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Sustainable organic waste management and nutrients replenishment in the soil by vermicompost: A review

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ABSTRACT

With the rapid growth of global population, food production and waste management are considered to be two major challenges faced by people in 21st century. Though application of chemical fertilizers enhances crop growth, vigor and yield thereby meeting the food security, it depletes the quality of environment and ecosystems. Recycling of organic wastes is considered to be a feasible solution which could mitigate the issues of waste management while uplifting the status of soil health and nutrients. The objective of this article is to reviews the currently available literature on vermicomposting as a tool for recycling of different organic waste materials and subsequent use as organic amendment to improve soil properties and as organic fertilizer to enhance growth and yield of various crops. Furthermore, models were proposed to improve education on vermicomposting as a solution for organic waste management among farmers, students, government offices and general public and develop as a community based micro-enterprise. Vermicomposting is defined as a process where earthworms convert organic wastes into humus like materials. It has been investigated worldwide taking its practical significance into account. Vermicompost is found to be a good source of plant macro nutrients, micro nutrients and growth regulators, including humic acid, indole acetic acid and kinetin. Microbes live in the alimentary canal of the earthworms improve the quality of vermicast hence vermicompost. Furthermore, vermicompost could absorb heavy metals in soil and water while eliminating of human pathogens such as Salmonella spp, fecal coliforms, Shigella spp, Enterobacter aerogenes, Enterobacter cloacae and eggs of helminthes. Reviewed literature indicated the potential of vermicomposting to be used as an efficient technique for bioconversion of organic wastes into a valuable organic fertilizer. Furthermore, the present review suggests vermicompost production as a micro-enterprise which could be used to uplift the livelihood of the resource poor farmers through economic empowerment while assuring sustainable crop production.

Keywords: *earthworms, organic waste, soil fertility, vermicompost, yield*

INTRODUCTION

On average, global solid waste generation in 2016 was 2.01 billion tones while average per capita generation per day was 0.74 kg. Due to rapid urbanization and population growth, waste generation is expected to be accelerated further. The expected value by 2050 is 3.4 billion tones which is 70% increase compared to 2016. Furthermore, high income countries and low and middle-income counties are expected to generate waste in the rate of 19% and 40%, respectively. East Asia and Pacific region generate 23%t of the world's waste. More than half of the waste generated by Sub-Saharan Africa, South Asia, the Middle East and North Africa dump openly at present (Kaza *et al*., 2018). The impact of waste on the health of human and animals together with the prosperity and the environment

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varies with the source of origin of the waste. Figure 1 shows projected solid waste generation by different regions in the world. According to the estimation, about 13.5% waste is recycled and 5.5% is composted. However, 40% of the waste generated worldwide is not disposed properly and dumped or burned in open fields (Kaza *et al*., 2018).

Food and green waste generate by high, middle and low-income counties are 32%, 53% and 57%, respectively. A negative correlation between the fraction of the organic waste generation and economic development of a country is observed (Figure 2A). However, on average, all regions generate around 50% of organic waste except Europe, Central Asia and North America where the proportion of dry waste is comparatively high (Kaza *et al*., 2018). On the other hand, 51% of the waste generated by the developed countries could be recycled while the respective figure in low-income countries is just 20%, suggesting that effective management of organic waste is essential for middle and low-income countries than developed countries.

Landfill accounts for 37% of the waste disposal where 8% of landfills possess landfill gas collection systems. Composting recovered 33% of global waste (Figure 2B). In 2016, greenhouse gas emissions due to solid waste treatments and disposal estimates as 1.6 billion tones, contributing 5% of global emission. Nearly 50% of emissions may occur due to food wastes. It is expected to be increased up to 2.38 billion tons of carbon dioxide (CO_2) equivalent greenhouse gas emissions by 2050, if does not pay attention to improve essential management practices (Kaza *et al*., 2018).

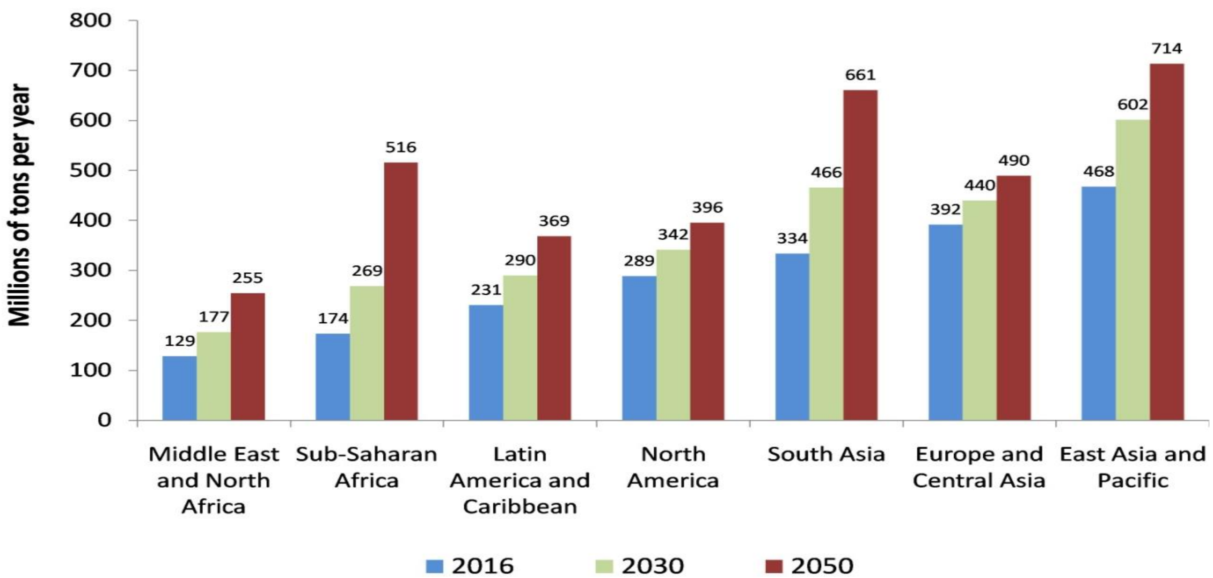

Figure 1. Projected solid waste generation by different regions in the world (Million tons per year) (Adopted from Kaza et al., 2018)

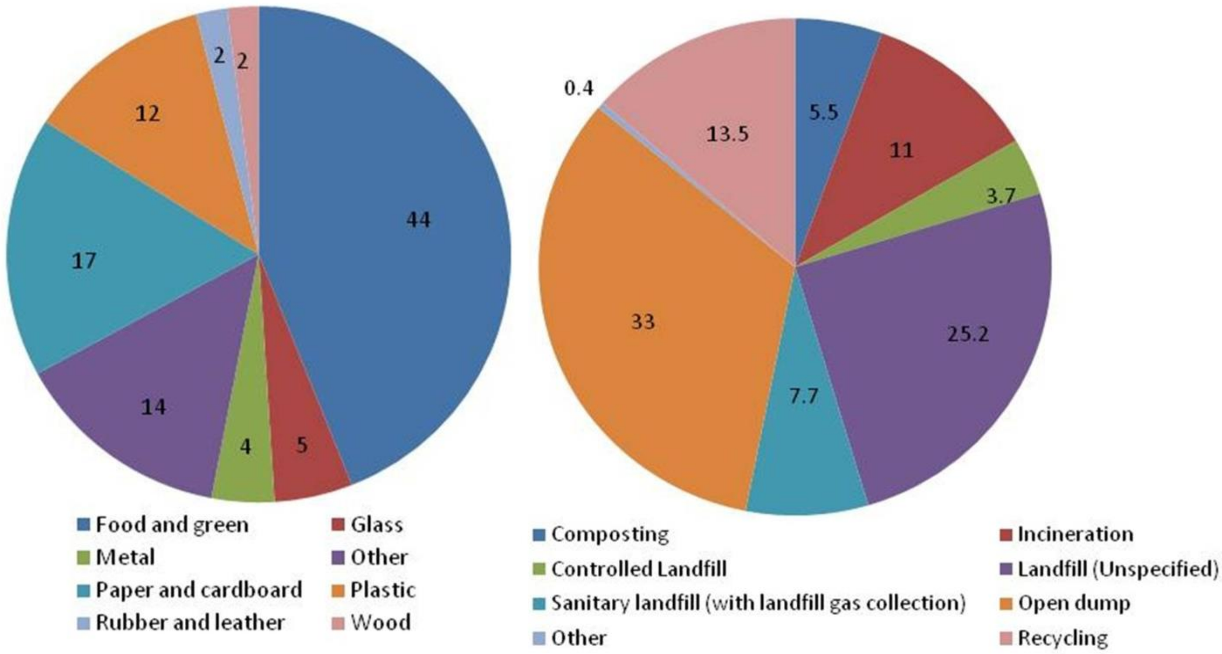

Figure 2: (A): Global waste composition (%) (B) Global treatment and disposal of waste (%) (Adopted from Kaza *et al*., 2018)

In many countries, large-scale processing facilities were among the most preferred methods for treating waste materials collected from various places and transporting long distances (Gorecki *et al*., 2010). However, transport cost was one of the main contributors of waste management. Therefore, several socio-economic and environmental advantages can achieve by introducing alternatively techniques to recycle and treat waste materials close to where it generates (Pleissner, 2016; Venus *et al*., 2018). Organic food wastes were considered as one of the useful resources for renewable energy production such as biogas (Zhan *et al*., 2014). Composting and vermicomposting techniques were used extensively as biological processes for converting organic waste into valuable soil amendments (Zaman, 2013). Organic wastes including biosolids (Contreras-Ramos *et al*.,2005, animal manure (Gutie´rrez-Miceli, *et al*., 2008) and kitchen waste (Warman and Anglopez, 2010) can be used to produce organic fertilizer rich with N, P and K. However, most of the municipal wastes cannot be used to prepare compost due to possible contaminations with harmful pathogens and toxic substances such as batteries, electronic wastes from electric and electronic devices (Calabrò, 2009). Therefore, they are incinerated and dumped in landfills neglecting the possible environmental and health issues including greenhouse gas emission (Skovgaard *et al.*, 2008; Calabrò, 2009). Furthermore, such a disposal could create favorable breeding places for flies and mosquitoes. Therefore, sustainable management of waste is extremely important. The objective of the present paper is to provide an analytical summary abstracted from recent publications on vermicomposting as a tool for recycling of different organic waste materials and subsequent use as organic amendment to improve soil properties and as organic fertilizer to enhance growth and yield of various crops. Furthermore, the published scientific evidences in peer reviewed journals and reports are used to collect information present in this review.

What is vermicompost?

Non-thermophilic biodegradation of organic matter into humus like substances, as a result of feeding earthworms, is referred as vermicomposting (Arancon *et al*., 2004; Arancon and Edwards 2005; Swati and Hait 2018). During this process organic waste materials pass through the gizzard of earthworms (Ndegwa and Thompson 2001; Hemalatha 2012) and produce vermicast which is rich in essential plant nutrients and unidentified plant growth inducing compounds (Sharma and Garg 2019). Vermicast is the end product of earthworms' digestion of organic waste which is homogeneous in nature (Ndegwa and Thompson 2001). Vermiculture has received a considerable attention in last few decades due to its potential role in organic waste management and sustainable soil fertility management (Tripathi and Bhardwaj, 2004; Singh *et al*., 2020). Vermicompost is used as an organic fertilizer, soil amendment and growth substrate. Soil physical and chemical properties including porosity, aeration and water holding capacity can be increased by applying vermicompost while increasing plant nutrient uptake efficiency (Edwards *et al*., 2004; Pramanik et al., 2007; Puga-Freitas and Blouin, 2015). This may be due tohigh rate of mineralization of organic substances and accelerated humification process(Garg and Gupta., 2011). Vermicompost is rich in nitrogen (N), phosphorus (P), soluble potassium (K) (Adhikary 2012) and exchangeable calcium (Ca). Surface area of the vermicompost is very high due to its fine texture. Hence increase micro sites for microbial activities and enhanced nutrient retention. Favorable bacteria, fungi and actinomycetes for soil heath can be identified in vermicompost (Adhikary 2012) and their density and population is very high when compared to garden soil. This practice was started in the middle of 20th century and first series of experiments were established in Holland in1970, and then in England and Canada. Afterward, some other counties including USA, Italy, Philippines, Thailand, China, Korea and Japan followed vermiculture and vermicomposting practices in the world (Sinha *et al*., 2002). At present, application of vermicomposting technique for converting organic waste materials into valuable organic fertilizer are reported worldwide (Bellitürk, 2018; Joseph *et al*., 2020; Gutie´rrez-Miceli, *et al*., 2008).

Bioconversion of organic waste

Bioconversion of organic half of the municipal waste together with cow dung into valuable vermicompost using *Eisenia fetida* was reported by Srivastava *et al*., 2020. Moreover, animal husbandry practices contribute significantly on organic waste generation (Ahmad *et al*., 2007). Effective and efficient management approaches are needed to minimize the negative impact of manure on the environment and human health. Since animal manure contains high level of organic matter and plant nutrients, it could be successfully used in enhancing organic matter content in the cultivated lands. Decomposition of organic matter by the actions of microorganisms improves nutrient cycling while forming soil aggregates. Microbial community available in the soil contributes substantially towards denitrification, nitrification and nitrogen fixation processes to which arbuscular mycorrhizal fungi, rhizobium bacteria which have the ability to fix atmospheric nitrogen, and phosphorus solubilizing micro-organisms, known as rhizospheric micro-organisms are actively involved (Bending *et al*., 2002; Ge *et al*., 2008). The highest growth and multiplication of earthworms was recorded in paper and kitchen waste media than kitchen yard waste media and cattle manure yard waste media. Furthermore, seed germination of radish (*Raphanus sativus*), marigold (*Tagete spatula*) and upland cress (*Barbarea verna*), increased with maturation of the vermicomposting while greater germination percentage was observed in un-amended vermicompost media (Warman and Anglopez, 2010). Biruntha *et al*. (2020) revealed that the possibility of vermiconversion of seaweed, sugarcane trash, coir pith and vegetable waste mixed with 1:1 ratio of cow dung, into vermicompost using earthworm species *Eudrilus eugeniae*. Organic matter, cellulose, organic carbon, lignin, C to N ratio and C to P ratio were significantly lower than compost while N, P and K content were greater than the compost. Balachandar *et al*. (2019a) conducted a similar study with pressmud, waste materials of sugar industry, cow dung, N rich green manure leaves of *Gliricidia sepium* and *Leucaena leucocephala* (2:1:1) and earthworm species *Eudrilus eugeniae* and reductions in pH, C to N ratio, total organic carbon, water soluble organic carbon and C to P ratio were observed while increasing N, P, K content and microbial population including bacteria, fungus and actinomycetes. Karmegam *et al*., (2019) used sludge produced by paper industry, green manure and cow dung to prepare vermicompost using *Eisenia fetida* successfully. *Lantana camara*, a perennial weed species which threatens native ecosystems could be converted into vermicompost by earthworm specie of *Eisenia fetida* and *Eudrilus eugeniae* in a mixture of cow dung (Devi and Khwairakpam 2020). Joseph *et al*. (2020) suggested that cattle solid wastes generated from indigenous cow breeds were preferred by epigeic earthworm species *Eudrilus eugeniae* over exotic cow breeds. According to Balachandar *et al*. (2019b), biomass of *Ipomoea staphylina*, an invasive weed species in India, mixed with cow dung and end products of the mushroom growing media could convert into vermicompost by *Eudrilus eugeniae* where 1:1:1 substrate mixture performed well in terms of N, P, K, Ca and sodium (Na) content. Similarly, Gajalakshmi *et al*. (2001a) converted water hyacinth (*Eichhornia crassipes*), a problematic aquatic weed, and cow dung mixture in to valuable vermicompost. Blouin *et al*., (2019) used meta-analysis to prepare quantitative summary based on the numerous research studies conducted for last few decades on vermicompost and reported that maximum plant growth could be achieved when 30-50% of soil is replaced by vermicompost. Furthermore, they identified that cattle manure as the best material of organic origin to produce vermicompost.

Vermicomposting to reduce toxicity of raw materials

The pH of the vermicompost prepared with sheep manure was reported to be 8.6 (Gutie´rrez-Miceli, *et al*., 2008). However, when cattle manure was employed for the production of vermicompost, the pH varies from 6 (Jordao *et al*., 2002) to 6.7 (Alves *et al*., 2001), while it was 5.3 (Atiyeh *et al*., 2002a) to 5.7 (Atiyeh *et al*., 2001) for pig manure vermicompost. pH value of the vermicompost derived from sewage sludge was 7.2 (Masciandaro *et al*., 2000). According to Alves *et al*. (2001), the pH variation may be related to the properties of the raw materials used in preparing vermicompost. According to Kaushik and Garg (2003), solid textile mill sludge can be converted to vermicompost by earthworm species *Eisenia foetida* when mixed with 30% of cow dung by weight. Significant reduction of C to N ratio, K and Ca in final vermicompost was reported while increased amount of N and P compared to the initial feedstock (Kaushik and Garg, 2003). Furthermore, total heavy metal content was slightly lower in vermicompost than the initial feedstock which may be associated with the leaching of metal ions with drainage water. However, poor performance in growth and sexual maturity of earthworms was observed when the fraction of solid textile mill sludge was increased in the feedstock (Kaushik and Garg, 2003). Similar results were reported by Contreras-Ramos *et al*. (2005) when mixed household and industrial biosolids of textiles, cow manure and oat straw in vermicomposting under different moisture levels fortwo months with *Eisenia foetida.* Best quality and stable vermicompost was obtained when 1800g of biosolids were mixed with 800g of cow manure without oat straw at 70% moisture level. They further reported that *Salmonella* spp in vermicompost was less than 3 $CFUg^{-1}$ while nonexistence of fecal coliforms, *Shigella* spp and eggs of helminthes were observed. Moreover, heavy metals including lead (Pb), chromium (Cr), zinc (Zn) and copper (Cu) did not exceed the permissible limits established by the United States Environmental Protection Agency. Gutie´rrez-Miceli, *et al*. (2008) reported that vermiconversion of sheep manure for 60 days destroy *E.coli*, *Shigella* spp, *Salmonella* spp or total coliforms when compared to raw sheep manure. This reduction of human pathogens may be associated with the antibacterial properties of vermicompost due to the activities of haemolytic system of the earthworm (Sinha *et al*., 2002).

As stated by Garg *et al*. (2005), earthworm species of *Eisenia foetida* could grow and reproduce well when a feeding mixture of solid textile mill sludge (30-40%) and poultry droppings (70-60%) were used. However, when the proportion of the solid textile mill sludge of the feeding mixture was more than 40%, the biomass increment and cocoon production of the earthworms was affected. Furthermore, the end product contained lesser amount of K, Zn, Ca, Pb, Fe and Cd compared to those in the initial feeding stock, though it contained higher amount of N and P. Yadav *et al.* (2013) demonstrated the potential use of vermicomposting process to convert biogas plant slurry mixed with cow dung to produce homogenous organic fertilizer rich in N, P and K. Industrial wastes such as sewage sludge (Benitez *et al*., 1999), dairy processing plant sludge (Elvira *et al*., 1997), vine fruit sludge (Atharasopoulous, 1993), brewery yeast (Butt 1993) and waste papers (Gajalakshmi *et al*., 2001b) could be converted into vermicompost by using different earthworm species. According to Rékási *et al.* (2019), organic carbon content, total N, P, K and available N, P, K of vermicompost prepared using partially digested sewage sludge were not significantly different from conventional compost prepared with the same sources. However, the concentration of kinetin, a plant growth regulator, found in vermicompost was two folds higher than that in conventional compost. However, Esmaeili *et al* (2020) found that combined compost-vermicompost process with pistachio waste mixed with cow dung could result in a good quality end product having low C:N ration and total organic carbon and high total N and P. *Eisenia foetida* could be employed in converting the feeding mixture of flay ash, waste material of thermal power station, and cow dung into valuable vermicompost (Gupta *et al.*, 2005). The maximum vermicast production along with high number of juveniles of earthworms resulted when the mixture contained 40% of fly ash and cow dung. They further reported that the mixture with 20% fly ash could result in the maximum weight gain of earthworms.

Previous studies indicated that depending on the pathogen type presence in the waste material and the earthworm species used, vermicomposting may reduce the *Salmonella enteriditis*, *Escherichia coli*, faecal coliforms, helminth ova and some human viruses down to a certain level (Edwards, 2011; Monroy *et al*., 2009). Aira *et al.* (2012) studied the effectiveness of earthworm species of *Eisenia andrei* on pathogenic load during cow dung vermicomposting at industrial scale in continuous feeding vermireactor. They found that spread of pathogens on mature vermicompost due to the introduction of new fresh feeding material may be associated with the nature of continuous feeding vermireactor. Furthermore, *Enterobacteria*, total coliforms and *Clostridium* and were not reduced by *Eisenia Andrei* though; levels of *Escherichia coli*, faecal coliforms and faecal enterococci were reduced to some extent. Depending on the earworm species, reduction of pathogen content and type in vermicompost may vary. Four earthworm species *Eisenia fetida*, *Eisenia andrei*, *Eudrilus eugeniae* and *Lumbricus rubellus* were found to be effective in reducing total coliform numbers (Monroy *et al*., 2008). Though, earthworms could eliminate total *Enterobacter aerogenes* and *Enterobacter cloacae* (Parthasarathi *et al.*, 2007), the level of *Klebsiella penumoniae* and *Morganella morganii* could not reduce. Some researchers suggested that reduction of total coliform in vermicomposting may be associated with the nature of earthworm, their digestive abilities and the efficacy of enzymatic digestion performed by bacteria species presence in the gut of the earthworms (Monroy *et al*., 2008, 2009; Edwards, 2011). Pathogen free compost has a growing demand as an organic fertilizer (Pandey *et al*., 2016). Paul *et al*. (2020) investigated the effect of biochar as an amendment to vegetable waste vermicomposting using epigeic earthworms; and found that vermicomposting process can be shortened by biochar while enhancing growth of earthworms. Further, it improved nutritive value of the vermicompost, reduced coliform bacteria while immobilizing the heavy metals during the process. Huang *et al*. (2019), based on the investigation of the effect of vermicompost on antibiotic resistance genes and human pathogenic bacteria suggested that use of sludge vermicompost provides limited advantages as a soil amendment for agricultural purposes.

Generally, agricultural and other industrial practices generate waste with considerable contents of heavy metals, in particular Pb (Houben *et al.*, 2013). Adsorption is identified as one of the remediation measures that could be employed in removing heavy metals from water and soil (Wu *et al.*, 2019; Xue *et al*., 2019). Animal manure and crop residuals are found to be excellent organic adsorbents of heavy metals (Wang *et al.*, 2015; Wang *et al*., 2015; Wnetrzak *et al.*, 2014). Zhang *et al.* (2020) investigated the potential of using vermicompost derived biochar as an adsorbent to remove $Pb^{+2}$from solutions. Biochar of cow manure based vermicompost were produced by the process of pyrolysis where raw materials are exposed to 350 and 700 °C. Low pH and high mineral content of the cow manure based vermicompost biochar would help to remove Pb^{+2} from the solutions rapidly. Therefore, biochar produced by cow manure vermicompost could be considered as one of the cost effective adsorbents to remove heavy metals from soil and water.

Soil fertility development

In sustainable farming systems, fertilization of the soil is more important than the fertilization of the crop (Koopmane and Goldstein, 2001). Earthworms are the mangers while bacteria are the workers of the process of vermicomposting. Declining of organic matter in soil reduces earthworm activities in the soil markedly. Application of organic matter such as compost, vermicompost, straw and green manure is eventually enhance the mineralization rate of the soil organic matter. However, during early growth of the crop, application of organic fertilizer may increase the completion between microorganisms and crop root system to uptake inorganic nutrients available in the fertilizer (Paterson, 2003). Compost, vermicompost and manure are well known amendments which improve plant growth, soil microbial activities, physical and chemical properties of the soil while suppressing pest and disease problems (Pathma and Sakthivel, 2012; Bending *et al*., 2002). Therefore, they could effectively be employed in restoring degraded lands (Zhang *et al*.,2012). Potential use of compost and vermicompost to enhance microbial activities and processes in soil is well documented (Bhadauria *et al*., 2014). A substantial amount of humic substances can be found in vermicompost which could enhance plant growth similar to growth regulators (Muscolo *et al*., 1999). Maji *et al*. (2016) used *Trichoderma atroviride*, a fungus, isolated from vermicompost to produce humic acid – rich vermicompost. This fungus has an ability to produce ligninases and celluloxylanases which could accelerate the decomposition of straw waste materials. Moreover, humic acid-rich vermicompost treated plants of *Pisum sativum* cv. Bonneville recorded about 109% and 26% higher shoot biomass compared to plants did not receive vermicompost and only received conventional vermicompost, respectively.

Growing mixture prepared for a container experiment with sheep manure vermicompost supplemented with peat moss improved maize (*Zea mays*) growth with addition of native Mexican diazotrophic bacteria and mycorrhiza fungi *Glomus fascicalatum* (Gutie´rrez-Miceli, *et al*., 2008). Only P content of the maize leaves was increased by mycorrhiza (Gutie´rrez-Miceli, *et al*., 2008) and diazotrophic bacteria had a positive influence on mycorrhizal colonization. Liu *et al*. (2020) revealed that application of vermicompost and humic fertilizer could improve aggregate microstructure in saline soil consequently salt leaching was increased while minimizing N losses. Growth and development of bacterial community lived in macro-aggregates was influenced by the improvements in aggregate microstructure.

Yield and quality improvement of crops

Effect of vermicompost on growth and yield of crops such as tomato (*Lycopersicum esculentum*) is well documented (Atiyeh *et al*., 2000; Atiyeh *et al*., 2002b; Bachman and Metzger 2007; Gutierrez-Miceli *et al*., 2007). Reduction of titratable acidity of tomato was reported while increasing soluble and insoluble solids in tomato fruits when potting soil was amended with vermicompost prepared by sheep manure under greenhouse condition (Gutierrez-Miceli *et al*., 2007). The potential of tomato plants infected by a soil born fungal disease, Fusarium wilt due to *Fusarium oxysporum* f. sp. *lycopersici* was significantly inhibited by vermicompost application despite the effect of yield increment (Szczech 1999). The level of protection provided by vermicompost against the pathogen was positively influenced by the application rate of vermicompost. Furthermore, the control of *F.oxysporum* spp may be due to antagonistic effect of the bacteria and fungi available in the vermicompost rather than the chemical properties of the vermicompost(Szczech, 1999). Premuzic *et al*. (1998) found that tomato plants grown in vermicompost yielded fruits with higher content of Ca, vitamin C and lesser Fe than those grown in hydroponic media. However, P and K concentrations in fruits were not significantly different among growth media (Premuzic *et al*., 1998). Bachman and Metzger (2007) found that germination media amended with

20% (by volume) pig manure vermicompost enhanced shoot and root weight, leaf area and shoot to root ratio of tomato (*Lycopersicum esculentum* Mill. 'Rutgers') and French marigold (*Tagetespatula* L. 'Queen Sophia') seedlings while effect of vermicompost on bell pepper (*Capsicum annuum* L. 'California Wonder') and cornflower seedlings (*Centaurea cyanus* L. 'Imperial') was not strong. However, upon transplanting the seedlings into growing media supplemented with same vermicompost, tomato, marigold and cornflower showed greater growth performances compared to bell pepper. According to Ayyobi *et al*. (2014), sustainable growth and yield of French Dwarf Bean (*Phaseolus vulgaris* L.) could be achieved by applying vermiwash and vermicompost leachate in field condition elsewhere, vermicompost leachate was reported to improve growth of tomato seedlings under salt stress conditions while reducing the accumulation on Na^+ in plant tissues, delaying senescence of young leaves and ethylene synthesis while increasing proline and anthocyanin (Benazzouk *et al*., 2020). Furthermore, it was revealed that vermicompost leachate is rich in benzoic acid, salicylic acid and aminocyclopropane carboxylic acid, though it contained small amount of jasmonates, proline and cytokinins (Benazzouk *et al*., 2020). Negative impact of vermicompost on crop growth and development due to high electrical conductivity (Gutie´rrez-Miceli *et al*., 2007) can also be minimized by applying it as a liquid fertilizer. Arancon *et al.* (2005) reported the positive effects of vermicompost prepared by food waste, cattle manure and paper waste of growth and yield of pepper (*Capsicum annuum*) var. King Arthur under field conditions where leaf area, above ground plant biomass and marketable fruit weight were increased. Moreover, application of vermicompost to soil results in increased microbial biomass of the soil and dehydrogenase activity. Mineral content in leaves, seeds and roots of bottle gourd (*Lagenaria siceraria*) were reported to increase with the application of vermicompost prepared by cow dung (Coulibaly *et al*. 2018). A series of experiments was conducted to study the effect of commercially produced humic acid and vermicompost extracted humic acid, indole acetic acid and their combinations on growth and yield of marigold, pepper and strawberry (Arancon *et al*., 2006). Growth of the roots of marigold and pepper enhanced when apply humic acid to the artificial growth media (Metro-Mix360) at the rate of 250 to 1000 mg kg^{-1} and root and fruit number of strawberry were also significantly increased (Arancon *et al*., 2006). According to the quantitative summary of meta-analysis by Blouin *et al.* (2019), in general, commercial yield of any plant, total biomass, shoot biomass and root biomass increased 26%, 13%, 78% and 57%, respectfully by vermicomposts.

Suggestions and future prospects of vermicompost production

The growth and yield performance of improved crop varieties depend heavily on chemical fertilizers and other agrochemicals (Evenson and Gollin, 2003). Despite the fact that crop yield has been boosted by several folds since the inception of Green Revolution, the health and environmental issues which are associated with agrochemicals are now in the central focus (Das *et al*., 2015). Eutrophication of surface water bodies (Bennett *et al*., 2001), deterioration of drinking water quality, destruction of natural cycles of the soil, degeneration of soil microbial biomass and emission of greenhouse gasses are among them (Savci 2012, Zhen *et al.*, 2014). Microbial denitrification is learnt to have significant contribution to the greenhouse gas production thereby making agriculture the second largest industrial contributor of greenhouse gas emission (Palme *et al.*, 2014).With the increasing concern on economy, environmental and human- animal health, global demand for organically produced food was increased significantly during last few decades where organic fertilizer including vermicompost received enormous attention (Dominguez 2004; Mengistu *et al.*, 2017; Yılmaz and Bellitürk, 2018). Furthermore, it is apparent that the production of fertilizers of non-renewable origin is limited in near future (Godfray *et al.*, 2010). However, despite research findings covering many aspects on the effect of vermicompost on soil fertility improvement, growth and yield of various crop species are available, production of vermicompost is not popular among many farmers (Blouin *et al.*, 2019).

Vermicompost is generally a free service provided by earthworms (Blouin *et al*., 2013; Bertrand *et al.*, 2015). Thus, farmers' should be educated about the prospects and the merits associated with the process. Higher education institutions and research stations could play a key role in this regard. Figure 3 shows a possible model for a well planned education program that could be implemented with the financial support of the respective governments and public/private sector investors. According to that technical information and procedure of vermicompost production will be provided by Vermi-Education Centers located in the universities where new knowledge is generated through research. Further, Vermi-Education Centers provide trainings and conduct workshops for government extension officers and agriculture instructors together with the local farmers. Municipal waste management would also be encouraged where involvement of government authorities are mandatory. Vermicompost production process will be monitored by field experts trained by the university while research station can contribute through their extension officers.

Development of vermin- circles and vermin villages would provide mutual benefits to farmers live in developing countries (Figure 4). As an effective tool for organic waste management vermicomposting received global attention massively during last few decades. Purkayastha (2012) discussed the potential of vermicompost production and vermiculture as a method of generating additional income for rural farmers who have accessed to ago based organic wastes, despite of well-known environmental benefits. It could be used to uplift the livelihood of the resource poor farmers through economic empowerment while assuring sustainable crop production hence a most appropriate tool for socio-economic betterment.

Production of vermicompost through community engaging micro-enterprise, which is generally a labor intensive, small scale, people-centric participatory business, could be identified as a viable source of income generation for the underprivileged people of the society. This is an approach most suitable for the countries having free education and agriculture-based economy. The vermicompost then could replace at least 10% of chemical fertilizers reducing the cost of production while minimizing the environmental issues in present-day agriculture.

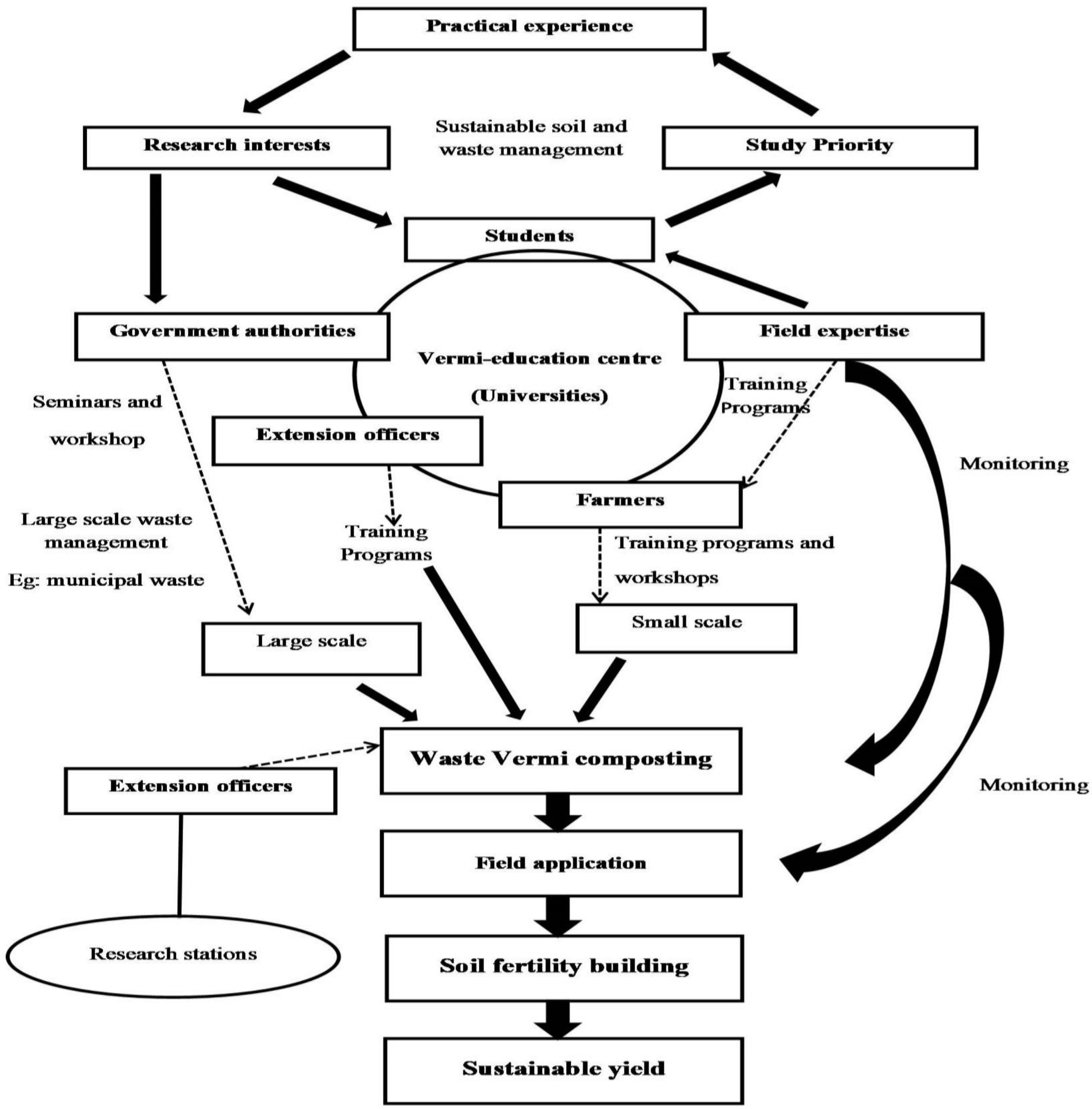

Figure 3: A model for sustainable education program on vermicomposting

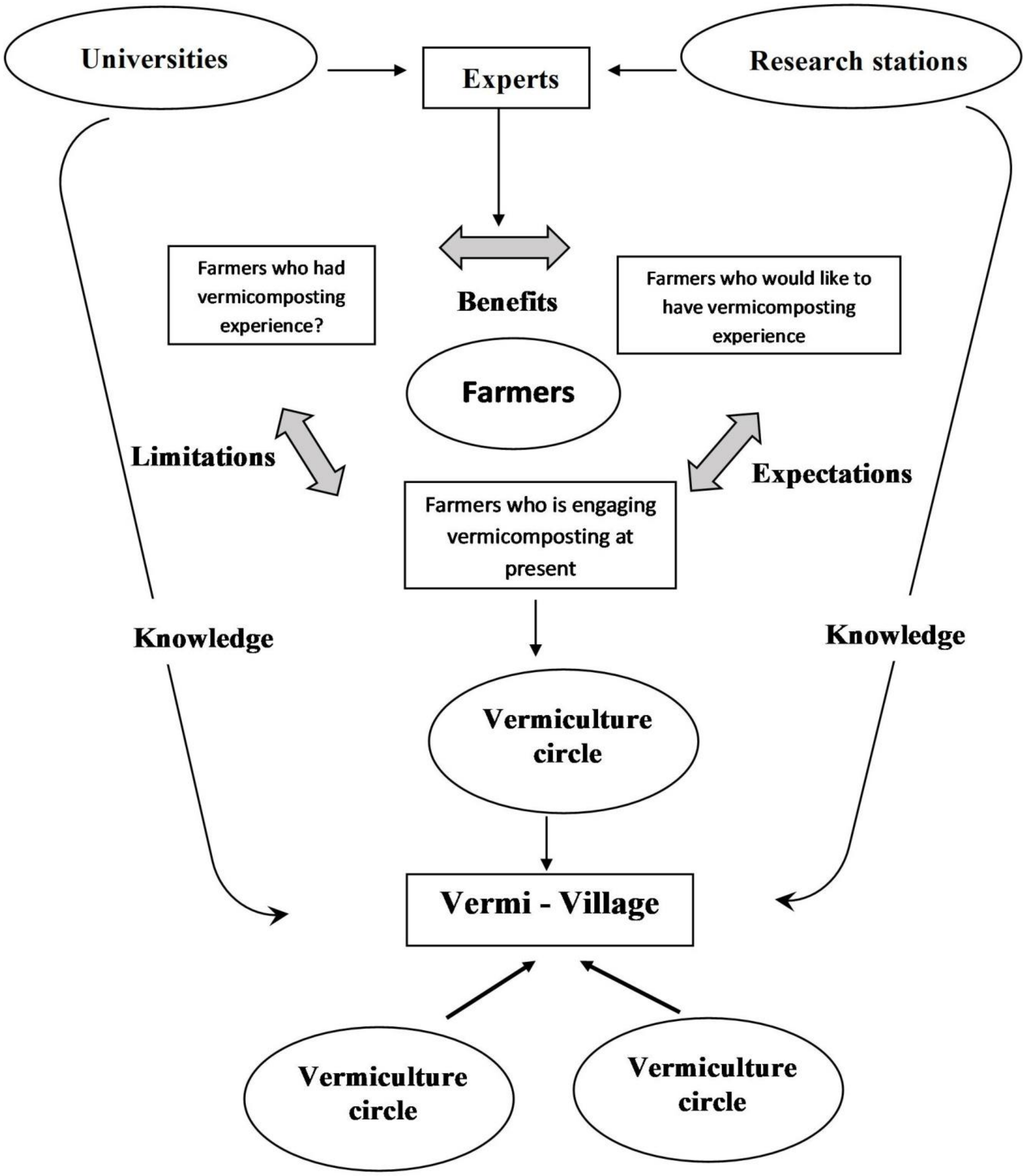

Figure 4: A model for community based micro-enterprise

CONCLUSION AND FUTURE PROSPECTS

Rapid growth of global population accelerated waste generation worldwide. At the same time food production should be hastened to fulfill the needs of growing populations. Therefore, waste management and food production are two of the major issues faced by people in 21st century. Application of high doses of chemical fertilizers increased food production while creating several environment and health related problems. Therefore, demand for organic food is receiving significant attention globally. Recycling organic waste materials into a valuable organic fertilizer could be used to uplift the status of soil nutrient while solving waste problem partially. Vermicomposting is the process by which earthworms convert organic waste materials into humus like substances rich with plant nutrients. Microbes live in the alimentary canal of the earthworm improve the quality of vermicast hence vermicompost. Vermicompost consisted with plant macro nutrients, micro nutrients and growth regulators, including humic acid, indole acetic acid and kinetin could be used to enhance soil fertility. It is well documented the positive effects of vermicomposting on growth and yield of vegetables, fruits and many other crops. Whereas, applicability of vermicomposting process to reduce the toxicity of different waste materials such as flu ash, biogas slurry, and textile mill sludge were investigated. Different sources of organic waste such as cow dung, pig manure, poultry litter, paper, sheep manure and kitchen waste were used to feed earthworms during vermicomposting process. Elimination of pathogens of *Salmonella* spp, fecal coliforms, *Shigella* spp, *Enterobacter aerogenes*, *Enterobacter cloacae* and eggs of helminthes were reported while increasing growth and performance of other favorable microorganisms such as diazotrophic bacteria and mycorrhiza living in the soil. Further, vermicomposting has a huge potential to improve as a micro-enterprise to uplift the livelihood of the resource poor farmers through economic empowerment while assuring sustainable crop production hence a most appropriate tool for socio-economic betterment by giving appropriate education and training.

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