EVALUATING THE VERMICOMPOSTING EFFICIENCY OF SOME EARTHWORM COLLECTIONS AND THE EFFECT OF THEIR VERMICOMPOST ON GROWTH AND YIELD OF TEF (*Eragrostis tef (*Zucc.Trotter*)*)

M.Sc. Thesis

By

Yohannes Belay Zewge

October, 2015

JIMMA, ETHIOPIA

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Submitted to the School of Graduate Studies, Jimma University, College of Agriculture and Veterinary Medicine

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DEDICATION

Dedicate to my mother Lidiya Bekele and my family for their dedicated partnership in the success of my life.

STATEMENT OF AUTHOR

First, I declare that this thesis is my original work and that all sources of materials used for this thesis have duly acknowledged. It has been submitted in partial fulfillment of the requirements for M.Sc degree in Agronomy at Jimma University. I truly declare that this thesis is not submitted to any other institution anywhere for the award of any academic certificate. Quotations from this thesis are allowable with accurate acknowledgement of source.

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Place: Jimma University,

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BIOGRAPHICAL SKETCH

The author, Yohannes Belay Zewge, was born on September 13, 1985 at Harer, Eastern Hararege of the Oromia Regional State. He attended his Elementary education at Alemaya University Community School and his Junnior and Secondary Education at Adama, Goro and Hawas Preparatory Schools, respectively. He successfully passed the Ethiopian School Leaving Certificate Examination (ESLCE) in 2005 and then joined Jimma University College of Agriculture and Veterinary Medicine, in 2006. After three years of study, he graduated with B.Sc degree in Crop Science. After his graduation, he was employed as an Expert of Crop Protection and production in Fedis Woreda Agriculture Bureau and worked from September 2008 to August 2009. In September 2012, he joined the School of Graduate Studies of Jimma University College of Agriculture and Veterinary Medicine to pursue a graduate study leading to a Master Science in Agronomy.

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ABBREVIATIONS AND ACRONYMS

ANOVA: Analysis of Variance

BoARD: Bureau of Agriculture and Rural Development

CF: Chemical fertilizer

CSA: Central Statistics Agency

CV: Coefficient of Variation

DAP: Diammonium phosphate

DZARC: Debre-Zeit Agricultural Research Center

EIAR: Ethiopia Institute of Agricultural Research

EW: Earthworms

FAO: Food and Agriculture Organization

FYM: Farm Yard Manure

INM: Integrated Nutrient Managements

ISD: Institute for Sustainable Development

m.a.s.l: meter above sea level

OC: Organic carbon

pH: power of hydrogen ion

SAS: Statistical Analysis System

VC: vermicompost

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Evaluating the Vermicomposting Efficiency of Some Earthworm Collections and the Effect of Their Vermicompost on Growth and Yield of Tef (*Eragrostis Tef (*Zucc.Trotter*)*)

ABSTRACT

Earthworms are considered as friends of farmers and natural soil engineers. Vermicompost obtained with the help of earthworm has many benefits soil, to plants and friendly to our environment. The aim of the present study was to assess the performance of local earthworm species for their compositing capacity of different feedstock (wheat straw, chickpea straw, khat waste , and mesquite) under controlled conditions at Debre-Zeit Agricultural Research Center (DZARC) and to evaluate the effect of selected vermicompost products on yield and yield components of tef (Eragrostis tef (Zucc.Trotter)). Vermicomposting process was prepared using Eisenia fetida (as standard check), Adet and Werta earthworms' collections as local source of earthworms for composting. The highest multiplication was observed on Adet earthworm spices fed with mesquite. The physicochemical variables like pH, organic carbon, nitrogen, available phosphorus were analyzed at the beginning of the experiment and at harvesting over a period of 72 days. At harvesting day the best vermicompost found at a pH of 7.15 with 1.1% (organic carbon), 0.448% (nitrogen) and 114.072ppm (available phosphorus) *were obtained from fed on mesquite. Significant differences were observed in tef yield and other variables of tef (variety DZ-Cr-387) due to vermicompost application. The highest plant height (84.2cm), panicle length (39.21cm), root length (30.33), root weight (28.91g/pot), fresh straw yield (88.233g/pot) and grain yield (2.64g/pot) were obtained from Vermicompost of mesquite. This study suggests that the earthworms that were collected from Adet could be used efficiently to produce good quality vermicompost from mesquite and also promising yield was result on tef crop.*

Keywords: earthworm, *Eisenia fetida*, feedstock, Tef, Vermicompost,

1. INTRODUCTION

Earthworms live in the soil, working their way through it to ingest and digest organic matter within it. They play an important role by giving high porosity, aerating, drainage and water holding capacity and increase nutrient availability of soil, enhances natural biodegradation and decomposition of organic matters (Rasool *et al***.,** 2008; Sinha *et al*., 2010a). To enhance earthworm growth, reproduction, and health there needs to be certain minimum care requirements for survivability in soil. However, human activity decrease earthworm population by deep and frequent tillage can reduce earthworm populations by as much as 90% (Steven *et al*., 2009). Earthworm abundance is strongly affected by the availability of organic residue in the field after harvesting the crop yield. The amount of organic matter in the soil strongly influences abundance and distribution of earthworms, and soils that are poor in organic matter do not usually support large number of earthworms (Addisu, 2007). Organic mulches enhance earthworm habitat by moderating microclimate and supplying a food source (Steven *et al*., 2009). Heavy application of commercial fertilizer also decreases the number of earthworm in the soil. Application of pesticides can increase mortality (22%-100%) on different earthworms' species (Mahanthaswamy and Patil, 2003;Addisu, 2007). Therefore, the farmers can be benefited and they can avoid extensive use of chemical fertilizers, Pesticides etc., which will affect the fertility of soil in long run. For this it is necessary to establish worm farm or apply a vermitechnology.

Earthworms mainly feed upon decaying organic matter found in the soil and leaf and other plant materials obtained on the soil surface (Gajalakshmi and Abbasi, 2003). Plant residues have different palatability, particle size, protein, crude fiber and some even contain special plant metabolites that may influence the growth and performance of earthworms as composting agent (Suthar, 2007). These factors may as well affect the quality of vermicompost produced from different feedstocks (Yan *et al.*, 2013).

Vermicompost can induce excellent plant growth and promote good crop production without chemical fertilizers. In Australia, using earthworms (*Aporrectodea trapezoids*) to prepared a vermicompost, they increased growth of wheat crops (*Triticum aestivum*) by 39%, grain yield by 35%, lifted protein value of the grain by 12% and the crop resisted diseases as compared to the control (Baker *et al*., 1997). In another experiment, cattle dung compost was applied four times more than that of vermicompost however, applications of vermicompost increased the yield by 6.9Q/ha and 5.58Q/ha over compost and chemical fertilizer respectively (Sinha *et al*., 2010c). This yield advantages come due to the vermicompost, which was enriching the physical and chemical properties of the soil, speed up the composting process, aerate the organic material in the soil (Hailu , 2009), less volatile nutrients (like Nitrogen in form of Ammonia) (Sinha *et al*.,2010a) induce resistance to plant (Mulusew and Nagappan, 2013). Vermicompost contains growth regulators and enhance the finished compost with nutrients and enzymes from their digestive tracts. Therefore choosing a local or native species of earthworm from the local soil for vermicomposting is an important step in improving productivity of crops (Kaviraj and Sharma, 2003).

Tef (*Eragrostic tef* (zucc.) Trotter) is an annual C_4 grass that belongs to the family Poacea (Kebede *et al*., 1989). In Ethiopia tef is a major staple food crop and considered as low risk crop, compared to other cereals. Because of less disease occurrence and high market accessibility, farmers select to produce tef crop (Bekabil *et al.,* 2011). In Ethiopia, according to the report from CSA (2015), tef covers around 24.02% of cultivated area of total grain crops (3,016,053.75 ha). Out of the total cereal grain produced (236,076,624.39quintals), tef accounts for 17.57% (47,506,572.79 quintals). Currently, it is grown throughout the world for the purpose of its grain and straw (Ketema, 1997; Mesfin *et al.,* 2004: Haftamu *et al.,* 2009).

The main constraints in tef production are low-yielding varieties, low moisture stress resistance, water logging, frost, weeds, poor soil fertility, diseases, insects and no use of integrated nutrient managements (INM) (Mary and Leigh, 2010).But most Ethiopian farmers use urea and DAP as Nitrogen and Phosphorus fertilizers sources (Gete *et al.,* 2010), but they are less productive when compared to the commercial compost due to un-integrated supply of each essential nutrients to crop (Tognetti *et al*., 2005). In northern Ethiopia, Tigray region, an experiment done to evaluate the impact of compost and commercial fertilizer on crop yields at farmers' fields showed compost having positive influence on tef productivity than chemical fertilizer (Sue Edwards, *et al*, 2007). Compost can be made in two ways: use of micro-organism and use of earthworms (Steven *et* *al.*,2009). Application of conventional compost (compost made by micro-organisms) is not excellent when compared to vermicompost (Snha *et al.*, 2010a).

In Ethiopia some studies was conducted with related to vermicompost; by Mulusew and Nagappan (2013) studied on the effects of vermicompost on cabbage growth and development related with sucking Pest, at Gondar. Also Yalaga and Shiferaw (2013) directed that local earthworm collection was check on different feed material, at Bale area. But, still it needs further studies. Especially on efficiency of local earthworms, and which feed enhance the population of earthworm. Within this; is there local Earthworm species capable of decomposing organic materials like that of EWs *Esenia fetida (*exotic species*)?* Is there significant vermicompost quality difference by feeding different organic wastes to Earthworm species? Is there tef yield difference by adding vermicompost as organic fertilizer?

General objective

The general objective of these experiments is to investigate the performance of earthworm species for their decomposition capacity of different feedstock and subsequent effect of the vermicompost on tef yield and yield components.

Specific objectives

1. To compare the vermicompost making efficacy of earthworm (EW) species supplied with different feedstock.
2. To determine quality of vermicompost prepared from different feedstock.
3. To evaluate the effect of selected vermicompost on tef yield and yield components.

2. LITERATURE REVIEW

2.1. Earthworm

2.1.1. Taxonomy

Earthworms are invertebrates belonging to the Phylum Annelida, Class Clitellata ,Subclass Oligochaeta, Order Haplotaxida (Gajalakshmi and Abbasi, 2003; Abdullah and Kaminie,2011). Researchers have identified and named around 34 families (Sherman, 2003), more than 700 genera and 7,000 species of earthworm, each with unique physical and behavioral characteristics that distinguish them one from the other (Reynolds and Wetzel, 2004; Hailu, 2009; Pechenik, 2009).

2.1.2. Biology of earthworm

The physical structure of earthworms is similar among the different species. Earthworms belong to the phylum Annelida, which means "ringed". The "rings" around worms are called segments. Segment is built with circular (segments) and longitudinal muscles and with their shrinkage and spread the EWs are able to move (Grdisa *et al.*, 2013). Earthworm bodies are streamlined, containing no protruding appendages or sense organs (eye, ear, nose, and tongue) to enable them to pass easily through soil. But earthworms sense light through photoreceptive organs along their back and on the prostomium (sensitive lobe of tissue overhanging the mouth that the worm uses to probe and sense its environment). Earthworms breathe through their skin (Yalaga and Shiferaw, 2013). The body of EWs is covered with small fluffs, which is important in environmental adjustment and for search of the food in the soil (Sherman, 2003; Grdisa *et al.*, 2013).

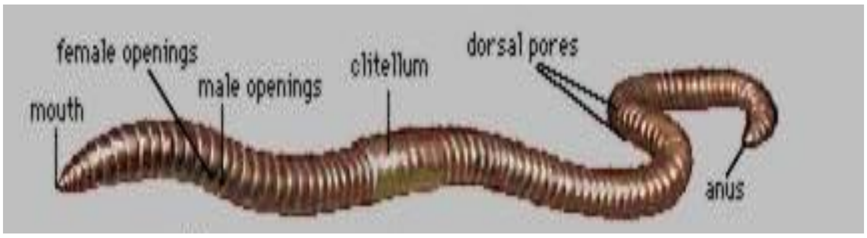


Figure 1. External anatomy of earthworm

Worms have well-developed nervous, circulatory, digestive, excretory, muscular, and reproductive systems (Sherman, 2003). Earthworms are hermaphrodites, which mean that they have both male and female sex organs at one organism (Grdisa *et al.*, 2013).

2.1.3. Environmental requirements of earthworm

Earthworms have certain minimum care requirements for their composting efficiency. The key environmental factors affecting earthworm growth, reproduction, health and decomposition rate are pH (acidity-alkalinity), temperature, moisture, aeration, light, and food material(Sherman, 2003; Mallappa *et al*., 2010).

pH: Power of hydrogen ion influences the conversion rate of waste or feed into vermicompost by earthworms and most earthworm experts' say that most earthworm prefers a pH of 7 or slightly higher (Georg, 2004;Mallappa *et al.*,2010; Yalaga and Shiferaw, 2013). But earthworms can grow and survives within a pH range of about 4.2 to 9.0(Edwards, 1998; Sherman, 2003; Yalaga and Shiferaw, 2013; Usman *et al*., 2015). However, commercial production, earthworm beds should be kept at a pH range of 6.8 to 7.2 (Sherman, 2003), but some time if it is below this range then it is necessary to add lime to rises the pH ions.

Temperature: Generally, most of the earthworm species can tolerate cold conditions much better than hot conditions (Slocum, 2000). Several studies revealed that it is necessary to keep the temperature above 10^0C (minimum) and preferably 15^0C to 20^0C for vermicomposting efficiency (Sherman, 2003; Mallappa *et al.*, 2010; Yalaga and Shiferaw, 2013). But according to Sherman (2003) earthworms can live and breed at temperatures between 12.78^0C and 29.4^0C. If bed temperatures rise too high, they may be lowered by adding water, activating fans in or near the system, and reducing the amount of feedstock applied.

Moisture: Most earthworm species prefer moist conditions than dry conditions. Moist condition of 70-90% is preferred for vermicomposting processes, but different author write different range; for instant Dominguez and Edwards (1997) found 80-90% range to be the best, with 85% optimum, while other findings indicate that 75-80% moisture contents produced the best growth and reproductive response (Georg, 2004; Mallappa *et al.*,2010)). Both of these studies found that vermicomposting operations could operate in the less mucky 70-90% range.

If moisture content is higher than 85% the earthworms move out from the bins, due to the excess moisture contents and anaerobic conditions in the bin. To overcome this problem spraying of water is minimized and the excess amount of water accumulated in the bins must be drained out through small holes made at the bottom and the periphery of the bins (Yalaga and Shiferaw, 2013).

Aeration: Earthworms can survive in relatively low O_2 and high CO_2 environments and even stay alive when submerged in water if it contains dissolved oxygen. If there is no O_2, however, earthworms can die. Oxygen may be depleted if earthworm beds are kept too wet or if too much feed is introduced. By reducing the amount of moisture, cutting back on feed, and turning the pile with a pitchfork or three-prong garden tool, oxygen will be restored. Turning the materials in the beds every two to three weeks will help keep the beds aerobic (Sherman, 2003).

Light: Earthworms are photophobic to some degree, meaning they react negatively to bright light. The severity of the reaction depends on the species of the worm, how bright the light and the level of light to which the worm is accustomed (Gajalakshmi and Abbasi, 2003). For example, earthworms accustomed to some light exposure will react less negatively to sudden bright light than worms accustomed to complete darkness. Some species of worm react negatively to bright light but are actually attracted by dim light. Earthworm sense light by organ photoreceptor (Sherman, 2003).

Food materials: Earthworms prefer to eat vegetable, fruit scraps, grains, coffee grounds and filters, tea bags, small amounts of bread, and other non-greasy foods. But they do not prefer to eat meat, bones, dairy products, pet feces, greasy foods, and citrus peels as these peels contain a natural insecticide that could kill the worms (Sherman, 2003). Beside this earthworm doesn't need volatile oil like citrus fruit, onion, garlic, toxic/harmful chemicals of congress weed, …etc (Bharti, 2010), because it decrease consumption rate of earthworm species (Mallappa *et al*.,2010). If there is a need to give these feeds it is necessary to put less combination/ratios in the compost or dry out the feed in the sun so that the feed loss the volatile oil. According to Gajlakshmi and Abbasi (2003) higher nitrogen ratios help in faster growth and greater production of cocoons. When the C/N ratio of the feed material increases, it becomes difficult to extract enough nitrogen for tissue production. Earthworms find it difficult to survive when the organic carbon content of the soil is low.

2.1.4. Economic importance of earthworm

In vermicomposting (degraded products of waste organics used as feed stock for worms) practice earthworms' biomass becomes a valuable byproduct. Earthworm biomass is also proving to be a great biological resource for mankind due to their importance in different industries (Sinha *et al*., 2010b; Roghaye, 2012).

2.1.4.1. Bioactive Compounds from Earthworms for Pharmaceutical Industries

Medication by earthworm started before Christ in China, Philippines and Egypt. In these countries, EW were used in folkloric healings of many sickness such as fever, inflammation of different parts of the body, stomach-aches and toothaches, rheumatism and arthritis, mumps and measles and even to make child delivery easier by faster contraction of the uterus and reducing labour pains (Sinha *et al*., 2010b; Grdisa *et al.*, 2013). The ash of earthworms was used as a tooth paste for cleaning teeth (Roghaye, 2012). In the past's 10 years, a number of earthworms' clot-dissolving, lytic and immune boosting compounds have been isolated and tested clinically. Some of these compounds have been found to be enzymes exhibiting anti-blood clotting effects (Cordero, 2005). Oral administration of earthworms' powder and enzymes were found to be effective in treating thrombotic diseases, arthritis, diabetes mellitus, pulmonary heart disease, lowering blood pressure, epilepsy, schizophrenia, mumps, chronic lumbago, anemia, vertigo and digestive ulcer (Cooper *et al*., 2004). Cooper (2009) found that earthworm leukocytes can recognize human cancer cells as foreign and can kill them. A peptide lumbricin isolated from *Lumbricus terrestris* by a Japanese scientist has been shown to inhibit mammary tumors in mice. The group of enzymes lumbrokinase also promises to wage a war on cancer (Sinha *et al*., 2010b).

The coelomic fluids of earthworms have been reported to have anti-pathogenic activities and are good biological compound for the production of antibiotics (Pierre *et al*., 1982). Several fatty acids have been isolated from earthworms. Important among them are lauric acid which are known for their anti-microbial properties. It is a precursor to monolaurin which is a more powerful anti-microbial agent that has potential to fight lipid-coated RNA and DNA viruses, several pathogenic Gram-positive bacteria, yeasts and various pathogenic protozoa (Lopez and Alis, 2005). Peptide 'lumbricin I' isolated from *L.lumbricus* also exhibits anti-microbial activity against both Gram positive and Gram negative bacteria as well as fungi (Sinha *et al*., 2010b; Cooper *et al.,* 2012; Grdisa *et al.*, 2013).

2.1.4.2. Raw Materials for different Industries

Earthworms are used as source of raw materials for Rubber, Lubricant, Detergent, Soaps and Cosmetic industries. Some biological compounds like protein, fatty acid and other compounds from earthworms are also finding industrial applications. Being biodegradable they are environmentally friendly and sustainable (Roghaye, 2012). Stearic acid found in earthworms is a long chain saturated fatty acid and widely used as lubricant and as an additive in industrial preparations. It is used in the manufacture of metallic stearates, pharmaceutical soaps, cosmetics and food packaging. It is also used as a softener, accelerator, activator and dispersing agents in rubber making. Industrial applications of lauric acid and its derivatives are as alkyd resins, wetting agents, a rubber accelerator and softener and in the manufacture of detergents and insecticides (Lopez and Alis, 2005). Earthworms are also finding new uses as a source of collagen for pharmaceutical industries (Sinha *et al*., 2010b).

2.1.4.3. Nutritive Feed Materials for Poultry, Dairy, Fishery Industries and Meal

Earthworms' biomass can be used as feed materials for Poultry, Dairy, Fishery and Humans meal, because earthworms are rich in high quality protein (65%) and complete protein with all essential amino acids. There is 70-80% high quality lysine and methionine. Glumatic acid, leucine, lysine and arginine are higher than in fish meals. Worms are also rich in Vitamins A and B. There is 0.25 mg of Vitamin B_1 and 2.3 mg of Vitamin B_2 in each 100g earthworms. Vitamin D accounts for 0.04–0.073 % of earthworms' wet weight. Thus worms are wonderful pro-biotic feed for fish, cattle and poultry. They are being used as additives to produce pellet feeds in the USA, Canada and Japan (Sinha *et al*., 2010b; Edwards and Niederer, 2011; Heni, 2011).

As earthworm protein is complete with 8-9 essential amino acids especially with the tasty glutamic acid it can be used for human beings as well. Worm protein is higher than in any meat products with about 2% lower fats than in meats and ideal for human consumption (Sinha *et al*., 2010b). In some countries like New Zealand some people can prepare delicious food of earthworms. In Japan a mince pie is made from earthworms (Roghaye, 2012).

2.1.4.4. Effects of Earth worm in soil nutrition

Earthworms have a potential to improve physical, chemical and biological properties of soil. Earthworms improve physically property by increasing soil bulk density, pore size, water infiltration rate, soil water content and water-holding capacity (Mayilswami and Brian, 2010; Sinha *et al*., 2010a). The improvement of soil properties is not only physical but also chemical (availability of N, P, K and others nutrient level), and biologically (increment of beneficial microorganisms). These improvements come due to direct and indirect effects of earthworm. When earthworm poops their cast on/in soil they build up important soil nutrient especially nitrogen (N), phosphors (P), potassium (K) and other important hormones (Borah *et al.*, 2007). In other way some deep burrows earthworm spices feed on rock and P minerals. Epigeic spicies of earthworm decompose dead plant matter to gain 37% more nitrogen, 66% more phosphates and 10% more potash within a year. The chloride content was less by 46% (Sinha *et al*., 2009a). The indirect effect of earthworm on soil nutrient was creating favorable condition to microorganisms, such as phosphate mineralizer bacteria, Agrobacteria, Rhizobia. Many consider the number of earthworms to be directly proportional to the health of a soil. When the number of earthworms increases the quality of the soil well improved.

Earthworms are now greatly relied nutrients in vermicompost and in soil to increase the yield of crop. Elmer (2012), concluded that earthworm plays vital role in altering the nutrient composition in soil and promote plant growth. The earthworm activities clearly accelerate the nutrient release and sequential uptake of nutrients (Sinha and Gokul, 2007).

2.1.5. Effect of agricultural managements on earthworm

Nowadays earthworms are known important organisms in soil fauna to provide the soil with fertility and improving soil structure of farm. Beside this, it is important to know how earthworm populations are affected by different agricultural practices adversely or favorably. The main agricultural practices that take place on farm soils are fertilization, tillage, use of pesticides, mulching and irrigation and drainage (Edwards and Bohlen, 1996b; Auburn, 2001).

2.1.5.1. Fertilization

Almost all organic fertilizers benefit earthworms. The addition of animal manure, sewage wastes and spent malt from breweries, paper pulp, or potato processing waste all showed a positive effect on earthworm numbers (Edwards *et al*., 1995). Additions of organic material can double or triple earthworm numbers in a single year. On the other hand ammonia and salt content of some liquid manure can have an adverse effect on EW, but the populations usually recover quickly (Edwards and Bohlen, 1996b).

The use of inorganic fertilizers also has a positive impact on earthworm numbers. This is probably an indirect effect of the increased crop biomass production and consequent increases in organic residues (Edwards and Bohlen, 1996b). the positive effect only organic residues left over on farm land, otherwise it kills the soil microorganism, earthworm and disturbs soil fauna.

Ammonia and ammonia-based fertilizers can adversely affect earthworms. Annual use of ammonium sulfate, anhydrous ammonia, and sulfur-coated urea has been shown to decrease earthworm populations. According to Edwards and Lofty (1977) after extremely long exposure to several levels of ammonium sulfate (0, 48, 97, and 145 kg/ha), the populations of earthworms were inversely proportional to the dose of nitrogen applied. This is probably due to the effect of these fertilizers on lowering soil pH. Direct exposure to anhydrous ammonia during application will kill up to 10% of the earthworm population (Auburn, 2001).

Lime seems to benefit earthworm populations in otherwise acid soils because most species of earthworms favor neutral pH levels and require calcium for growth. Lime may indirectly benefit earthworms by increasing plant growth and therefore plant residues (Auburn, 2001).

2.1.5.2. Tillage

As the number and intensity of tillage operations increase, so does the physical destruction of burrows, cocoons, and the earthworm bodies themselves. Less intensive tillage systems that leave residues on the surface throughout the year improve the environment for earthworms. Decreased tillage disturbances particularly benefit night crawlers (*L. terrestris*). When tillage destroys the burrow, some earthworms will not have the energy reserve to form a new burrow to their food source,but endogeic (shallow dwelling) earthworms will tolerate annual tillage because they continually form new burrows and acquire a greater proportion of their food from the soil rather than surface litter. No-till and other methods of conservation tillage such as chisel plowing and ridge tillage can increase populations of both types of earthworms (Edwards and Bohlen, 1996a; Auburn, 2001).

A single tillage can't radically reduce earthworm populations, repeated tillage over time will cause a decline in earthworm populations. Research has found the following: Earthworms were reduced by 70% compared to previously undisturbed soil after five years of plowing (Edwards and Bohlen, 1996b).After 25 years of conventional tillage of crop production earthworm populations were only 11-16% of what existed in the original grass field (Edwards and Bohlen, 1996b). Edwards *et al*. (1995) reported up to 30 times more earthworms in no-till systems compared to plowed fields.

2.1.5.3. Pesticide

The objective of pesticides application to crops is to protect the crop from the pests, but beside this we lose important beneficial organisms such as bees, earthworms, and generally predatorily insects. 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 *et al*., 2009b).That is why most herbicides are harmless to earthworms (Edwards and Bohlen, 1996b; Auburn, 2001).

Certain species of earthworms such as *Eisenia fetida, Aporrectodea tuberculata, Lumbricus terrestris, L. rubellus, Dendrobaena rubida, D. veneta, Eiseniella tetraedra, Allobophora chlorotica* have been found to tolerate and remove wide range of chemicals from soil (Safawat *et al.*, 2002). But some class of pesticides have different toxicity levels on earthworms species (Appendix Table 1).

2.1.5.4. Irrigation and Drainage

Irrigated soil can support high levels of earthworm activity where moisture levels would otherwise be too dry. Irrigation also increases crop production, resulting in more food and increased earthworm populations. Irrigation waters that carry earthworms and their cocoons may act as a source of inoculum for certain species. Draining poorly drained soils will potentially provide a more favorable environment for earthworm activity by aerating the soil (Auburn, 2001).

2.1.6. Efficiency of different earthworm species on vermicomposting

In the world there are different species of earthworm. We can categorize them in to three associated with their ecology/habitat(Edwards and Bohlen, 1996b;Brown et al., 2000; Sherman, 2003; Madhuri *et al.*,2013; Usman *et al*.,2015*)*. These are:- **Epigeic** are litter dwellers and feeders and do not bury far down into the soil. These type of worms frequently used for worm farms, home composting and naturally found in forests and anywhere there is a surface litter of vegetation. In this class of earthworm the most know species is *Eisenia fetida.* **Endogeic** lives in the top 30 cm or so of soil, and also the surface litter. They possess a strong, functioning gizzard. In this group the most popular one is *Eudrilus eugeniae.* **Anecic** are the deep dwelling worms, larger in size and forming permanent vertical burrows. In this group the most common one is *Lumbricus terristris*

These three earthworms differentiated from one group to the other by characteristics of living environment, food, burrow formation, cocoon production rate, life cycle and compost efficiency. The detail characteristics of earthworm's types are shown in Appendix Table 2.

So based on the above information the best worms for vermicompost is Epigeic worms, because they are easy to replicate, needless effort, exhibit high reproduction rate and highly suitable for vermicompost farm. In world most known Epigetic species was *Eisenia fetida* (Sinha *et al.*, 2010b; Usman *et al*., 2015)

2.1.7.Vermi-technology

Vermicomposting technology is a technology that utilizes earthworms to convert organic waste in to vermicompost, vermiculture, vermitea, vermi-wash and also earthworm can be used as vermi-medication (Aalok *et al*., 2008; Manyuchi *et al.*, 2013).

2.1.7.1. Vermi-compost

Vermicompost is one source of an organic fertilizer which is rich in NPK, macro and micronutrients, beneficial soil microbes like nitrogen-fixing bacteria and mycorrhizal fungi and excellent growth promoters, thus can have several benefits over the conventionally produced compost. It has also ability to suppress disease and ability to repel pests (Hossein *et al*.,2014). Atiyeh *et al*. (2000) found that the vermicompost tended to be higher in nitrates, which is the more bio-available form of nitrogen for plants. Tomati *et. al.* (1987) reported that vermicompost do have the ability to stimulate plant growth, consistently improved seed germination, enhanced seedling growth and development, and increased plant productivity. Due to the presence of plant growth hormones (auxins, gibberlins and cytokinins) in it. Vermicompost also contain enzymes like amylase, lipase, cellulase and chitinase (Aalok *et al*., 2008). More significantly, vermicompost contains 'humus' which makes it markedly different from other organic fertilizers. It takes very long time for soil or any organic matter to decompose to form humus while earthworms secrete humus in their excreta. Suhane (2007) found that the total bacterial count was more than 1010/g of vermicompost. It included Actinomycetes, Azotobacter, Rhizobium, Nitrobacter and Phosphate Solubilizing Bacteria ranging from 102-106 per g of vermicompost (Sinha *et al*., 2010b). Additionally, it provides many benefits to agricultural soil, including increased ability to retain moisture, better nutrient-holding capacity, better soil structure, and higher levels of microbial activity (Usman *et al*., 2015). So vermicomposting and vermi-culture offer potential to organic farmers as sources of supplemental income (EIAR, 2014; Hossein *et al*., 2014).

2.1.7.2. Vermi-culture

Vermi-culture is one of vermicomposting technology that refers to the science and technology of breeding earthworms. Vermi-culture focuses on the rearing of worms, rather than production of vermicompost (Aalok *et al*., 2008; Jensen *et al*., 2011; Sujit, 2012). The goal is to continually increase the number of worms in order to obtain a sustainable harvest. Growing worms efficiently requires a somewhat different set of conditions than vermicomposting (Jensen *et al*., 2011). The worms are either used to expand a vermicomposting operation, sold to customers who use them for the same purpose, for industries (such as cosmetics, food processors, etc) or to feed animals. Producing worms will require considerable attention, especially at the start. Because worm reproduction and growth requires optimization of temperature, aeration, pH and moisture conditions (EIAR, 2014).

2.1.7.3. Vermi-tea and vermi-wash

In vermicomposting technology there are two liquids by-products produced from vermicomposting process. These are vermi-wash and vermi-tea that can be utilized as liquid fertilizer or bio-fertilizers. Vermi-tea can be produced in the process of vermicomposting and a leaching liquid is called vermi-tea, whereas vermi-wash is produced by culturing of earthworm into less heated water (Edwards and Niederer, 2011; Manyuchi *et al.*, 2013). During vermi-wash preparation, earthworm evacuates the residual waste from their guts the culumic fluid into water (Ansari and Ismail, 2012).Vermi-wash and vermi-tea are liquid bio fertilizer, which are rich in macro and micro-nutrients. These vermi-products can be utilized as bio-fertilizers and has been applied in various crops (Manyuchi *et al.*, 2013).

2.1.8. Movement of vermi technology globally and in Ethiopia

First Green Revolution used destructive agro-chemical to increase agricultural productivity of in the world. The agro-chemicals effect is not well known in 1960s, but now day agro-chemicals are the cause of human disease (like cancer, respiratory problem and others), soil fauna disturbance, addictiveness of the farm land to chemical fertilizer year to year, and cost increment of chemical fertilizer from time to time (Harendra and Keshav, 2012; Anitha *et al*., 2014; Hossein *et al*., 2014).

Nowadays the global scientific community is searching for a technology which should be "economically viable" (cheaper to be afforded by all nations), "environmentally sustainable" (friendly to the environment-flora, fauna, soil, air and water, with no adverse effect on them) and "socially acceptable" (beneficial to the society with no adverse effect on human health) (Sinha *et al*., 2010b). So it is necessary to accompany in the feature agricultural revolution by vermi-agro-production technology replacing the destructive agro-chemicals.

Today the movement of vermi-technology is going forward world widely. Worldwide large-scale vermicompost operations have been found. Countries like Australia, Canada, India, Cuba, Russia, North America, Philippines, Netherlands, United States, Argentina, UK, are where the most large-scale vermicompost operations have been found worldwide (Sinha *et al*., 2010b; Edwards *et al*., 2011).Composting companies are also participating in vermicomposting business, composting all types of organic wastes on commercial scale and selling them to the farmers. This has dual benefits in cutting cost on landfill disposal of waste while earning revenues from sale of worms and vermicompost (Munroe, 2007; Sinha *et. al*., 2009b; Hossein *et al*., 2014).

Under Ethiopian condition we are yet to use vermicompost as organic fertilizer source. Three decades ago Russian experts were the first to introduce and raise an exotic earthworm species in Ethiopia, while they were working at the then Ambo Plant Pathology Laboratory. These worms were the red wigglers or *Eisenia fetida* species. Ambo Agricultural Research center has been able to maintain these worms for some time after the Russians left the center. Later on, the then Germen technical cooperation GTZ branch in South Gondar was the one to start raising both exotic and local earthworm species for vermicomposting process. After this the vermicomposting study had been extended to different agricultural research centers like Adet, Gondar, Holetta, DebreBirhan, Jimma and Debre Zeit(EIAR, 2014).

Currently, very few agricultural research centers and professional societies in Ethiopia have been started production of vermicompost for research purpose. Neither the private investors nor farmers and community based entrepreneurs are participating in vermicompost/ vermi-culture production. Ethiopia has ample of unused crop residues and *in situ* decomposable plant species favorable for vermicompost production. Huge volume of these crop residues and animals dung, in particular crop residues in large scale farms have been burnt during land preparation (Rani *et al*., 2007). Starting with niche crop residues and litter products with established markets is seen to ensure success in vermicomposting. However, the country has the potential for both vermi-culture and vermicompost produce (EIAR, 2014).

Ethiopian farmers are familiar with the production and process of conventional compost making because of the agricultural extension systems/activities in the farming community for the last 12 years (EIAR, 2014). However, compost production has not been practiced on commercial or large scale basis. Similar to this, worm compost or vermicompost, which is a nutrient-rich, natural fertilizer and end product of the breakdown of organic matter by special varieties of earthworms is less known by the farmers as well as by the public, but it is attractive and it has also great acceptances in farmer community (Yalaga and Tilaye, 2013; Kassa *et al., 2014*). Earthworms play an integral component in agriculture. These worms are important biological resources that have a tremendous potential in agro ecosystems because they significantly affect soil physical structures and organic matter dynamics, and promote plant growth.

If farmers produce crops organically then they restore, maintain and enhance ecological harmony. Compost being essential components of organic farming could play vital role in increasing crop productivity and in maintaining long term soil fertility in agriculture. Beside this the farmer could increase profit by 59.4% (Rani *et al*., 2007). According to Rani *et al*. (2007) in Ethiopia, cost of production for organic farming was about 40.6% less than that for inorganic farming. In Jimma area researchers obtained promising results through the use of organic farming that curtain inorganic farming system.

2.1.9. Source of earthworm feed in Ethiopia

In 2013/2014 main cropping season, Ethiopia used 7,104,646 quintals of inorganic fertilizer (CSA, 2014) for 5,806,319 hectares. Also Rani *et al.* (2007) stated that. Ethiopia has plenty of organic fertilizer. The amount required for 3.25 million hectares (total agricultural land) per year for compost/vermicompost, poultry manure, FYM and bio-pesticides are 3.25×10^{10} ton, 3.2×10^{9} ton, 9.7×10^{7} ton and 1.6×10^{10} ton respectively. The total amounts available per year in the country for each category were 1.6×10^{11} ton of compost/vermicompost, 8.5×10^{9} ton of poultry manure, 1.8×10^{10} ton of FYM and bio-pesticides are in abundance. This could show the amounts of essential elements for sustainable development in Ethiopia.

In Ethiopia wheat straw (*Triticum spp*), chickpea (*Cicer arietinum*), and khat (*Cathaedulis*) covered an area of 13.25% (1,663,837.58 hectares), 1.91% (about 239,747.51 hectares) and 1.75% (222,078.54 hectares) (CSA, 2015), respectively. Also *mesquite* (*Prosopis juliflora)* has covered one million hectares according to BoARD (2009).

2.2. Tef

2.2.1. General information on tef

Tef [*Eragrostis tef* (Zucc.) Trotter] is the only cultivated cereal in the genus Eragrostis under the family Poaceae. Ethiopia is the center of origin of tef (Vavilov, 1951; Jones *et al*.,1978). Ethiopian farmers prefer tef, because the grain and straw bring good prices. Tef is also culturally deep entrenched in the food-habit of the Ethiopian population. In Ethiopia, tef covers an area of around 24.02% from total grain crop area (3,016,053.75ha), and out of the total cereal grain produced (236,076,624.39q), tef accounted for 17.57% (47,506,572.79 q) (CSA,2015). Its production area is increasing at unprecedented scale due to increased market-demand both local and foreign (Abdul, 2009).

2.2.2. Economic importance of tef

Tef crop is the widely grown food crop in Ethiopia and for forge in the reset of the world. The primary production of tef crop is for the purposes of grain in Ethiopia. The tef grain is use for producing tef flour. Tef flour is used for making injera, gluten free pancakes like food and sometimes for making porridge. The grain is also used to make local alcoholic drinks, called tela and katikala (Ketema, 1997; Alemayehu, 2001). Doris (2002) reported that tef contains 11% protein and is an excellent source of essential amino acids, especially lysine, the amino acid that is most often deficient in grain foods. He further mentioned that tef is also an excellent source of fiber and iron, and has many times the amount of calcium, potassium and other essential minerals found in an equal amount of other grains. He also noted that tef is nearly gluten-free, and is gaining popularity in the whole food and health food industry in the U.S. as an alternative grain for persons with gluten sensitivity.

Tef straw, besides being the most appreciated feed for cattle, is also used to reinforce mud and plaster the walls of tukuls and local grain storage facilities called gotera (Ketema, 1997; Alemayehu, 2001). Due to these tef straw is preferred to any other cereal straws and can fetch premium price (Ketema, 1993). Gilbert (1997) indicated that tef straw from threshed grains is considered to be excellent forage, superior to straws from other cereal species

2.2.2. Fertilizer requirement

Most Ethiopian farmers use diammonium phosphate (DAP) and Urea fertilizers as sources of Nitrogen and phosphors. The tef fertilizer recommendation according to Ministry of Agriculture and Rural Development was 100kg DAP/ha and 100kg urea/ha (Kenea *et al.*, 2001), but according to Haftamu *et al*. (2009) application of 69kg N/ha gave optimum biomass and grain yields of tef and hence farmers have to use this rate for tef production on Vertisols. As an alternative, farmers can also use 46kgN/ha to get comparable income from the crop on Vertisols. Generally, this implies that farmers can apply N-fertilizers at a rate ranging from 46-69kg N/ha to get optimum tef yield on vertisols. Major factors affecting tef fertilizer recommendation are water logging, seasons of planting, cropping history, lodging and weed growth (Kenea *et al.*, 2001).But in Ethiopia the actual rate of fertilizer used by farmers is below the blanket recommendation and not in integrated way. In Ethiopian conventional compost was used for the last 10 years and well known by farmer. According to Institute for Sustainable Development (ISD) experimental results on farmers filed in Tigray region, were they compared conventional compost (applied 5ton/ha) and chemical fertilizers (DAP and Urea(applied 120kg/ha)) as source of nutrients, the use of compost gave higher yields than the use of chemical fertilizer (Kassie *et al*., 2009: Kassie *et al.*, 2010). Similarly, Elkhtab (2006) two seasons cropping experiment showed that vermicompost and conventional compost led to better crop performance than chemical fertilizer.

2.2.4. Production of tef in Ethiopia

The main producer of tef in the world is Ethiopia. Tef can grow under wide and diverse agro-ecological ranges. Ethiopia have 18 major agro ecological zones, in this agro ecologies two type of rain exists: the Belg (short rainy season) and Meher (main rainy season). The length of the growing period ranges from 60 to 180 days (depending on the variety and altitude) with an optimum of 90 to 130 days (Deckers *et al*., 2001).

In Ethiopia, tef is mainly produced in Amhara and Oromia, with smaller quantities in the Tigray and SNNP regions. There are 19 major tef producing zones in the country. The Central and South Tigray zones are the major tef producing zones in Tigray. Within the Amhara Region: East Gojjam, West Gojjam, North Gonder, South Gonder, North Wollo, South Wollo, North Showa and Awi Zones are the major producers of tef. In Oromia region the major tef producing zones include the East Shoa, West Shoa, South West Shoa, North Shoa, East Wallega, Horo Guduroo Wallega, Jimma, Illubabor and Arsi. The production of tef in Ethiopia occupies 24.02% of the total grain crop area crop (3,016,053.75 hectare)(CSA, 2015).

3. MATERIALS AND METHODS

3.1. Description of Experimental Site

The experiment was conducted at Debre-Zeit Agricultural Research Center (DZARC). DZARC is located 47 km away from the capital city, South East Addis Ababa. The research center is geographically located at altitude of 1900masl, latitude of 8°44'N and longitude of 38°58'E. It has average annual rainfall of 839 mm and mean air temperature of 18.5 ^{0}c. The center consists of heavy clay Pellic Vertisols and light textured Chromic Vertisols (www.eiar.gov.et).

3.2. Experiment-I: Effect of Different Feeds on Vermicompost Production and Earthworm Multiplication

3.2.1. Experimental design and applied managements

The experimental design for vermicompost making efficacy of local earthworm (EW) species fed with different feedstock were compared using two factors (the first factor (factor A) being the feed materials at four levels and the second factor (factor B) was earthworm species at three levels). The treatment combinations were replicated three times and arranged in Completely Randomized Design (CRD). In this experiment management practices in terms of added amount of water, bin size, grinding of the feeding materials, number of EW added and environmental conditions were maintained similarly to all experimental units.

3.2.2. Experimental materials

The experimental materials used in this experiment were three earthworm species, namely *Eisenia fetida* (control), Wereta collection (We-20-2001) and Adete collection (AD-20-2004); and four type of feed stocks: wheat straw, chickpea straw, khat waste and mesquite (Appendix Table 4).

3.2.3. Preparation of bin

For this experiment bins were made from wood and tin materials. The bin size for all treatments was 60 cm×45 cm×57 cm (0.1539 m^3). The bin box sides were made from timber and the bottom with tin. The top of the bins were and covered with wire mesh to protect the earthworms from predators.

3.2.4. Preparation of bedding

Bedding is necessary prerequisite step to inoculate earthworms into their bins to start vermicomposting. For bedding of earthworm there is no rule or step or composition of bedding. Thus tef straw, soil and dried cow dung (Appendix Table 4) at a ratio of 2:1:1.5 respectively with two bedding layers were used in all cases. The total height of bedding was 39 cm. After adding the bedding materials into each bin, the bins were left for one week after adding 10 litre of water before inoculating earthworms.

3.2.5. Preparation of feed

In this experiment, four type of feed were tested. These are wheat straw, chickpea straw, khat waste and mesquite. Wheat and chickpea straw were obtained from DZARC experimental field and the feed stocks were chopped into 1-2 cm size. Whereas, the khat waste was collected from street and khat cafe. Khat waste was used after shade drying for 5 days and chopping to the same size as other feed materials (1-2 cm). Mesquite was collected from Welenchity Woreda and chopped to 1-2 cm before use.

3.2.6. Pedigree of earthworms

The earthworm species were provided from DZARC earthworm culturing unit. The *E. fetidia* EW species were brought to Ethiopia from Russia through phytopathology laboratory at Ambo. The Adet EW species were collected from around BahirDar, West Gojam Yilmana Densa district near Adet Agricultural research centre (2400 masl). The Woreta EW species collected from around Woreta town 60 km North of BahirDar, Fogera district (1900 masl). These earthworm species have unique characters (Appendix Table 3)

3.2.7. Inoculation of earthworm

Before the inoculation of EW, the bedding was prepared and 10 litters of water was added to the bedding materials. Adding of 10 litters of water was done to create favourable conditions for the EW and microbial organisms (Appendix Table 5). Finally, 45 individual worms, each from the three species, were introduced to each bin and maintained for 72 days, for decomposes of the feeding materials.

3.2.8. Feeding of earthworm

Feeding of the earthworms was done three days after their introduction to the bins. One and half kilo of each feed was added to each bin on top of the bedding materials, then one litter of water was added to each bin to maintain moist environment favourable to the EW feeding on the feeding materials.

3.2.9. Harvesting of vermicompost

After 72 days of incubations the process of vermicompost was stopped and the earthworms were separated from the vermi-cast. In the current experiment light harvesting method was used to separate earthworms from the vermi-cast . The compost was harvested by spreading a sheet of plastic under a bright light. The contents of the bed leaving the bedding materials were divided into a number of heaps on the sheet. Then, the worms crawled away from the light into the centre of each heap and the compost was brushed away from the outside of the heaps by hand as described by Adhikary (2012). And the vermi-cast was sent to laboratory for nutrient analyses.

3.2.10. Data Collected

Decomposing efficiency of earthworm species was assessed in terms of vermicomposting quality and biomass potential of the earthworms. After 72 the days vermicompost was harvested from each bin and the following data were collected.

- **Number of earthworms**
- **Growth percentage (GP):** GP was calculated by dividing difference between final number of EW and initial number to initial number of EW(Renu *et al*., 2006).

$$GP = \frac{Final\ \text{Number} - Initial\ \text{Number}}{Initial\ \text{Number}} x100\%$$

- **Total weight of the earthworms**: The total weight of EW was measured by weighing all EW on sensitive balance at the beginning and end of experiment.
- **Individual weight:** individual weight of the EW was calculated by dividing total weight of earthworms to the number of earthworms (Renu *et al*., 2006).

$$\text{Individual weight} = \frac{\text{Total weight of EW}}{\text{Number of EW}}$$

Quality of vermicompost

Vermicompost samples were taken from each bin and air dried. To determine the quality of the vermicompost, each sample was analyzed at DZARC soil laboratory following standard procedures at soil laboratory.

- **pH:** The pH of the samples was measured by a digital pH meter (1:2.5 ratio).
- **N:** total nitrogen (TN %) was determined using Kjedahl method.

1. 0.5 gms of the sample was wrapped in aluminum foil and then was put in a kjeldhal flask. The catalyst mixture was added and digestion was carried out.
2. Sample was heated on flame for 10-30 min till charred. The flask was rotated until the organic matter destruction and till gray colored solution obtained.
3. Digested sample was then diluted with 10 ml of distilled water and 5ml was taken in condensation flask. Flask was then heated till solution boils.
4. At the end titration was carried out with 0.1 ml HCl by adding phenolphthalein indicator. End point – Purple to pink.

- **P:** available phosphorus was extracted using Oleson method.

1. 1 gm of dried sample was taken and 200 ml of 0.002 N H_2SO_4 was added in it and mixture was stirred for half an hour.
2. Solution was then filtered through Whatman filter paper no. 42.
3. 5 ml of filtrate was taken and 2 ml of ammonium molybdate along with 05 drops of $SnCl_2$ was added in it.
4. Total volume of the mixture was made to 100 ml with distilled water and absorbance was taken at 690 nm.

5. Standard graph was plotted and readings were extrapolated.

Calculation:

% Available Phosphorus = mg P/l of sample/50.

- **OC:** organic carbon (OC%) was determined following Walkely and Black (1947) wet oxidation method.

1. Oven dried sample was passed through 0.5 mm sieve then 10 grams of the sample was added to 500ml flask.
2. 10 ml of 1N $K_2 Cr_2O_7$ AND 20 ML of Concentrated H_2SO_4 was mixed in it. Flask was then kept for 30 minutes for incubation then content was diluted to 200 ml with distilled water.
3. 10 ml of phosphoric acid and 1ml of DPA indicator was added to the sample and was then titrated against 0.5N ferrous ammonium sulphate. End point was brilliant green.

Calculations: % Carbon = 3.951/G X (1-T/S)

G= wt. of the sample

S= ml of Ferrous ammonium sulphate

T=Titration reading in ml.

3.3. Experiment-II: Effects of Selected Vermicompost on Yield and Yield Components of Tef

3.3.1. Experimental design and applied managements

The evaluation of different vermicompost fertilizer on tef yield and yield components consisted of four vermicompost products and two controls as treatments. The treatments were: Mesquite vermicompost by Adete EW collection (Vm), Wheat vermicompost by Werta EW collection (Vw), Chickpea vermicompost by *E. fetida* (Vc), Khat vermicompost by Adete EW collection (Vk), positive and negative control, arranged in Completely Randomized Design (CRD) with three replications. In this experiment all agronomic practices were applied as per the recommendation for tef crop in the area except fertilizer application.

3.3.2. Experimental materials

For the experiment the most popular tef varietyDZ-Cr-387 (Quncho) was used. Quncho was released in 2005 from DAZAC. It's color is white and matures in 86-151days. The height of the variety is about 72-104cm, yield on station 25-27q/ha, and on farm16-20q/ha (Bekabil *et al.*, 2011). The variety was sown in a pot (18.5cm diameter with 16 cm height) and maintained under greenhouse conditions.

3.3.3. Selection of vermicompost

In the first experiment, twelve vermicomposts were produced through the combination of four feed materials and three EW species. From these vermicompost, selection was made based on the nitrogen content following the analysis. Four vermicomposts were selected. These are: the vermicompost prepared from wheat straw, chickpea straw, khat waste and mesquite by the three species of earthworm was selected based on their nutrient content quality.

3.3.4. Pot preparation

The pots were filled with three layers: first layer was big gravel (162 g), second layer was small gravel (530 g) and third layer was air dried vermicompost/soil (940 g).

3.3.5. Data collected

Growth variables, yield and yield component of tef

- **Plant height**: Plant height was measured at physiological maturity from the ground level to the tip of the panicle from five randomly selected tef plants in each pot.
- **Panicle length:** It is the length of the panicle from the node where the first panicle branch emerges to the tip of the panicle which was determined from an average of five randomly selected plants per pot.
- **Number of effective tillers**: The numbers of effctive tillers was determined by counting the tillers from five randomly selected plants per pot.
- **Root dry weight and length**: Plant root length was measured at physiological maturity from the ground level to the tip of roots from five randomly selected plants in each pot. Dry weight of the roots was measured after oven drying the of roots from five randomly selected plants per pot.
- **Main panicle seed weight**: The average seed weight of the main panicle at harvest was recorded from five randomly selected plants per pot.
- **Grain yield:** Grain yield was measured by harvesting the crop from the net pot area.
- **Biomass yield:** At maturity, the whole plant parts, including leaves and stems, and seeds from the total pot area were harvested and weight measured before and after oven drying.
- **Straw yield**: After threshing and measuring the grain yield, the straw yield was measured by subtracting the grain yield from the total above ground biomass yield.
- **Harvest index**: Harvest index was calculated by dividing grain yield by the total above ground dry biomass yield (Fleischer et al., 1989).

$$HI=\frac{\text{Grain yield (g/pot)}}{\text{Total biomass yield (g/pot)}} \text{x100} ()$$

3.4. Statistical Analysis

First of all collected data were fed into Excel sheets and analysis of variance (ANOVA) was applied by using general linear model (GLM) procedures of SAS version 9.2 (SAS Institute, 2008) and mean separation was carried out, for those variables found significant, using least significant difference (LSD) at 5% level of significance. Before, analysis of each data were checked for satisfaction of ANOVA assumptions.

4. RESULTS AND DISCUSSIONS

4.1. Experiment I: Effect of Different Feeds on Vermicompost Production and Earthworm Multiplication

4.1.1. Growth performance and productivity of earthworms

Total weight of earthworms: The interaction effects of earthworm species and different feeds provided to the earthworm showed significant differences ($p < 0.05$) on weight of earthworm (Appendix Table 7; Table 1). Maximum mean weight, 452.50 g, was recorded when Woreta collection earthworm species was fed with wheat straw, which were statically at par with *E. fetida* fed with mesquite (400.33 g). However, the lowest weight (192.33 g) was obtained when *E. fetida* was provided with khat waste. This was statistically at par with *E. fetida* fed with wheat straw (198.67 g), chick pea straw (203.00 g); Adet EW collection fed with chick pea straw (203.67 g), khat waste (225.33 g), wheat straw (249.00 g); and Wereta EW collection fed with wheat straw (249.00 g).

The above results indicate comparatively mesquite was the favorable feed among the other treatment in increasing weight of Ews. Whereas the least comfort feed for earthworm was khat waste and chickpea straw. Naturally earthworm doesn't prefer oily/greasy feed. However, khat plant was known to contain 0.9% oil (Algabr *et al*., 2014). And chickpea straw have large amount of protein and less content of organic carbons compared to wheat straw. Kale *et al*., (1982) suggested that decomposition of cellulose and lignin present in organic wastes was known to enhance the weight of earthworm. With regard to the species of EWs, they were may be genetically different and phenotypic plasticity from each other that contributed to the weight difference after the experimental period, i.e., Wereta EW collection (E_2) were heavier than the Adet EW collection and *E. fetida* EWs.

Table 1. Interaction effect of earthworm species and different feedstock on EWs Weight (g)

EW species	**Feedstocks**			
	wheat straw	chickpea straw	khat waste	mesquite
E. fetida	198.67[ef]	203.00[ef]	192.33[f]	400.33[ab]
Adet collection	249.00[def]	203.67[ef]	225.33[ef]	343.67[bc]
Wereta collection	452.50[a]	249.17[def]	269.00[cde]	316.67[cd]
CV: 16.16%; $LSD_{5\%}$ for interaction: 74.96				

Final Individual earthworm body weight: The interaction effects of earthworm species and different feedstocks fed to the earthworm indicated significant difference ($p < 0.05$) on individual body weight of the earthworm (Appendix Table 8; Table 2). Maximum individual earthworm body weight, 0.2937 g, was recorded when Woreta collection earthworm species were with wheat straw, which were statically different when compared with other combinations of EWs and feedstocks. However, the lowest weight (0.1171g) was obtained when Adet EW collection was provided with chick pea straw. This was statistically at par when *E. fetida* was fed with wheat straw (0.1137 g), chick pea straw (0.1317 g), khat waste (0.1267 g); when Adet EW collection was fed with wheat straw (0.1426 g), khat waste (0.1442 g), mesquite (0.1383 g); and when Wereta EW collection were fed with mesquite (0.1473 g).

In terms of individual body weight; considering the earthworm species, Wereta collection worms are the best to grow, when fed with is wheat straw. This might be due to the fact that wheat straw is high in organic carbon content, which increases the individual body weight than reproduction of the earth worms. The present result is supported by Hailu (2009) who reported that C:N of feed have effect on reproduction and individual weight. He further opined that when the organic carbon content is higher the earthworms go to increase in individual body weight, rather than reproduction. But if the feed have higher proportion of nitrogen content then high fecundity occurs in earthworm population with increased reproduction rate than body building. Comparatively the highest individual weight obtained from Wereta EW collection was may due to the genetic difference and environment effects of this species (naturally big) when compared to the other earthworm species.

Table 2. Individual body Weight (g) of earthworm species as affected by interaction effect of different EW species and different feedstock

EW species	Feedstocks			
	wheat straw	chickpea straw	khat waste	mesquite
E. fetida	0.1137[e]	0.1317[de]	0.1267[de]	0.1614[bcd]
Adet collection	0.1426[de]	0.1171[e]	0.1442[de]	0.1383[de]
Wereta collection	0.2937[a]	0.1848[bc]	0.1962[b]	0.1473[cde]
CV=14.74%;	**$LSD_{5\%}$ for interaction:0.0393**			

Growth percentage (%): The interaction effects of earthworm species and different feedstock fed to the earthworm indicated non-significant difference ($p > 0.05$) on growth percentage of earthworm (Appendix Table 9). Whereas the main effects of earthworm species was significantly different ($P<0.05$) in terms of growth percentage of the earthworm (Table 3). The highest mean number of earthworm was documented when Adet EW collection was inoculated to the feeds, 3769.3, which was statically at par with *E. fetida* earthworm (3578.3). Significantly, minimum number (3293.4) of earthworms was obtained from Wereta collection.

Similarly there was significant difference ($p < 0.05$) in terms of growth percentage of earthworm when they were fed with different feedstock (Table 3). Significantly highest mean growth percentage of earthworms was recorded when they were fed with mesquite (4089.4). On the other hand, the least number of earthworms were recorded when they were fed with khat waste (3202.0) which were statically similar with chick pea straw fed earthworms (3341.6).

Table 3. Growth percentage (%) of *E. fetida* and Ethiopian local earthworm's species as affected by feedstock

EW species	Feedstocks				Means of EW species
	wheat straw	chickpea straw	khat waste	mesquite	
E. fetida	3521.4	3350.2	3391.1	4050.4	3578.3a
Adet collection	3764.6	3778.4	3236.3	4297.8	3769.3a
Wereta collection	3378.5	2896.4	2978.5	3920.	3293.4b
Means of feedstock	3554.8b	3341.6bc	3202.0c	4089.4a	

CV= 8.57%   LSD for feedstock: 295.69   LSD for EW species: 256.08

Based on the above results, growth percentage performance of earthworms is affected with the species of earthworms and the feed provided to them during their growth stage. Among the feedstock provided to the earthworms, the best feed in influencing growth of the earthworm species was mesquite. This may happen due to high organic carbon content and nitrogen in the mesquite feed as opposed to the other feedstocks (Appendix Table 1). This agree with that of Suthar (2007) report, who found that the waste decomposition and earthworm production was associated strongly with the quality of the substrate, especially with their chemical as well as biological composition. Similarly Suthar and Singh (2008), observed that earthworms when introduced in to organic wastes they had increased growth rate and reproduction activity. It is true that different species of earthworm prefer different kind of feeds (Manna *et al.,* 1997). According to these authors for *P. excavates* earthworm species the best feed was maize stover followed by city garbage, wheat straw, chickpea straw and soybean straw in that order. In the when study the earthworm species more preferred mesquite and less preferred khate waste, because mesquite has high organic carbon content oil content is less as opposed to khat waste. Khat waste contains 0.9% oil in its leaves (Algabr *et al*., 2014) which is high and less attractive for earthworms.

Similarly growth and population of Adet collection was influenced by different feedstocks with maximum preference to mesquite followed by chickpea straw, wheat straw and khat waste. For *E. fidiea* and Woreta collection earthworms the best preferred feed was also mesquite; however, the next preferred feeds were wheat straw, khat waste and chick pea straw (Figure 2).

Inoculation of feedstock with earthworms accelerated the decomposition process, which resulted in a reduction in the duration of decomposition. Adet collection earthworms found to exhibit the highest growth performance when compared to *E. fetida* and Woreta collection earthworms (Figure 2). This might be due to conducive environment to Adet collection earthworm (collected from cold environment similar to DZ) than the other earthworms. Bisen *et al*. (2011) compared three different EW species collected from places with different environmental conditions. They observed faster multiplication of the local EW as opposed to earthworm species collected from other environment like *E. fetida* and *Eudrillus euginae*, which might be due to less adaptability to local environmental conditions.

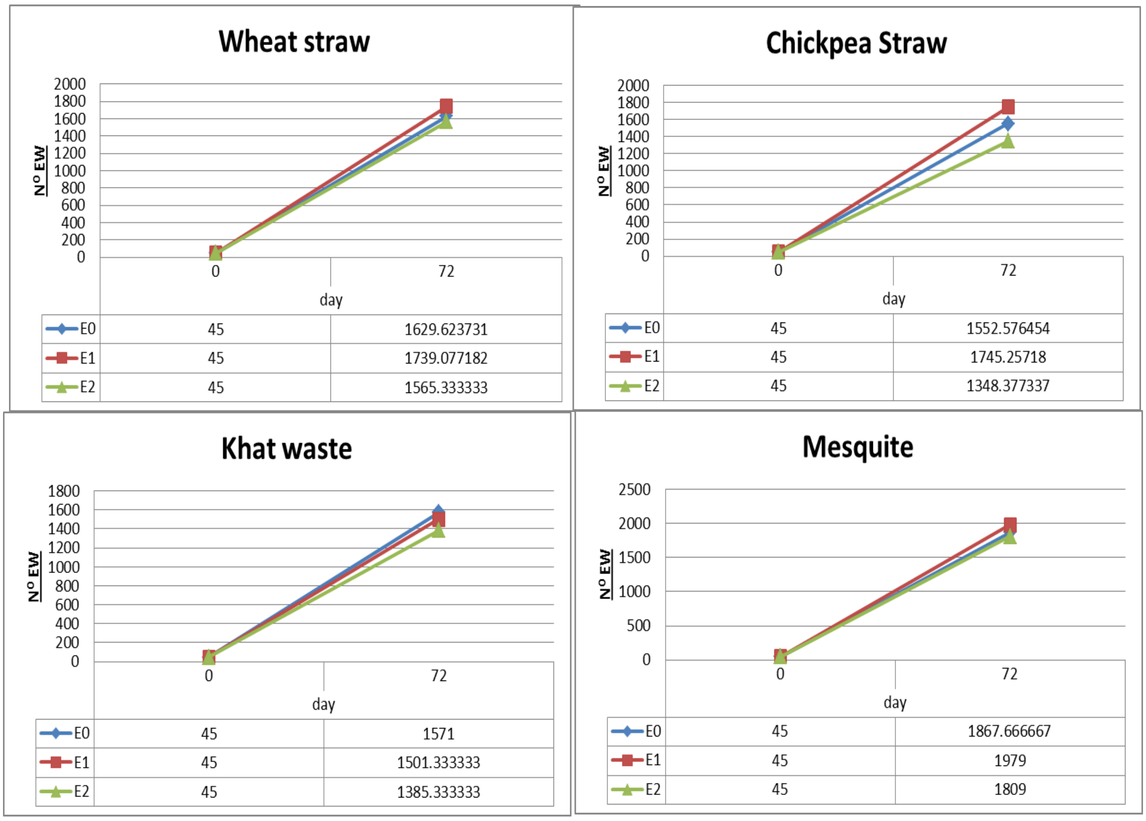


Figure 2. Effect feedstock on number of earthworm species.

4.1.2. Vermicompost Quality

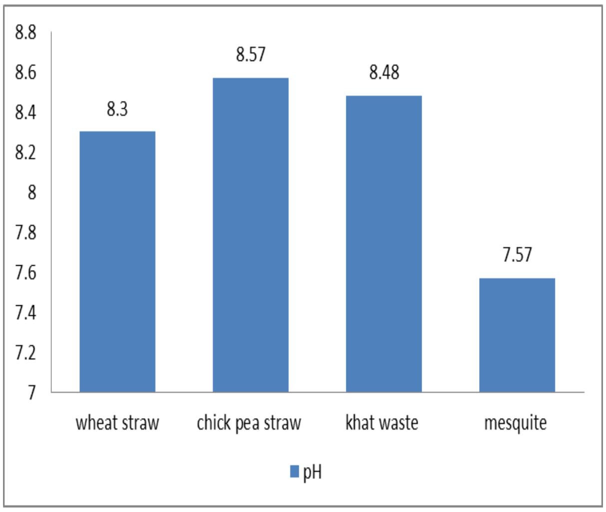
The end product of vermicompost quality can be differences due to process types and raw materials (Edwards and Arancon, 2004). This quality determine by the laboratory analysis such as pH, OC, N, P, K CEC ,and other.

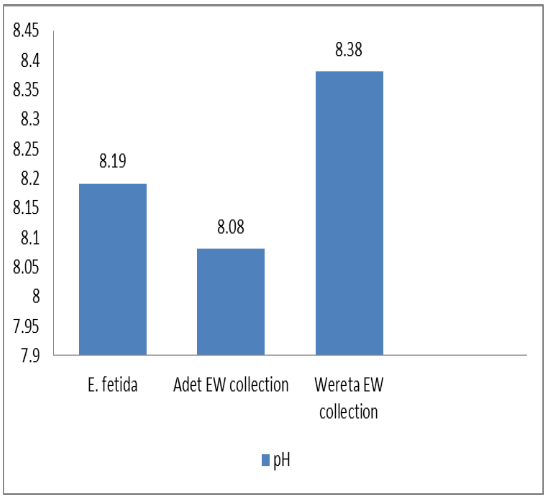
p**H:** p**H** is determine both quality and quantity determinants of nutrients contents in vermicompost. However, the interaction effects of earthworm species and different feedstock fed to the earthworm indicated non-significant difference ($p > 0.05$) on pH value (Appendix Table 10; Figure. 3). Whereas the main effects of the earthworm species and feedstock's were significantly different ($p < 0.05$) in terms of pH content of the vermicompost. The highest mean value of pH was recorded when Wereta EW collection was inoculated to the feeds, 8.38, which was at par with *E. fetida* earthworm species (8.19). Whereas, the least pH value, 8.08, was documented from Adet EW collections.

Similarly there was a significant difference ($p < 0.05$) in terms of pH value when the main effect of feedstock was assessed (Figure. 3). The highest mean pH value, 8.57, for the vermicompost was observed when chick pea straw was provided to the earthworms which were statically similar with khat waste (8.48). On the other hand, least pH value (7.52) of vermicompost was obtained when mesquite was provided as a fed to the EWs.

Decomposition of organic matter leads to formation of two different components, these are ammonium ions and humic acids, and these have exactly opposite effects on the value of pH. Presence of acids result in lowering of pH while base ions can increase the pH value of the vermicompost. The pH of vermicompost from mesquite was near neutral, but higher pH value was recorded for vermicompost made from chickpea straw, followed by vermicompost of khat waste and vermicompost of wheat straw. Therefore, the pH value of vermicompost also dependents on substrate utilized. Gutierrez-Miceli *et al*. (2007) observed a pH value of 8.6 from sheep manure while Lazcano *et al*. (2008) documented 7.73 pH value from vermicompost made of cattle manure. Also Atiyeh *et al*. (2002) recorded a pH value of 5.3 for vermicompost made from pig manure. These authors and their findings justify the fact that differences in the substrate used for compositing would result in the formation of vermicompost with different pH values.

Figure 3. pH value of vermicompost produced from different feedstocks using EW species





Total Nitrogen: The interaction effects of earthworm species and different feeds fed to the earthworm indicated no significant difference ($p > 0.05$) on available nitrogen (Appendix Table 6). Also no significance ($p > 0.05$) difference happened because of feed type and earthworm specie (Appendix Table 11).

Available phosphorus: The interaction effects of earthworm species and different feeds fed to the earthworm indicated a significant ($p < 0.01$) difference on phosphorus (Appendix Table 12, Table 4). The highest available phosphorus, 151.474, was recorded when Woreta collection earthworm species was feed with chickpea straw. This was statistically at par when *E. fetida* was fed with wheat straw (140.565), and khat waste (138.725). However, the lowest available phosphorus (105.206) was obtained when Adet EW collection was provided with wheat straw. This was statistically similar when *E. fetida* was fed with mosquite (120.352); when Adet EW collection was fed with khat waste (107.288), mesquite (114.072g); and Wereta EW collection were fed with khat waste (12.238).

These results indicate that mineralization of P during vermicompost depends on both type of the feedstocks and EW species. *E.fetida* has highest mineralization of Phosphorus nutrient from the feed wheat straw, chickpea straw and khat waste than the other earth worm. This is due to higher cast (faecal) of *E.fetida*. This shows that during composting preparation using earthworms (vermicomposting) the concentration of P in the composted material (vermicompost) varies with the type the material and the earthworms species. Based on the type of feedstocks available different EW species can be selected for different feedstocks sources. Therefore, having different EW collections, could be helpful in vermi composting of different materials at different locations. Garg *et al* (2006) and

Nedunchezhiyan *et al*. (2011) reported that phosphorus mineralization and mobilization was a result of bacterial and faecal phosphatase activity of earthworms. Also Yan *et al* (2012) reported that the initial wastes material affects the final nutrient contents of vermicompost.

Table 4. Phosphorus (ppm) content of vermicompost produced by interaction effect of different EW species and feed materials

EW species	Feedstocks			
	wheat straw	chickpea straw	khat waste	mesquite
E. fetida	140.565[ab]	127.529[bcd]	138.725[abc]	120.352[def]
Adet collection	105.206[f]	123.671[dc]	107.288[ef]	114.072[def]
Wereta collection	121.760[ed]	151.474[a]	120.238[def]	128.583[bcd]
CV=7.255%	**$LSD_{5\%}$ for interaction: 15.28**			

C:N: The interaction effects of earthworm species and different feedstock fed to the earthworm indicated no significant difference ($p > 0.05$) on C:N value (Appendix Table 13). Also there was no significant difference ($p > 0.05$) in terms of C:N when they were fed with different earthworm species (Table 5). But the main effects of feedstock was significantly different ($P < 0.05$) in terms of C:N value, when the different feeds were inoculated with different earthworm species . The highest C:N was 3.2499 recorded when wheat straw was provided to the earthworms. On the other hand, least C:N value (2.63) of earthworm was obtained when mesquite was provided as a fed to the EWs which were statically similar with khat waste (2.72) and chick pea straw(2.766).

The C/N ratios of vermicompost treatments were lower over the initial feed treatments due to the process of mineralization by earthworm and microorganisms. So, the final values of C:N of all treatments were between 2.33:1 and 3.42:1 whereas the initial feed was 39.07-130. Moreover, the gradual decrease in C:N ratio with time may be explained by the loss organic carbon as CO_2 (Bisen *et al*., 2011) due to microorganisms and earthworm with in process of mineralization. Higher C:N ratio indicates slower mineralization of substrate by the species (Haug, 1993).

Table 5. C:N ratio content of vermicompost produced from different feed materials

Feedstocks	wheat straw	chickpea straw	khat waste	mesquite
Means of feedstock	3.2499a	2.7662b	2.72b	2.63b
Initial C:N ratio	126.81	52.80	39.07	70.11
CV: 16.473%	**$LSD_{5\%}$ for Feed:0.455**			

4.2. Experiment II: Effects of Different Vermicompost on Yield and Yield Components of Tef

4.2.1. Plant height

Tef plant height was significantly ($p < 0.05$) affected by the application of different vermicompost (Appendix Table 14; Table 6). The highest plant height was observed by the application of chemical fertilizer, 89.67 cm, but this was not statically different from application of vermicompost prepared from chickpea (84.27 cm), khat (84.20 cm) and mesquite (82.53 cm). Whereas the lowest plant height was recorded form negative control, 66.07 cm. This indicate that application of vermicompost from these sources cause significant increase on tef plant height, which might be due to the impact of nitrogen within the nutrient sources that usually favors vegetative growth of plants. Elkhtab (2006) also noticed application of sources of nitrogen fertilizers to plants causes better plant height.

4.2.2. Tiller

The total number of tillers and number of effective tillers were also found to vary significantly ($p < 0.05$) due to the application of vermicompost (Appendix Table 15, and 16; Table 6). Maximum number of tillers and effective tillers were noted from plants that received the recommended chemical fertilizer, 5.2 and 3.83, which was statically similar with vermicompost fertilizer prepared from mesquite (4.53) in case of total number of tillers. On the contrary, the lowest number of tillers and effective tillers were recorded from untreated pots (2.47 and 0.08, respectively) which were significant different from the other treatments.

The analyses of variance (ANOVA) showed that the percentage of effective tillers has shown a significant difference at $p < 0.5$. The highest percentage of effective tillers on tef was observed by uses of chemical fertilizer (74.561%) which is at par with application of vermicompost prepared from wheat straw (70.216%), mesquite (69.557%) and chickpea straw (66.598%). However, the smallest percentage of effective tillers on tef was obtained from negative the control treatment (33.114%). Table 6 indicates vermicompost fertilizer prepared from mesquite has got the highest tiller value and the lowest number of effective tillers were obtained from pots treated with vermicompost fertilizer prepared from khat. This is because of pH value and availability of nutrient in vermicompost media. The availability of nutrient depends on pH value. The best for number of tiller was application of chemical fertilizer and vermicompost fertilizer prepared from mesquite which supplied efficient nitrogen nutrient to the roots. The current result is in agreement with that of Genene (2003) who reported higher tillerring and maximum survival percentage of tillers with increasing nutrient in bread wheat.

4.2.3. Panicle length

Panicle length was significantly ($p < 0.05$) influenced by the application of vermicompost (Appendix Table 17; Table 6). Application of vermicompost fertilizer increased the panicle length. However there was no significant difference among chemical fertilizer and all the vermicompost prepared from different feed stocks on panicle length. This result is in agreement with Abdolamir and Mehdi (2014). These authors reported that wheat panicle length increased in response to vermicompost application with significant variation between different vermicompost even though the longest panicles being obtained at the highest (100%) recommended rate of nitrogen fertilizer.

Table 6. Effect of different vermicomposts on tef plant growth attributes

Treatments	**Plant height (cm)**	**Total Nº of Tillers**	**Effective Nº of tiller (Nº)**	**Tiller effectiveness(%)**	**Panicle Length(cm)**
Control(+)	89.67^{a}	5.20^{a}	3.83^{a}	74.561^{a}	41.08^{a}
Control(-)	66.07^{c}	2.47^{d}	0.80^{d}	33.114^{c}	31.125^{b}
V_w	77.53^{b}	3.60^{c}	2.53^{c}	70.216^{ab}	40.15^{a}
V_c	84.27^{ab}	3.80^{bc}	2.53^{c}	66.598^{ab}	41.0^{a}
V_k	84.2^{ab}	4.00^{bc}	2.4^{c}	59.764^{b}	39.21^{a}
V_m	82.53^{ab}	4.53^{ab}	2.80^{b}	69.557^{ab}	40.86^{a}
$CV_{\%}$	7.35	11.68	12.69524	12.96	7.585
$LSD_{0.05}$	**10.55**	**0.8174**	**0.5734**	**14.366**	**5.2336**

Key:- V: vermicompost; Vw: Wheat vermicompost by Werta EW collection ; Vc : Chickpea vermicompost by *E. fetida*; Vk: Khat vermicompost by Adet EW collection; Vm: Mesquite vermicompost by Adet EW collection; Control (+): Application NP fertilizer at 90/15; Control (-): No application of any fertilizer source.

4.2.4. Root length and weight

Root length and network is very important for higher nutrient assimilation. Root length was not significantly ($p > 0.5$) different between treatments(Appendix Table 18). The highest mean root length was observed from V_m (30.33 cm) application followed by the positive control (29.33 cm), V_W (28.67 cm), V_K (26.83 cm), V_C (26.00 cm) and negative control (24.67 cm) in that order.

By the application of different vermicompost fertilizers on tef, root weight significant ($p < 0.05$) difference (Appendix Table 18; Table 7). The highest mean root weight, 28.91 g/pot, was recorded from application of vermicompost prepared from mesquite using Adet EW collection. This might be due to the fact that this vermicompost might have created suitable pH value which could be related to soil enzymes, plant growth hormones, microbial populations and available nutrients over longer periods. Padmavathiamma *et al*. (2008) opined that addition of vermicompost improved soil environment and encouraged proliferation of roots that drew more water and nutrients from larger area. The positive response of vermicompost on plant growth and yield was probably not only due to the available nutrients but also due to the availability of plant growth influencing materials, such as growth regulators, humic acids produced by the microbial population resulting from earthworm activity (Ndegwa and Thompson, 2001; Arancon *et al*. 2004).

4.2.5. Straw yield

Fresh and oven dried straw yield were found to vary significantly ($p < 0.05$) due to the application of vermicompost of different sources (Appendix Table 20, and 21; Table 7). Maximum gram of fresh and oven dried straw yield were obtained from pots that received of the V_m, 88.233g/pot and 37.293g/pot respectively, which were significantly different from the other treatments. On the contrary, minimum fresh and oven dry weight of straw yield were recorded from untreated pots (36.167g/pot and 15.840).

Vermicompost prepared from mesquite by Adet EW collections emerged as best growth medium in terms of straw yield (Table 7). This may be attributed to the vigorous vegetative growth enhancing property of integrated nutrient whereby increased number of tillers and dry matter may have been produced. This is because of naturally sufficient nutrient statuses in vermicompost fertilizer. Integration of nutrient usually favors yield of tef which results in highest straw yield. The current result is in agreement with that of Elkhtab (2006), who reported that use of cotton manure, vermicompost (worms) and farmyard manure resulted in the highest fresh weight value than chemical fertilizer. Similarly, Sue Edwards *et al*. (2007), found that in application of compost and recommended chemical fertilizer to tef plant, there were good performance recorded due to compost applications.

Table 7. Effect of different vermicompost fertilizer on tef straw yield, root length and weight

Treatments	**Straw yield (g/pot)**		**Root length (cm)**	**Root wt(gm)**
	Fresh	oven dry		
Control(+)	63.500^{b}	29.217^{b}	29.33	22.02^{b}
Control(-)	36.167^{d}	15.840^{c}	24.67	12.73^{d}
$\mathbf{V_w}$	60.433^{bc}	25.253^{b}	28.67	17.55^{c}
$\mathbf{V_c}$	47.600^{cd}	20.627^{cb}	26.00	15.03^{cd}
$\mathbf{V_k}$	51.20^{bc}	23.883^{cb}	26.83	17.62^{c}
$\mathbf{V_m}$	88.233^{a}	37.293^{a}	30.33	28.91^{a}
$CV_{\%}$	13.0076	14.63864	16.803	12.784
$LSD_{5\%}$	13.388	6.6601	NS	4.3165

Key:- V: vermicompost; Vw: Wheat vermicompost by Werta EW collection ; Vc: Chickpea vermicompost by *E. fetida*; Vk : Khat vermicompost by Adete EW collection; Vm: Mesquite vermicompost by Adete EW collection; Control (+): Application NP fertilizer at 90/15; Control (-): No application of any fertilizer source. NS: not significant

4.2.6. Grain yield

The analysis of variance showed that grain yield harvested from total pot was significantly different ($p < 0.05$) under different vermicompost application (Appendix Table 22). The highest grain yield on tef was observed by the use of V_m (2.64 g/pot). While the lowest grain yield was recorded by applying Vk,1.26 g/pot, which is at par with the negative control (1.32 g/pot)(Table 8).

Besides, the grain yield harvested from tef tillers was significant ($P< 0.05$) up on application of different sources of vermicompost (Appendix Table 23). The highest tiller grain yield was obtained from chemical fertilizer applied per pot, 1.42 g/pot, statically similar with V_m (1.4 g/pot) and V_W (1.31 g/pot). The lowest tiller grain yield was collected from the negative control (0.72 g/pot) was at par with V_K (0.74 g/pot). When the number of tillers and effective tillers was higher, then the source of grain yield will be better.

The highest grain yield per pot was obtained from plant treated with vermicompost prepared from mesquite Adet earthworm collections. This could be due to the effectiveness of Adet EW collection in converting mesquite feed stock as compared with other EW types. This is because integrated nutrient usually favors yield of tef which results in highest grain yield. These results were in conformity with the experiment of Elkhtab (2006), who reported that use of cotton manure, vermicompost (worms) and farmyard manure recorded highest value of grain yield than chemical fertilizer. Similarly Sue Edwards *et al*. (2007), found that application of compost gave better performance than and recommended chemical fertilizer to tef plant. Similarly Brhan (2012) and Fayera (2014) reported highest grain yield due to applications of blended fertilizer that the conventional recommended fertilizers (DAP and Urea).

4.2.7. Biomass

Biomass yield was significantly ($p < 0.05$) influenced by application of vermicompost fertilizer (Appendix Table 24; Table 8). The highest biomass yield was recorded by application of mesquite vermicompost fertilizer (90.87 g/pot) among the others Vm improved the biomass yield by 38% compared to the chemical fertilizer, followed by V_w (45%), V_k (73%), V_c (83%) and negative control (142%). V_m is the best when comparaing to the other Vermicompost and chemical fertilizers. The superiority of Vm may be the suitability of pH and high availability of nutrient contained in it that improved the growth of tef plant. If all macro and micro nutrients are in good supply in adequate way then there will be higher biomass. This result agrees with Brhan (2012) and Fayera (2014), who reported an increase in biomass of tef with an increased when application of with blended fertilizer.

4.2.8. Harvest Index (HI)

Harvest index was significantly ($p < 0.05$) influenced by application of vermicompost fertilizer (Appendix Table 25; Table 8). The highest mean value recorded on Vc, (9.353%), which was at par with Vw (7.973%), negative (7.785%) and positive control (7.445%). The lowest harvest index was observed on Vk, (5.085%) which was statically similar with Vm (6.468). This is due to less nutrient assimilation by tef root because of uncomfortable soil media for more root network growth. The idea lines up with Shridhar *et al* (2012) who showed that when root:shoot ratio increases, then the HI will increase. And also the highest HI recorded on Vc is due to higher nitrogen content. This finding agrees with Sinclair (1998) who reported that on his review that high accumulation of nitrogen level have high grain yields, and thus, high levels of nitrogen are commonly associated with crops having high harvest indices.

Table 8. Effect of different vermicompost fertilizers on tef yields

Treatments	**Grain yield(g/pot)**			**Above ground biomass (g/pot)**	**Harvest index %**
	main plant	Tiller	Total/ pot		
Control(+)	0.93[b]	1.4167[a]	2.34[b]	65.84[b]	7.445[ab]
Control(-)	0.6[c]	0.72[c]	1.32[c]	37.490[d]	7.785[ab]
V_w	0.94[b]	1.2467[ab]	2.25[b]	62.683[bc]	7.973[ab]
V_c	1.08[b]	1.0500[b]	2.10[b]	49.703[cd]	9.353[a]
V_k	0.51[c]	0.7433[c]	1.26[c]	52.457[bc]	5.085[c]
V_m	1.24[a]	1.40[a]	2.64[a]	90.87[a]	6.468[bc]
$CV_{\%}$	8.10095	13.6187	7.950861	13.688	14.97234
$LSD_{5\%}$	0.1264	0.2656	0.2791	6.7086	1.96

Key:- V: vermicompost; Vw: Wheat vermicompost by Werta EW collection ; Vc: Chickpea vermicompost by *E. fetida*; Vk: Khat vermicompost by Adete EW collection; Vm: Mesquite vermicompost by Adete EW collection; Control (+): Application NP fertilizer at 90/15; Control (-): No application of any fertilizer source.

5. SUMMARY, CONCLUSION AND RECOMMENDATION

Vermicompost supply all plants nutrients, hormones, microorganism, enzymes and humus. This help the plant to repeal and resist to pests like aphid and best production with socially accepted agricultural production method. EW need well organized feedstock for their reproduction and builds up them. The mesquites have better performance than the other feed in terms of multiplication of EW.

In Ethiopia, low soil fertility is one of the factors limiting the productivity of crops, including tef. Unless something is done to restore soil fertility, other efforts to increase crop production could end up with little success. Hence, sustaining soil fertility in intensive cropping systems for higher yields of better quality can be achieved through applications of organic fertilizer. Use of Vermicompost fertilizer increases the production and quality of tef crop. Tef is the staple food of most Ethiopian people; the present production system is not satisfying the consumers' demand; because the farming system that farmers use is traditional methods not supported by modern technologies. Due to this use of blended fertilizers is not economically profitable for farmers. So it is better to apply vermicompost fertilizer for effective nutrient source to plant and alternative resource of fertilizer for poor farmers to grow their crops without polluting the environments by agricultural chemicals (fertilizer and pesticides).

Use of vermicomposting method has a dual positive effect on environment. On one hand it provides a good solution to cities solid waste and on the other hand it improves the soil fertility. Thus, from the present study the following conclusion can be forwarded:-

- Weight of EW species increased with the use of mesquite as a feedstock material which is a notorious alien invasive weed spices. Thus composting of this species is a double win situation for Ethiopia agriculture.
- Mean individual weight of EW increased as a result of wheat straw feeding
- Number of EWs was higher when Mesquite/*Prosopis* feed was given to EW spices.
- Mesquite/*Prosopis* showed the least pH value, which is convenient for EW multiplications

- All feed materials used for this study showed vermicompost product with very good C:N (<4) which is better than any fertile soil C:N value.
- Tef planted with vermicompost made from mesquite by Adet EWs showed overall higher seed yield than the rest of treatments.

Taking the above mentioned conclusions into accounts the following recommendation may be considered:

- Ethiopian soil harbors best, effective and efficient earthworm species, which is very comparable with that of the well-known exotic earthworm species (*Esenia fetida*), so it is best to use for vermi-culture around Debre Zeit area.
- The vermicompost of VC, VW and VK have highest pH values, which has the capacity to neutralize most acid soils and provide nutrient for better yield.
- Segregation of organic waste material is very important to obtain quality vermicompost as a fertilizer
- Vermicompost prepared from mesquite by Adet EW spices is suitable and optional source of organic fertilizer for tef crop.

Future line of work

Since, the present study was done only in some selected feeds (weeds, crop residues and khat waste), it must be repeated using other crop residues, organic cities waste, weeds, and waste of industry. The present study addressed only one species and one feeds in one bin, but it is necessary to see the combination of different earthworm species and feedstock type at once, to come up with full recommendations. This experiment only considered tef crop, it is suggested to conduct further experiment on different field crop, vegetables, flowers, and others to see the responses for specific and/or combination of organic fertilizer with chemical fertilizer.

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APPENDICES

Appendix 1. Effects of different chemicals on earthworms

Nº	Class	Example	Level of toxicity
1	broad-spectrum fumigants	Methyl bromide	very high
2	Carbamate	carbofuran (Furadan)	Moderate
		aldicarb (Temik), aminocarb, bufencarb, carbaryl (Sevin), methiocarb (Measural), methomyl (Lannate), oxamyl (Vydate), promecarb, propoxur (Baygon), and thiofanox	highly toxic
3	organophosphate	phorate (Thimet), chloropyrifos (Dursban, Equity, Tenure, etc.), ethoprophos (Mocap), ethyl-parathion, and isazophos	Extremely or Highly toxic
	Triazine	atrazine, cyanazine, cyprozine, simazine, procyazine, propazine	moderate

(Mahanthaswamy and Patil, 2003)

Appendix 2. Characteristics of earthworms of different ecological categories

Characteristics	Epigeic	Endogeic	Anecic
Habitat	Litter dwellers	Naturally found in upper organic rich soil layers	Deep burrowing
Food	Litter and humus feeder	Litter and organic rich soil feeder	Litter and soil feeder
Burrow formation	Do not construct burrows and remains active in litter layers, top15cm	Construct horizontal burrows lined by mucus and excretory products , top 30cm	Construct vertical burrow ,more than 2m
Cocoon production rate	Highest	Moderate–high	Low
Life cycle	Short	Intermediate	Long
Efficiency in waste Recycling	Well established	Well established in some species	Efficiency data is not available
Species adopted in	*Eiseniafetida*	*Eudriluseugeniae*	*Pheretimaelongata*

waste management	*Bimastosparvus* *Dendrobaenarubida* *Eiseniahortensis*	*Octolasionlacteum* *Allolobophoracaliginosa*	*Perionyxexcavatus* *Lumbricusterristris* *Perionyxsanisbaricus* *Lumbricusrubellus*

Sources: Bouche 1977; Sherman, 2003;Usman*et al*.,2015

Appendix 3. Characteristic of earthworm species used in the experiment

Nº	Characters	*E.fetida*	AD-20-2004	We-20-2001
1	Total length	9.93cm	7.7cm	11.67cm
	Length of head to culitulem	2.667cm	1.51cm	2.5cm
	Length of culitulem	0.7cm	0.467cm	0.83cm
	Length of culitulem to end	4.767cm	4.95cm	6.67cm
2	Total Segment number	164	136	196
	Segment number of head to culitulem	26	25	28
	Segment number of culitulem	13	10	18
	Segment number of culitulem to end	125	101	150
3	Color of total body	Red	red	red
	Color of culitulem	Pink	Deep pink	Very light pink
4	Culitulem type	Invisible	Visible	Invisible
5	Body size comparatively	Moderate	Small	Larger
6.	Coelumic fluid	Less	Less	more
7	Escaping capacity	High	normal	Normal

Appendix 4.Nutrient contents of the experimental material (feeds and beddings before compositing)

Name	Nutrient analysis units				
	N	$P_2 0_5$	OC	pH	OC:N
tef (*Eragrostistef*) feed [1]	0.62	-	47.91	-	77.27
soil[1]	0.196	90.35	0.85	6.9	4.34
cow dung[1]	0.40		33.1		81.6
Wheat straw (*Triticum spp*)[2]	0.37		46.92	-	126.81
chickpea (*Cicerarietinum*) [2]	0.96		50.68	-	52.80
Khat (*CathaEdulis*) [2]	1.24		48.44	-	39.07
Mesquite(*Prosopisjuliflora*) [2]	1.77		123.3	-	70.11

1- beddingmateriel; 2- feeds of earthworm

Appendix 5.Total added water during 72 days of vermicomposting process.

No	Days adding of water	Amount of water add	Gap b/n days	
1	02/08/2006	2	4	
2	06/08/2006	2.5	5	
3	11/08/2006	2	6	
4	17/08/2006	2	8	
5	25/08/2006	2	3	
6	28/08/2006	2	2	
7	30/08/2006	2	2	
8	02/09/2006	2	6	
9	08/09/2006	2	3	
10	11/09/2006	2	6	
11	17/09/2006	2	7	
12	24/09/2006	2	3	
13	27/09/2006	3	7	
14	04/10/2006	1.5		
	Total added water	29		

Appendix 6. Total Nitrogen % content of vermicompost produced from different EW species and feed materials

EW species	**Feedstock**				**Means of EW species**
	F_0	F_1	F_2	F_3	
$\mathbf{E_0}$	0.441	0.490	0.476	0.435	0.4691
$\mathbf{E_1}$	0.434	0.455	0.476	0.448	0.4700
$\mathbf{E_2}$	0.455	0.455	0.448	0.427	0.4570
Means of feedstock	0.456	0.481	0.471	0.453	
Initial N content	0.37	0.96	1.24	0.77	
CV=12.36216	**LSD for feed ns**	**LSD for EW ns**	**LSD for interaction ns**		
SFNE	F_WE_2	F_CE_0	F_KE_1	F_mE_1	

<u>Key</u>: F: Feedstock; F_0: wheat straw, F_1: chickpea straw, F_2: khat waste, F_3: mesquite; E: earthworm species; E_0: *E. fetida*, E_1: Adet collection, E_2: Wereta collection; NS: not significant; SFNE: selected feed for next experiment.

Appendix 7. Anova of total biomass gain

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Feed	3	108939.5000	36313.1667	18.35	<.0001

Ew	2	39293.7222	19646.8611	9.93	0.0007
feed*ew	6	93099.1667	15516.5278	7.84	<.0001
Error	24	47495.3333	1978.9722		
Corrected Total	35	288827.7222			

R-Square	CoeffVar	Root MSE	TB Mean	LSD F	LSD EW
0.835558	16.16027	44.48564	275.2778	43.281	37.483

Appendix 8.Anova of individual weight

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Feed	3	0.00817569	0.00272523	5.01	0.0077
Ew	2	0.04042143	0.02021071	37.17	<.0001
feed*ew	6	0.03192392	0.00532065	9.79	<.0001
Error	24	0.01304960	0.00054373		
Corrected Total	35	0.09357064			

R-Square	CoeffVar	Root MSE	IW Mean	LSD
0.860537	14.74272	0.023318	0.158167	0.0227

Appendix 9.Anova of growth percentage

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Feed	3	4099109.839	1366369.946	14.79	<.0001
Ew	2	1376544.014	688272.007	7.45	0.0030
feed*ew	6	500781.315	83463.552	0.90	0.5086
Error	24	2216774.623	92365.609		
Corrected Total	35	8193209.791			

R-Square	CoeffVar	Root MSE	N2 Mean	LSD feed	LSD EW
0.729345	8.571280	303.9171	3546.959	295.69	256.08

Appendix 10.Anova of PH

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Feed	3	6.18972222	2.06324074	34.71	<.0001
Ew	2	0.55388889	0.27694444	4.66	0.0195
feed*ew	6	0.78611111	0.13101852	2.20	0.0779
Error	24	1.42666667	0.05944444		
Corrected Total	35	8.95638889			

R-Square	CoeffVar	Root MSE	pH Mean	LSD F	LSD EW
0.840710	2.966287	0.243812	8.219444	0.2372	0.2054

Appendix 11.Anova of Nitrogen

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Feed	3	0.00460100	0.00153367	0.46	0.7105
Ew	2	0.00127089	0.00063544	0.19	0.8266
feed*ew	6	0.00607800	0.00101300	0.31	0.9276
Error	24	0.07943867	0.00330994		
Corrected Total	35	0.09138856			

R-Square CoeffVar Root MSE pH Mean LSD F LSD EW
0.130759 12.36216 0.057532 0.465389 0.056 0.0485

Appendix 12.Anova of available phosphors

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Feed	3	1042.0229	347.34099	4.23	0.0156
Ew	2	2775.74908	1387.874544	16.88	<.0001
feed*ew	6	2279.04588	379.84098	4.62	0.003
Error	24	1972.769267	82.198719		
Corrected Total	35	8069.587231			

R-Square CoeffVar Root MSE p Mean
0.755530 7.255773 9.066351 124.9536

Appendix 13. Anova of C:N ratio

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Feed	3	2.10727753	0.70242584	3.21	0.0410
Ew	2	0.33218804	0.16609402	0.76	0.4792
feed*ew	6	0.96874392	0.16145732	0.74	0.6245
Error	24	5. 25391531	0.21891314		
Corrected Total	35	8.66212480			

R-Square CoeffVar Root MSE pH Mean LSD F LSD EW
0.393461 16.47351 0.467882 2.840205 0.4552 0.3942

Appendix 14. Anova of plant height

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Treatments	5	998.684444	199.736889	5.67	0.0065
Error	12	422.773333	35.231111		
Corrected Total	17	1421.457778			

R-Square CoeffVar Root MSE hight Mean LSD
0.702578 7.354105 5.935580 80.711111 0.559

Appendix 15.Anova of Number of tiller

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F

Treatments	5	12.7467	2.5493	12.08	0.0002
Error	12	2.533	0.2111		
Corrected Total	17	15.28111111			

R-Square	CoeffVar	Root MSE	tiller Mean	LSD
0.834206	11.68140	0.459468	3.933333	0.8174

Appendix 16.Anova of Number of effective tiller

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Treatments	5	15.216	3.04322222	29.29	<.0001
Error	12	1.2467	0.10388889		
Corrected Total	17	16.4627			

R-Square	CoeffVar	Root MSE	ET	MeanLSD
0.924274	12.69524	0.322318	2.538889	0.5734

Appendix 17.Anova of Number of panicle length

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Treatments	5	277.945590	55.589118	6.42	0.0040
Error	12	103.8562500	8.6546875		
Corrected Total	17	381.8018403			

R-Square	CoeffVar	Root MSE	PL	LSD
0.727984	7.586795	2.941885	38.77639	5.2336

Appendix 18. Anova of maximum root length of tef plant

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Treatments	5	70.0694444	14.0138889	0.65	0.6674
Error	12	258.8333333	21.5694444		
Corrected Total	17	328.9027778			

R-Square	CoeffVar	Root MSE	hight Mean	LSD
0.213040	16.80347	4.644292	27.63889	8.2622

Appendix 19.Anova of maximum root weight of tef plant

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Treatments	5	499.2967611	99.8593522	16.96	<.0001
Error	12	70.6489333	5.887411		
Corrected Total	17	569.9456944			

R-Square	CoeffVar	Root MSE	rootweight Mean	LSD
0.876043	12.78435	2.426399	18.97944	4.3165

Appendix 20.Anova of total straw of pot before oven

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Treatments	5	4743.584444	948.716889	16.75	<.0001
Error	12	679.620000	56.635000		
Corrected Total	17	5423.204444			

R-Square	CoeffVar	Root MSE	StrawBMean	LSD
0.874683	13.00761	7.525623	57.85556	13.388

Appendix 21. Anova of total straw yield of pot after oven

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Treatments	5	917.487511	183.497502	13.09	0.0002
Error	12	168.187933	14.015661		
Corrected Total	17	1085.675444			

R-Square	CoeffVar	Root MSE	strawA Mean	LSD
0.845085	14.63864	3.743750	25.57444	6.6601

Appendix 22. Anova of total grain yield of plant

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Treatments	5	4.7170000	0.9434000	38.32	<.0001
Error	12	0.29540000	0.02461667		
Corrected Total	17	5.01240000			

R-Square	CoeffVar	Root MSE	MG Mean	LSD
0.941066	7.950861	0.156897	1.973333	0.2791

Appendix 23. Anova of grain yield of tiller plant

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Treatments	5	1.45742778	0.29148556	13.08	0.0002
Error	12	0.26740000	0.02228333		
Corrected Total	17	1.72482778			

R-Square	CoeffVar	Root MSE	tiller grain	LSD
0.844970	13.61870	0.149276	1.096111	0.2656

Appendix 24. Anova of biomass of total pot

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Treatments	5	1023.408244	204.681649	14.39	<.0001
Error	12	170.644067	14.22033		
Corrected Total	17	1194.052311			

R-Square	CoeffVar	Root MSE	total biomass Mean	LSD
0.857088	13.68890	3.770986	27.54778	6.7086

Appendix 25. Anova of HI(harvest index) of total pot

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Treatments	5	0.0031484	0.00062968	5.20	0.0091
Error	12	0.00145423	0.00012119		
Corrected Total	17	0.00460264			

R-Square	CoeffVar	Root MSE	HI Mean	LSD
0.684044	14.97234	0.011008	0.073525	0.0196