buragohain et al. 2017). Vermicomposting is an effective method of reducing organic waste in order to produce vermicompost which is the transformation of garbage to valuable product with high market value that can substitute the chemical fertilizers in agriculture in an effective way by improving the soil health in terms of enhancement of soil microbial community with effective recycling of minerals ensuring safe environment and human health (Asma et al. 2016). Vermicomposting is the process of producing compost by utilizing earthworms to turn organic waste into high-quality compost that consists mainly of worm cast in addition to decayed organic matter (Ismail 2005; Devi and Prakash 2015; Verma et al. 2015). Vermicomposting helps to convert the organic wastes (agro-wastes, animal manure, and domestic refuse) into highly nutrient fertilizers for plant and soil (Gajalakshmi and Abassi 2003; Yadav et al. 2018b). Vermicompost is soft light and dark black material like peat with all the properties of standard compost like structure, aeration, and moisture enriched with useful microbes (Ismail 2005; Edwards et al. 2011; Meena et al. 2015b).

Organic farming through the use of vermicompost which is enriched with NPK and micronutrients and essential microbes like nitrogen-fixing and phosphate-solubilizing bacteria and actinomycetes is an alternative to chemical fertilizer-based agriculture (Sinha et al. 2011). Vermicompost not only enhances plant growth but also plays a role in plant protection without causing any harm to the plants (Ansari and Jaikishun 2011; Meena and Yadav 2015).

The organic waste generated has been a serious problem affecting the environment and has caused a global concern. These concerns can be addressed by solving the problems with sustainable solutions using organic waste recycled and composted materials like vermicompost. Researchers across many countries have carried out researches on organic waste management through various methods and technologies to produce composted materials. The organic solid waste is a major problem in fast-growing urbanized areas in many developing countries. The recycling of these organic wastes through vermicomposting to produce organic fertilizers like vermicompost is highly cost effective and critical for farming practices (Ansari 2008; Meena et al. 2015c). Reduction in the use of chemical fertilizers/pesticides and reduced environmental hazards are the critical benefits of recycling organic waste (Nath et al. 2009; Varma et al. 2017b).

Soil is defined as the unconsolidated mineral material on the immediate surface of the earth that serves as a natural medium for the growth of land plants (Donahue et al. 1990). Soils are formed from hard rocks and other organic residues. Soil formation is determined by the climate, living organisms, nature of parent material, topography, and time period and is brought about by the following processes (Brady 1999):

1. Weathering and organic matter breakdown
2. Translocation of inorganic and organic materials up and down the soil profile
3. Accumulation of soil material in horizons in the soil profile

The physical properties of soil include texture, structure, density, porosity, consistency, temperature, color, and water content. According to the US Department of Agriculture, soils are classified into 12 textural classes based on the percentage of soil separates – sand, silt, and clay: sands, loamy sands, sandy loam, loam, silt loam, silt, sandy clay loam, silty clay loam, clay loam, sandy clay, silty clay, and clay. The chemical properties of soil include mineral solubility, nutrient availability, pH, cation exchange, and buffering action. The biological properties of soil are due to the activity of soil dwellers like rodents, worms, insects, bacteria, fungi, actinomycetes, algae, and protozoa, which, by churning the soil and mixing organic residues, alter the physical conditions of the soil (Donahue et al. 1990; Sihag et al. 2015).

Soil is a living system that contains essential nutrients like NPK and macro- and micronutrients. It also contains microbial community supported by macroinvertebrates. Soil undergoes physical and biological processes that maintain the structure and stability with different physiological processes like respiration, nutrient recycling, and decomposition. The addition of chemical fertilizers and pesticides used in crop productivity provides available nutrients and promotes plant growth. The chemical fertilizers and pesticides have been an important component of modern agriculture for the past decade. But over the years, due to persistent and excessive use, it has resulted in maneuvering the soil physical, chemical, and biological properties. It has caused the hardening/compaction of soil, reduction in soil fertility, and pesticide residue in soil, thus changing the nature of soil in terms of its properties (soil degradation). Compaction is an important indication of soil degradation which is affecting the modern agriculture. Soil porosity is reduced leading to increase in bulk density. One of the major reasons is frequent and excessive use of chemical fertilizers over longer period of time (Mari et al. 2008; Varma et al. 2017a). Soil compaction results in poor soil aeration and percolation of water, soil erosion, restricting the root growth, and excessive runoff. The groundwater recharge and mineral movement are also affected (Blanco et al. 2002; Batey 2009). Across the globe, the fertile soils have been transformed into desertified lands, problematic soils like alkaline/saline/sodic soils, and acidic soils due to indiscriminate modern agricultural practices.

Large extents of land in India and other parts of the world are affected by salinity and alkalinity due to major degradation processes like salinization, water logging, chemical impairment, and desertification (Dagar and Singh 1994; Dagar et al. 1994; Datta et al. 2017b). Twenty-seven subgroups of salt-affected soils have been identified based on clay mineralogy, presence or absence of calcic horizon, textural variations, and groundwater conditions (Murthy et al. 1980). In India these are classified as saline soils, alkali (sodic) soils, and saline-alkali soils. Saline soils contain a concentration of neutral soluble salts with the electrical conductivity (EC) of a saturated extract of the soil being more than 4 dSm^{-1}. The exchangeable sodium percentage (ESP) is less than 15, and the pH is less than 8.5 because the salts are neutral; the chlorides and sulfates of the base-forming cations dominate. Saline-alkali soils contain appreciable quantities of neutral soluble salts and enough sodium. ESP is greater than 15 and EC of the saturated soil extract is more than 4 dSm^{-1}. The pH is 8.5 or less.

Sodic soil (Fig. 3.1) does not contain any significant amount of soluble salts. The detrimental effects these soils have on plants are not only due to the toxicity of Na^+, HCO_3^-, and OH^- ions but also due to reduced water infiltration and aeration. The pH is always above 8.5, often rising to 10.0 and above due to hydrolysis of Na_2CO_3.

These problematic soils have also been reclaimed using organic amendment methods. The use of organic amendments, such as composts, biosolids, straw, sawdust, manures, and all crop residues (Wallace and Terry 1998), enhances bioremediation by improving physical properties, including infiltration, aeration, and water holding capacity as well as conditions for microbial growth, such as aeration, nutrients, and available organic carbon (Bollag and Bollag 1995). The effectiveness of an organic material in reclaiming alkali soils depends on the amount of CO_2 produced and conditions resulting through a drop in the redox potential (Swarup 1994). Mulches and composts are important soil amendments (Figs. 3.2 and 3.3). Organic mulches are carbon-containing material derived from sources such as sawdust, wood chips, hay, straw, and leaves (Wallace and Terry 1998) and are applied to the

Fig. 3.1 Alkaline/sodic soils

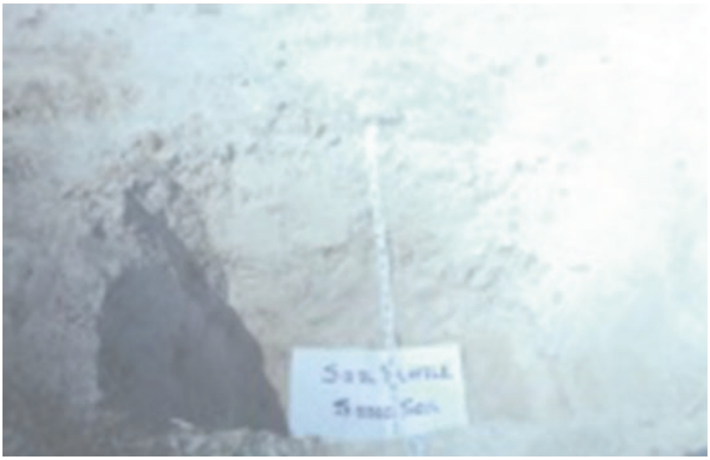

Fig. 3.2 Soil profile of sodic soil

soil surface, whereas composts are humus-like products of an engineered process (Stratton et al. 1995). Many organic materials like rice straw (Midmore 1983), grass clippings (Castle et al. 1995), hay (Borland and Weinstein 1989), uncomposted leaves (Borland and Weinstein 1989), and manure (Castle et al. 1995) have been evaluated as effective mulches.

Fig. 3.3 Soil profile of bio-remediated sodic soil using organic amendments

3.2 Earthworms in Soil Fertility and Nutrient Management

Soil fertility and nutrient recycling are the essential roles of earthworms in soil. Organic nutrients are processed by earthworms that are up taken by plants efficiently for plant growth. Soil fertility is affected in terms of transformation in terms of physical, chemical, and biological properties. The earthworm cast released in the earthworm burrows in the soil enriches it with diverse microflora. Earthworms are categorized into three ecological groups:

1. Epigeics (*Eisenia foetida*, *Eudrilus eugeniae*) – These are earthworms dwelling on the surface of the soil and are efficient in feeding on detritus material like leaf litter. They are phytophagous and do not affect the soil structure directly as they do not move into the soil.
2. Anecics (*Lampito mauritii*) – These earthworms have the ability to recycle leaf litter (detritus) along with the soil and are found in the upper layers of the soil. They are geophytophagous in nature. They also produce cast on surface of the soil and bring about changes in the soil structure in terms of nutrient movement, moisture retention, and soil porosity.
3. Endogeic earthworms (*Octochaetona thurstoni*) – These earthworms are found dwelling in the deeper layers of the soil and feed only on the soil and derive nutrients from the organically rich soil. They do not play a role in composting (Ismail 2005).

3.3 Vermicomposting and Organic Agriculture

Organic agriculture involves the use of organic inputs (organic manures, biofertilizers, and biopesticides/biocontrol agents) for the cultivation of crops (Thampan 1995; Meena et al. 2016a). Use of vermicompost for plant growth is one of the important organic fertilizers that is being used in many countries involved in organic agriculture. Vermicomposting is a controlled and sustainable method of recycling biodegradable organic waste to produce useful end product vermicompost through the use of epigeic and anecic earthworms. Vermicompost is an organic fertilizer that is enriched with nitrogen (1.2–6.1% more than farmyard manure), phosphates (1.8–2.0% more than farmyard manure), and potassium (0.5–0.75% more than farmyard manure). There is presence of phytohormones like auxins and cytokinins, enzymes, vitamins, and essential microbes like *Actinomycetes*, *Azotobacter*, *Nitrosomonas*, protozoans, and fungi (Ismail 1997). It is considered to be good soil conditioner that is being used by practitioners of organic agriculture in many developed and developing countries. The quality of vermicompost depends on the starting organic material (enriched with nutrients) fed to the earthworms that is transformed into cast which is present in vermicompost and can be readily available to plants when added (Ismail 1997).

The beneficial effects of vermicompost are as follows (Hussain and Abbasi 2018):

1. Vermicompost contains higher nutrient content than the other composts due to increased mineralization and humification process through earthworm activity.
2. Vermicompost contains higher available nutrients like NPK, soluble calcium, and trace elements necessary for plant growth.
3. There is presence of humic acid in vermicompost that is responsible for slow release of nutrients.
4. Vermicompost is rich in organic matter that increases the soil porosity, aeration, and reduce bulk density.
5. Contain higher concentration and diversity of microbiota that play a role in production of plant growth regulators, enzymes, and phytohormones (auxins and cytokinins).

3.4 Types of Earthworms for Vermicomposting

Commonly used earthworms in vermicomposting and vermiculture are *Bimastos parvus*, *Dendrobaena rubida*, *D. veneta*, *Eisenia foetida* (Fig. 3.4), *E. hortensis* and *Eudrilus andrei*, *E. eugeniae* (Fig. 3.6), *Amynthas diffringens*, *A. morrisi*, *Lampito*

Fig. 3.4 *Eisenia foetida*

mauritii, *Metaphire anomala*, *M. birmanica*, *Perionyx excavatus* (Fig. 3.5), *P. sansibaricus*, *Megascolex megascolex*, *Pontoscolex corethrurus*, *Octochaetona serrata*, *O. surensis*, *Pheretima elongata*, and *P. posthuma* (Munnoli et al. 2010). On a large scale, very few of the abovementioned earthworms are used in vermicomposting (Domínguez and Edwards 2011; Datta et al. 2017a), because they differ in their ability to degrade the litter matter. Epigeics like *Eisenia foetida* and *Eudrilus eugeniae* are often used in the process of vermicomposting to turn food waste, agriculture waste, and manures into a valuable soil amendment called vermicompost (Fig. 3.6).

Fig. 3.5 *Perionyx excavatus*

Fig. 3.6 *Eudrilus eugeniae*

3.5 Types of Waste Material Used for Vermicomposting

There are different types of organic waste that can be recycled through vermicomposting. These can be grouped as follows (Hussain and Abbasi 2018):

- *Agricultural waste*: Agricultural fields – stubble waste, husk, straw, and farmyard manure.
- Stems, leaf matter, fruit rind, pulp, and stubble. But be careful while handling an all-citric waste.
- *Animal waste*: Dung, urine, and biogas slurry.
- *Urban solid waste*: Kitchen waste from household and restaurants, waste from market yards and places of worship, and sludge from sewage treatment plants).
- *Agro industries*: Food processing units – peel, rind, and unused pulp of fruits and vegetables, fine bagasse, press mud and seed husk, stems, leaves, and flowers after extraction of oil.

Culture, breeding, and multiplication of epigeic earthworms and their use in organic waste recycling have become an important practical and scientific tool (Sinha et al. 2010). The technology of vermicomposting gives a great opportunity to effectively manage household, agricultural (rice straw, grass clippings, coffee husk), and agro-industrial waste (vegetable market solid waste) (Mane and Raskar 2012; Okwor et al. 2012; Yadav et al. 2018a). According to Suthar (2009), the degradable materials are used to obtain vermicompost in this process.

Large-scale organic waste (cattle dung, grass clippings, and water hyacinth) recycled through partial digestion (anaerobic and aerobic processes) through bio-dung composting for 30 days followed by vermicomposting (*Eisenia foetida*) for next 25 days can be a successful process to produce nutrient-rich vermicompost (Ansari 2008; Ansari and Rajpersaud 2012; Meena et al. 2018a).

3.6 Effect of Environmental Factors on Earthworms and Vermicomposting

Temperature, moisture, and pH are important factors, as earthworms have known to have tolerance level to these environmental parameters. If these limits are exceeded, the earthworms move to safe areas in the wastes, leave it, or die, and as a result the processing of organic waste slows down (Ansari 2012).

3.6.1 Temperature

The activity, metabolism, growth, respiration and reproduction, fecundity, and growth period from hatching to sexual maturity of earthworms are greatly influenced by temperature. According to Dominguez and Edwards (2011), during the process of vermicomposting, the temperature range should be between 0 °C and

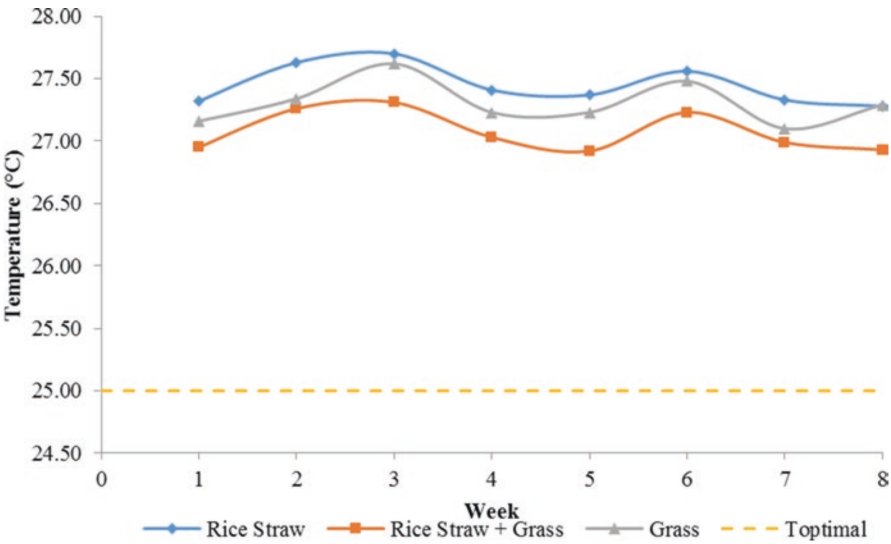

Fig. 3.7 Temperature changes during vermicomposting

35 °C, but the optimal temperature is 25 °C. Munnoli (2007) suggested a temperature range of 25–35 °C for *Eisenia foetida* in vermibeds (Fig. 3.7).

3.6.2 Moisture

Dominguez and Edwards (2011) reported that during the process of vermicomposting, for a rapid growth of *Eisenia foetida*, the moisture should be between 80% and 90%, and the optimal moisture is 85%. Water forms 75–90% of the body weight of the earthworms, and therefore it is important to keep the optimum level of moisture in in vermicomposting units (Fig. 3.8). This facilitates the progression of composting without any hindrance to earthworm activity and microbial degradation in vermi-reactors.

In natural soil-based ecosystem, the earthworms move to safer areas with more moisture in case of loss of soil moisture in the dwelling areas. When there is drastic loss of moisture in the soil, the earthworm has reasonable ability to adjust and survive through water loss from the body (Munnoli et al. 2010; Kumar et al. 2018).

3.6.3 pH

The pH fluctuates in the range of 5–9 during the progress of vermicomposting (Fig. 3.9) and reaches to neutral at the end of the process when the vermicompost is ready for harvest (Dominguez and Edwards 2011). This may occur due to the production of CO_2 and the organic acids produced during microbial metabolism.

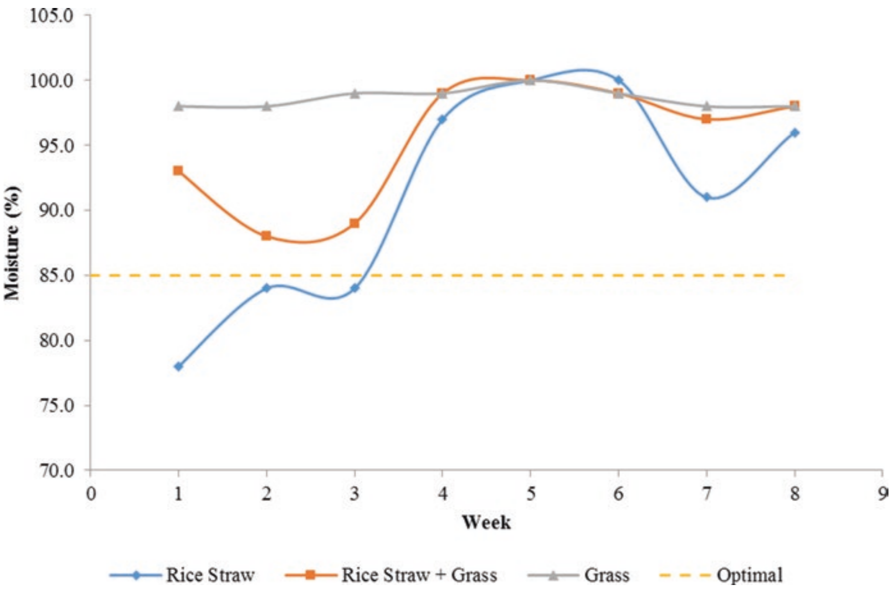

Fig. 3.8 Moisture changes during vermicomposting

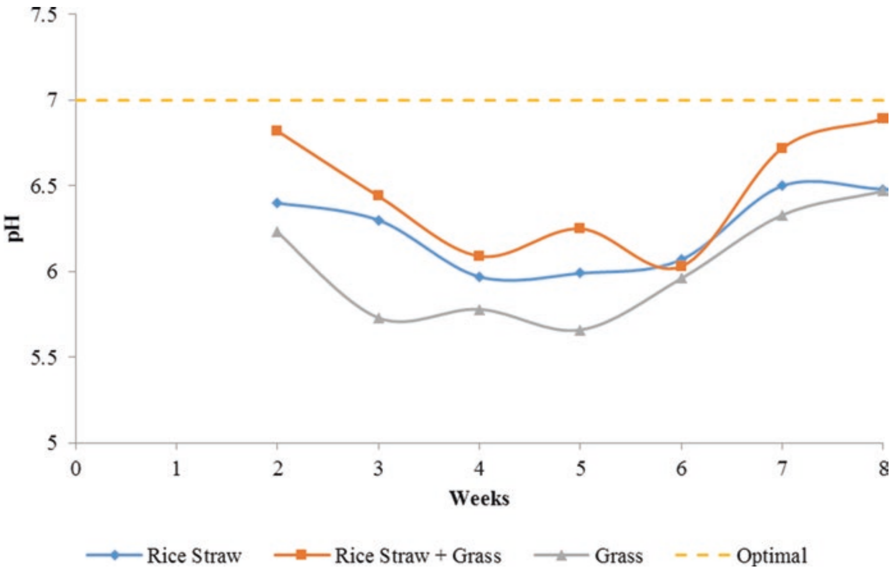

Fig. 3.9 Changes in pH during vermicomposting

Several researchers reported that most species of earthworms have an optimum pH of about 7.0 (Narayan 2000; Pagaria and Totwat 2007; Suthar 2008; Panday and Yadav 2009; Yadav et al. 2017c). Edwards (1988) noted that *Eisenia foetida* have a tolerance pH range from 4.0 to 7.0.

3.7 Criteria of Vermicompost Maturity

A mature vermicompost is dark black and is composed of fine granular material like peat with excellent physical, chemical, and biological properties that could impact the soil in terms of structure, porosity, and aeration (Dominguez and Edwards 2011; Meena et al. 2014). During vermicomposting, the earthworms feed on the detritus material that passes through earthworm gut where it mixes with gut microflora and is churn, degraded along with the activity of microbes present in the composting material. The material that is excreted is cast which mixes with material undergoing composting which is further enhanced by continuous activity of microbes and finally converted to a fine dark sweet-smelling vermicompost which is stabilized and becomes homogeneous. This is a very good source of desired level of plant growth nutrients with negligible levels of contaminants. The micronutrients are present in available form at higher levels when compared with the starting material (Edwards and Bohlen 1996).

3.8 Evaluation of Compost Stability

According to Dominguez and Edwards (2011), the most common method to evaluate the compost stability are C:N ratio, humic substances, absence of plant inhibitors, and human pathogens. Below a specific C:N ratio and absence of human pathogens are important aspects in determining the stability of vermicompost.

3.8.1 Carbon/Nitrogen Ratio

One of the important parameters commonly used to see the progression of organic material undergoing the process of vermicomposting process is C:N ratio, and there is distinct variation in C:N ratio depending on the type of starting organic material in the process. The ideal C:N ratio at the time of harvesting mature vermicompost is 10, but it is hardly achieved due to presence of various recalcitrant organic compounds and some of the materials undergoing poor decomposition. Therefore the acceptable C:N ratio ranges between 14 and 20 in vermicomposts at maturity (Dominguez and Edwards 2011; Dadhich and Meena 2014).

3.8.2 Absence of Human Pathogens

Absence of adequate information on the presence of potential human pathogens in vermicomposts produced from different organic waste materials like sewage-based biosolids and different animal manures is major obstacle in acceptance of vermicomposting as an alternative means of organic solid waste management. Based on researches, vermicompost is considered hygienic if does not contain *Salmonella*, human viruses, infective parasitic helminthic eggs, and no more than 5×10^4 fecal coliforms and 5×10^5 fecal streptococci per 100 grams of sample (Dominguez and Edwards 2011).

3.9 Chemical Properties of Vermicompost

The process of vermicomposting is an aerobic method of decomposition, and there is complete involvement of mesophilic microbial activity. There are complex food webs associated with vermicomposting systems, and there are several nutrient elements which undergo changes to different chemical forms finally modified to stable organic compounds important in nutrient dynamics and plant growth regulators (Dominguez and Edwards 2011; Dhakal et al. 2015). Below the pH and soluble salt concentrations are discussed.

3.9.1 pH

The pH of soil or potting mixture to grow the plants is critical for different aspects of soil fertility and plant growth parameters. The pH of vermicompost varies based on the type of raw materials used in the process of vermicomposting. Vermicompost produced from cattle dung has pH range of 6.0–6.7. The pH should be regulated between 6 and 7 during vermicomposting to get the final vermicompost which is suitable for the optimum release of plant nutrients (NPK and other micronutrients) and effective absorption by plants (Edwards and Bohlen 1996).

3.9.2 Soluble Salt Concentrations

The growth media or soil conditioners should have the soluble salt concentration (electrical conductivity) should be less than 100–200 mS/m for seedlings and sensitive plants. For established plants, it should be less than 200–300 mS/m. The effective vermicomposting process normally ensures that the salt contents are low which is as a result of activity due to earthworms. If the salt content is greater than 0.5%, then the earthworms are affected in their activity (Edwards and Arancon 2004).

3.10 Nutrient Contents in Vermicompost

3.10.1 Total Organic Carbon

Organic matter in vermicompost determines the total organic carbon. From the initial process of vermicomposting to the final stages, the organic carbon content changes which is an important indicator of how the process is proceeds and stabilization occurs (Edwards et al. 2011; Meena et al. 2016b).

3.10.2 Total Nitrogen

The range of total nitrogen content in vermicomposts varies and depends on the type of organic input processed through vermicomposting. It varies from 0.1% to 4% and can be increased further by manipulation of nitrogen-rich starting material and is an important parameter in determining the quality of vermicompost in terms of usage for various crop productions (Edwards and Bohlen 1996).

3.10.3 Carbon/Nitrogen Ratio

Carbon/nitrogen ratio is critical in vermicomposting process, and it normally decreases from the initial phase to final stages where it tends to reduce, indicting the stabilization of vermicompost. At this stage the C:N ratio should be below 20–22 (Edwards and Bohlen 1996).

3.10.4 Total Phosphorus and Potassium

The mature vermicompost when stabilized should have the optimum macronutrients – phosphates and potassium – which are an indication of quality. Phosphates in general should be more than 0.5%. It is necessary to specify the total content of P and K in finished vermicompost as it is an indication of overall macronutrient value. Generally, P contents of more than 0.5% is desirable. Seedlings and some plants that are sensitive to phosphates may require less than 0.1% (Edwards and Bohlen 1996).

3.10.5 Total Calcium and Magnesium

Calcium and magnesium are critical for plant growth, and it is important to check these in mature vermicompost which should contribute to overall nutrient status (Edwards and Bohlen 1996).

3.10.6 Micronutrients (Manganese, Copper, Zinc, and Iron)

The micronutrients are also essential for plant growth and are present in optimal quantity in vermicompost. It is possible in some situations that there may be excess of micronutrient element in vermicompost that may be toxic to specific plants (Edwards and Bohlen 1996).

3.11 Vermicomposting Process

Vermicomposting is a method of composting by utilization of epigeic and anecic earthworms at an optimum population in recycling of organic waste in order to produce an effective organic fertilizer vermicompost. Vermicompost is enriched with macro- and micronutrients in optimum levels of organic matter and organic acids like humic acid along with inoculum of useful microbiota. It can be applied in wide-ranging soil conditions as soil conditioner and for cultivation of variety of crops at different rates based on the requirements of each crop. The use of earthworms is essential in vermicomposting as they tend to convert the organic material with the aid of gut micoflora into fine earth like material. The process is beneficial and cost-effective and utilizes the organic waste material. It is in turn also helping in ecosystem services like reducing the organic waste to useful organic fertilizer that can substitute the chemical fertilizers. The technology is environmentally friendly and is the best of reducing the organic garbage to zero waste.

Vermicomposting can be done in many ways. The vermicomposting units can be set up in tanks, boxes, containers, basket, drums, and pits in the soil. The depth of the units should be less than 1 meter or 1 foot. These should be provided with appropriate drainage at the bottom (with appropriate perforations). The other dimensions can vary based on suitability and quantity of vermicompost production required. The ideal size of the tank or pit could be 2 m × 1 m × 0.75 m which can produce approximately 100 kg of vermicompost per harvest. The units should be set up in shade (outside), or shade house can be constructed.

The temperature and moisture are key factors in regulating the units and should always be maintained at optimum levels. The organic materials should be added gradually and in small quantity say, for example, three additions per week or every day if the quantity is very small. The material should be turn at least once in a week. The units should be sprinkled with water every day to maintain the optimum moisture levels of 80%. The units should be left to dry unless it is time for harvest. At the time of harvest, the units should not be sprinkled with water for 2–3 days, and then the vermicompost can be harvested. Initial period to set up the unit takes 50–60 days. This is for stabilization of the units and to achieve the appropriate density of earthworms in units. The units can be inoculated with the number of epigeic earthworms (approximately 100–500). The number depends on the size of the units. When the optimum population is reached (50–60 days), then start loading thee units with organic waste at regular intervals. The vermicompost can be harvested every 40–45 days.

The basic layer at the bottom of the unit is filled with broken bricks/pebbles/blue metal (5–6 cm thick). This is followed by addition of layer of coarse sand (10 cm thick). Then layer is created with good loamy soil (10 cm thick). The units should be sprinkled with water so that all the layers are moistened with the drainage system at the bottom the unit working in perfect condition. This is followed by organic materials like dried grass/leaves/plant litter and cattle dung to make a layer of 5–6 cm. The epigeic earthworms (100–200) can then be inoculated in the units. After the initial phase which is first 50–60 days, the materials should be added once per week. The vermicomposting units (Fig. 3.10) are stabilized after the initial phase following which the loading of organic waste can be optimized to three times per week. Then the vermicompost can be harvested every 40–45 days (Fig. 3.11). At the time of harvest the addition of water to units can be stopped for 2–3 days so that the earthworms can move to the bottom layers. A heap is created within the unit and removed so that earthworms are least disturbed. The vermicompost is packed in

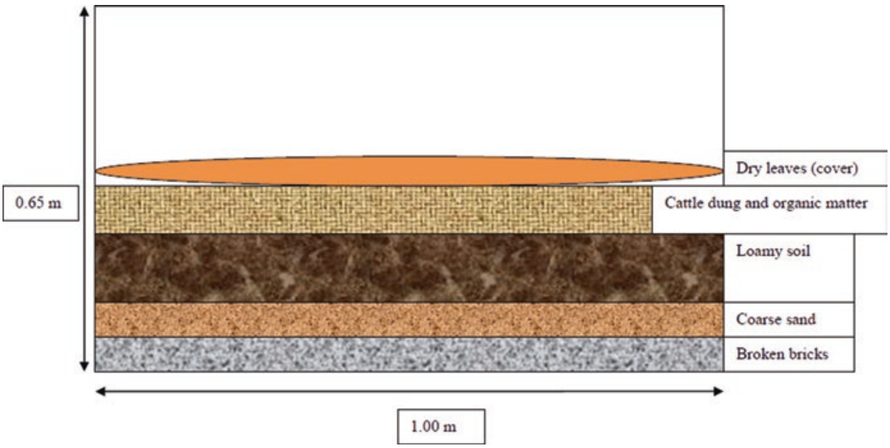

Fig. 3.10 Setup of vermicomposting unit

Fig. 3.11 Vermicompost at harvest

bags with proper aeration and optimum moisture level to sustain the microbial population. It can be directly applied to the soil at the required rate of the specific crop. It can be stored up to a period to 3 months in proper bags without any nutrient loss.

3.12 Use of Vermicompost as Soil Amendment and in Crop Productivity

Vermicompost serves as a nutrient-rich natural fertilizer; improves the physical, chemical, and biological properties of soil; and reduces the use of chemical fertilizers (Kale 1998; Nath et al. 2009; Ansari and Jaikishun 2011; Meena et al. 2015e). It also increases the amount of readily available water and induction of N, P, and K exchange, which results in better growth of the plants (Ismail 2005). Application of vermicompost to soil reduces the bulk density, thereby increasing the soil porosity and aeration which facilitates the movement of nutrients. It also helps in soil aggregate formation and better root development during plant growth. Soil pH is maintained by humic acid component of vermicompost that acts as buffer and facilitates the slow release of nutrients. Thus use of vermicompost as organic amendment improves and restores the physical, chemical, and biological properties of soil (Hussain and Abbasi 2018; Yadav et al. 2017b).

A samba rice cultivation study reveals that the addition of vermicompost has significant positive effects on the soil physical, chemical properties and plant growth parameters (Tharmaraj et al. 2011). The application of vermicompost increases the soil properties such as organic matter, total nitrogen, phosphorus, potassium, sulfur, zinc, and boron contents; grain and straw yields of rapeseed also increased significantly, when increasing the dose of vermicompost.

Vermicompost has shown to improve plant growth significantly (Lalitha et al. 2000), and it has positive influence on yield parameters of potato (*Solanum tuberosum*), spinach (*Spinacia oleracea*), turnip (*Brassica campestris*), okra (*Abelmoschus esculentus*) (Ansari, 2008; Ansari and Sukhraj 2010; Varma et al. 2017b), and black gram (*Vigna mungo*) (Tharmaraj et al. 2010). According to Sinha et al. (2011) in experiments with corn and wheat crops, tomato and egg-plants vermicompost has displayed excellent growth performances in terms of height of plants, color and texture of leaves, appearance of flowers and fruits, seed ears as compared to chemical fertilizers, and the conventional compost. The application of vermicompost also increased the shelf life and total soluble solids in tomato fruits (Ansari 2012).

Vermicompost can be applied to different crops, and some of the recommended dosages are as follows:

- Rice/wheat/sugarcane: 4–5 tonnes per hectares
- Vegetables (okra, brinjal, tomatoes): 500 g per plant or 2–3 tonnes per hectares
- Potted plants: 500 grams to 1 kg depending on stage

3.13 Recent Experiments on Vermicomposting in Guyana and Suriname

3.13.1 Experiment 1

Experiment 1 was conducted on large-scale vermicomposting of cattle dung, rice straw, and grass clippings and was carried out during the year 2014 at the National Agricultural Research and Extension Institute (NARIE). Four tanks with dimension of 2.1 × 2.1 × 1.0 m^2 were set up (Fig. 3.12) based on structural guidelines of Vermitech and inoculated with 625 earthworms (*Eisenia foetida*) each. The vermicompost was harvested after 60 days and was subjected to physicochemical analysis. Promix which is widely used in agricultural system in Guyana was also analyzed for chemical parameters. Earthworm population was also recorded. The results indicated that the vermicompost productivity (Figs. 3.13 and 3.14) was to the tune of 1376.42 kg (Table 3.1) and numbers of earthworms were 29,110 (9.6/kg/m^2). Comparative analysis showed that vermicompost is better than promix in terms of total nitrogen, calcium potassium, and phosphates (Table 3.2) whereas equally potent in other nutrients indicating that vermicompost can be better substitute in nursery management in terms of quality as well as cost implications. Based on the experiment, vermicompost was found to be enriched with nutrients and has potential to ameliorate the different soil conditions. The potential effect and benefits of vermicomposting on environment are considerable. Thus, this technique may prove to be beneficial to the soil enrichment with reduction in the use of synthetic fertilizers.

3.13.2 Experiment 2

Experiment was carried out during 2014–2015 at Anton de Kom University of Suriname, Paramaribo, with the objective of exploring the vermicomposting process. The research was done in different stages: building of a vermicompost station at the

Fig. 3.12 Vermicomposting unit at the NARIE

Fig. 3.13 Raw material in vermicomposting units

Fig. 3.14 Mature vermicompost

Table 3.1 Vermicompost production matrix

Unit (grass clippings + cattle dung)	No. of earthworms introduced (*Eisenia foetida*)	Earthworm population/2.2 m^2	Vermicompost harvest kg/2.2 m^2
T1	500	22701.0	771.6
T2	1000	52289.8	1631.3
T3	500	26942.0	1416.1
T4	500	14507.0	1686.7
Average	625	29110.0	1376.4

Table 3.2 Nutrient analysis

Parameters	Vermicompost	Promix
pH	6.36	6.2
Organic carbon (%)	5.18	6.35
Total nitrogen (%)	0.91	0.65
C/N ratio	5.69	9.77
Available phosphate (mg/kg)	102	80
Calcium (mg/kg)	1.66	0.48
Magnesium (mg/kg)	10.55	2.78
Potassium (mg/kg)	6.71	5.41
Manganese (ppm)	40.60	54.20
Iron (ppm)	5.11	3.68
Copper (ppm)	0.22	0.57
Zinc (ppm)	28.80	29.70

University compound; import of a compost earthworm, *Eisenia foetida*, from Guyana; and production of vermicompost using dry grass clippings, rice straw, and cow manure. Vermicomposting (Vermitech pattern) was done using *Eisenia foetida* with three treatments [T1 (rice straw), T2 (rice straw + grass), and T3 (grass)] in the units. During the process, the temperature, humidity, and pH were measured for all the three treatments. The population of earthworms, the production of vermicompost, and chemical and microbial analyses of the vermicompost were recorded after a hundred and forty (140) days. The results were collected and analyzed using Sigma Plot 12.0 tools. Results indicated that for all the three treatments, the temperature was in range of 0–35 °C, the humidity was between 80 and 100%, and the pH fluctuated in the range of 5.5–7.0 and stabilized to near neutral on the 60th day. The number of earthworms was counted using the hand count method. The vermicomposting results showed that the dry grass clippings and rice straw along with cow manure were successfully processed to vermicompost during the period of 60 days and had a dark color, mull-like soil odor and were homogeneous. The combination of rice straw and grass had the highest production of 105 kg, followed by grass and rice straw with 102.5 kg and 87 kg, respectively (Table 3.3). The harvested vermicompost had an excellent nutrient status (Table 3.4), which was confirmed by the chemical analyses and had all the essential macro and micro plant nutrients like N, P, K, Ca, Mg, Mn, Cu, Zn, and Fe, indicating the achievement of getting an environmentally friendly enriched nutrient fertilizer for the agriculture sector.

3.14 Impact of Organic Inputs in the Soil

3.14.1 Significance of Vermicompost as Organic Input

Organic inputs like vermicompost facilitate the process of humification in the soil with enhanced microbial activity and enzyme productivity that improves the soil stability with aggregate formation, porosity, aeration, and nutrient cycling (Perucci

Table 3.3 Harvest data of vermicompost

Units (composition)	Rice straw (T1)	Rice straw + grass (T2)	Grass (T3)
Total mass of feed (kg) initially	168	168	168
Average harvest per unit (kg)	10.90	13.80	9.80
1st harvested vermicompost (kg)	43.50	55	39
Production of vermicompost (%)	***25.90***	***32.70***	***23.20***
Total mass of feed (kg) secondly	96	96	96
Average harvest per unit (kg)	10.90	12.50	15.90
2nd harvested vermicompost (kg)	43.50	50	63.50
Production of vermicompost (%)	***45.30***	***52.10***	***66.20***
Total harvested vermicompost (kg)	**87**	**105**	**102.50**

Table 3.4 Physicochemical properties of raw material and vermicompost

Parameter	Dry grass clippings	Cow manure	Vermicompost
pH-H_2O	6.50	6.20	6.50
EC (mS/cm)	3.00	5.72	3.71
Total organic carbon (%)	42.96	21.02	18.53
Total-N (%)	1.88	1.57	1.36
C/N ratio	23:1	13:1	13:1
Total-P (%)	0.26	0.78	0.58
Total-K (%)	1.23	0.86	0.56
Total-Zn (ppm)	118	921	611
Total-Mn (ppm)	235	633	544
Total-Cu (ppm)	6.80	34.8	26.90
Total-Fe (%)	0.18	1.62	1.56

1990). Organic matter added in the soil binds the nutrients like calcium, magnesium, and potassium in the form of soil colloids with humic acids that are critical for plant growth (Haynes 1986). Addition of organic matter in soil causes improvement in soil which is indicated by microbial biomass and activity of enzymes (Perucci 1990). It is also reported that casting present in vermicompost contains plant growth promoters like auxins and cytokinins (Krishnamoorthy and Vajranabhaiah 1986; Yadav et al. 2017a).

Application of vermicompost as organic amendment is one of the better composts that contains earthworm cast and contains high available nitrogen and microbial inoculum (Satchell and Martin 1984; Satchell et al. 1992; Verma et al. 2015b). This enhances microbial activity like stimulating nitrogen-fixing bacteria and actinomycetes (Kale 1998; Borken et al. 2002; Meena et al. 2015a). Several researchers have reported that application of organic inputs like vermicompost increases crop yield and productivity which is as a result of available nutrients like phosphorus and potassium in optimum levels. These also facilitate microorganisms phosphatases in soil (Ozores-Hampton et al. 1994; Kumar et al. 2017a). The synergistic role of the microorganisms in vermicompost-amended soil has positive effects in nutrient management (Buchanan and Gliessman 1990; Dhakal et al. 2016).

3.14.2 Effect of Vermicompost on Plant Growth Productivity

Several researchers (Sharma and Mittra 1991; Ismail 1997; Meena et al. 2017a) have reported increase in crop yield with reference to wheat-paddy cropping system. The readily available nutrients in vermicompost cause the positive effect on the plant growth parameters (Ozores-Hampton et al. 1994; Rajkhowa et al. 2000; Dadhich et al. 2015). Plants absorption is very effective due to microbial activity in soil amendment like vermicompost. This solubilizes the phosphorus (Mishra and Banger, 1986; Singh et al. 1987). The cost of cultivation is reduced, and higher income has been recorded in various organic farming trails like wheat, paddy peanut (*Arachis hypogaea*), and eggplant (*Solanum melongena*) cultivation through Vermitech in comparison with chemical fertilizers (Ismail 1997). With the experiences across the globe, countries like India and New Zealand have proved that organic farming is efficient in terms of cost, sustainability, and environmental impact (Reganold et al. 2001; Ram and Meena 2014).

Significant results have also been reported on the researches on the effect of earthworms and vermicompost on cultivation of vegetable crops like tomato (*Lycopersicum esculentum*), brinjal (*Solanum melongena*), and okra (*Abelmoschus esculentus*) (Ismail 1997). Application of organic input like vermicompost on vegetables and other crops has been successful in several extension trials by farmers (Ismail 1997). Such practices can contribute to higher quality food production (Ouédraogo et al. 2001; Verma et al. 2015a). Application of organic inputs like vermicompost contributes to slow release on nutrients and also contains plant growth promoters like gibberellin, cytokinin, and auxins (Lalitha et al. 2000; Meena and Yadav 2014).). Vermicompost-treated plots were reported to show higher productivity of potato tubers attributed to increase in availability of phosphorus (Erich et al. 2002). Other researchers have reported significant yield of spinach and onions by application of vermicompost and vermiwash in soil which facilitated the release of exchangeable nutrients in soil (Cook et al. 1980; Tiwari et al. 1989). During the recent years, concern has been raised about excessive use of chemical fertilizers and pesticides causing damages to soil and environment, thereby affecting the crop productivity and human health. So alternative agricultural practices with the use of organic inputs like vermicompost can be very promising and suitable for sustainable organic agriculture for better future (Reganold et al. 2001).

3.15 Conclusion

Soil is an integral system for natural ecosystem like agricultural fields that require nutrient resources. Intensive use of agricultural chemicals over the years worldwide has caused negative effects on soil like soil degradation and acidification. The organic agriculture can be substantiated with the use of organic fertilizers like vermicompost toward sustainable crop productivity and stable soil bio-systems. Organic agriculture can be integrated with not only vermicompost production and application on various crop system but can be integrated with other organic composting technologies based on different microbial inoculum, biopesticide production and use, and biocontrol mechanisms. These would be in the near future can help us to achieve sustainable goal toward food security with least impact on the environment.

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