AgriFoSe2030
Report 23, 2019

An AgriFoSe2030 Final Report from Theme 2 - Multifunctional landscapes for increased food security

Vermi-composting for increased agricultural productivity, women empowerment and environmental sanitation in northern Ethiopia

Kassa Teka[1], Eunce Githae[2], Yemane Welday[1], Efrem Gidey[3]

[1]Mekelle University, Ethiopia; [2]Kenyatta University, Kenya; [3]Wukro St. Mary's Institute, Tigray, Ethiopia

AgriFoSe2030

Agriculture for Food Security 2030
- Translating science into policy and practice

SLU LUND UNIVERSITY SEI UNIVERSITY OF GOTHENBURG

Today more than 800 million people around the world suffer from chronic hunger and about 2 billion from under-nutrition.

This failure by humanity is challenged in UN Sustainable Development Goal (SDG) 2: "End hunger, achieve food security and improve nutrition and promote sustainable agriculture".

The AgriFoSe2030 program directly targets SDG 2 in low-income countries by translating state-of-the-art science into clear, relevant insights that can be used to inform better practices and policies for smallholders.

The AgriFoSe2030 program is implemented by a consortium of scientists from the Swedish University of Agricultural Sciences (SLU), Lund University, Gothenburg University and Stockholm Environment Institute and is hosted by the platform SLU Global.

The program is funded by the Swedish International Development Agency (Sida). News, events and more information are available at www.slu.se/agrifose

ISBN: 978-91-576-9706-6

ACKNOWLEDGMENTS

The project members would like to thank the AgriFoSe2030 theme 2, Multifunctional Landscape for Food Security Program for the financial support; Wukro St. Mary's Institute and Wukro Agricultural Poly Technique College for the technical support; Mekelle University (College of Dryland Agriculture and Natural Resources) for the logistic support; Tigray National State Bureau of Agriculture and Rural Development and all district offices as well as extension agents for facilitation of the pilot project activities; the Tigray National State Bureau of Science and Technology, and the Tigray Urban Greening and Beautification for being potential stakeholders for scaling – up the technology to urban areas of Tigray for organic solid waste management at household level.

Front picture: Vermi-compost treated orange and maize. Photo: Kassa Teka.

Summary

Ethiopian agriculture is characterized by high soil degradation, rain-fed and fragmented land holding, extremely low external inputs and high dependency on traditional farming techniques, which affects the productivity. Women headed households are the most vulnerable to these challenges due to factors such as persistent gender disparities in the labor market and the "double day burden" where they have to fulfil both domestic duties and make money outside the home. By supporting female-headed households through trainings on new organic farming technologies, these households can diversify their sources of livelihood and boost their resilience to climate change and variability.

Organic farming systems using vermi-compost (composting with the use of worms) are thought to be the answer for the future food safety and farm security since it improves soil fertility and protect soils from degradation while also promoting plant growth and provides environmental sanitation. Vermi-culture can also enhance the lives of the poor by generating self-employment opportunities. This pilot project aimed at 1) Scaling up the vermi-composting technology to contribute to increased agricultural productivity; 2) training women headed households on the technology to empower them economically and socially; and 3) determining vermi-compost application rates for different soil and crop types under different agro-ecologies in the Tigray regional state, Ethiopia.

The produced vermi-compost generated an income of around 107 to 286 US Dollars per household from increased crop productivity, and an additional income of 9 to 296 US Dollars per household from vermi-worms selling. Experimental studies on maize, bread wheat and apple also reported an increase in soil fertility as well as crop yield by vermi-compost addition compared to conventional compost and chemical fertilizer. The trained female household heads perceived the technology as beneficial due to improvements in soil fertility and crop productivity, reduced cost of purchasing chemical fertilizer, easy technology that can be managed by any family member and improved household sanitation through continuous waste removal as worm feed.

The technique has proven beneficial, but to scale-up the project to the entire region, the knowledge about the technology by stakeholders needs to be enhanced to secure technical and financial support for up-scaling. Priority also needs to shift from chemical fertilizers to organic ones by extension agents, and the farm level research and demonstration on the technology need to be boosted.

Contents

1. INTRODUCTION

1.1. Background

Agriculture is the backbone of the Ethiopian economy, accounting for 47.5% of the country's GDP (World Bank, 2007). However, the performance of agriculture in the nation varies with natural factors and the intensity of agricultural inputs (Bezabih et al., 2010). Agriculture in Ethiopia is characterized by low soil fertility, high soil degradation, rain-fed and fragmented land holding, extremely low external inputs such as fertilizer and agro-chemicals, and high dependency on traditional farming techniques (Bezabih et al., 2010).

Women-headed households, households headed by a woman instead of a man, are the most vulnerable to the consequence of the above challenges for three big reasons, which researchers call a "triple burden" (Flato et al., 2016): i) these households face persistent gender disparities in the labor market and other productive activities (e.g. limited access to formal credit markets and land), which in turn contribute to greater economic disadvantage; ii) women-headed households often have a higher total dependency ratio (women take care of a higher proportion of dependent children and the elderly); iii) women who are household heads with no other adult help have a "double day burden" where they have to fulfil both domestic duties and make money outside the home. That means female household heads face greater time and mobility constraints, and may have to work fewer hours or choose lower-paying jobs. Hence, studies such as Alhassan et al (2019) recommend that female-headed households should be given priority in agricultural projects through financial resource support and trainings on new organic farming technologies. This would enable them to diversify their sources of livelihood to boost their resilience to climate change and variability.

The Ethiopian government is, therefore, urgently looking for an economically viable and environmentally sustainable option to improve agriculture, moving from 'maintaining' to 'enhancing' farm production per hectare of available land. Organic farming systems with the aid of various nutrients of biological origin such as vermi-compost (composting with the use of worms) are thought to be the answer for the future food safety and farm security (Hailu, 2010). In the last few years, the use of earthworms as a composting technique known as vermi-compost has been strategically introduced to farmers in a few areas of the country. Vermicomposting is a natural process of quick recycling of organic material into nutrient rich compost using earthworms (usually red wigglers – *Esenia fetida)* under aerobic conditions (Aira et al., 2002; Bisen et al., 2017).

Vermi-composts contain plenty of beneficial soil microbes which help in soil regeneration and fertility improvement (De Brito et al., 1995). They also promote plant growth and improve environmental sanitation (Scheuerell and Mahaffee, 2002) as kitchen and other household wastes can be transformed to organic fertilizer through vermi-composting. Studies in India also indicated that Vermi-culture enhanced the lives of poor by generating self-employment opportunities (Hati, 2001). In any vermi-culture practice, earthworms biomass comes as a valuable source of nutritive 'worm meal' for fishery, dairy and poultry industry (Visvanathan *et al*., 2005). This technology can also be used by any member of a household (especially women) at any time and place.

Organizing and training women headed households to culture vermi-worms and vermi-composts could help improve their livelihood through increased farm productivity and production, as well as self-employment opportunities. Hence, the AgriFoSe2030-funded 2-year pilot project entitled 'Vermi-Composting for Increased Agricultural Productivity, Women Empowerment and Environmental Sanitation in Northern Ethiopia' was initiated in January 2018 to accomplish the objectives listed below.

1.2. Aims of the project

The specific objectives of the pilot project were:

- To scale-up the vermi-composting technology to the entire region to contribute to increased agricultural productivity and diversity;
- To train women-headed households to empower them economically and socially;
- To determine vermi-compost application rates for different soil types and crops under different agro-ecologies, compared to chemical fertilizer.

The project objectives are line with the Ethiopian Agricultural Growth Plan -AGP II, which focuses on the promotion of crop productivity enhancing technologies and Soil Fertility Management Services (MoA, 2015). The project supports the sustainable development goals (SDGs): end extreme poverty in all forms by 2030 (SDG1); end hunger, achieve food security and improved nutrition and promote sustainable agriculture (SDG2); ensure healthy lives and promote well-being for all at all ages (SDG3); achieve gender equality and empower all women and girls (SDG5); ensure availability and sustainable management of water and sanitation for all (SDG6); promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all (SDG8); make cities and human settlements inclusive, safe, resilient and sustainable (SDG11); Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss (SDG15).

2. DESCRIPTION OF THE PROJECT AREA

The pilot project was implemented in the Tigray regional state (Northern Ethiopia). The following seven (7) villages representing three agro-ecologies were selected (Table 1).

Table 1. Description of the project sites

Agro-ecology	District	Village	Coordinate	Center location (meter above sea level)
Highland (2300 m – 3200 m elevation)	Atsbi-Wemberta District	Ruba-feleg	13°56’41.04”N 39°43’48.62”E,	2744
Midland (1500 m – 2300 m elevation)	Kilte-Awulaelo	Tahtay Adikisandid	13°49’10.84”N 39°36’41.50”E,	2036
	Kilte-Awulaelo	Mesanu	13°42’08.07”N 39°38’41.54”E,	2073
	Kilte-Awulaelo	Aynalem	13°45’14.87”N 39°33’02.30”E,	2008
	Kilte-Awulaelo	Gemad	13°53’00.81”N 39°34’44.61”E,	2330
	Kilte-Awulaelo	Tsaedanaele	13°54’26.86”N 39°34’56.68”E,	2359
Lowland (500 m – 1500 m elevation)	Kola-Tembien	Adiha	13°44’41.32”N 39°05’33.41”E,	1491

3. PROJECT ACTIVITIES

The planned activities of the pilot project were grouped into the following major activities: i) initial vermi-worms culturing; ii) training of women-headed households; iii) worm culturing by women headed households; iv) experimental site set-up for vermi-compost application rate and determination of their economic significance; v) organization of meetings and site visits with stakeholders; vi) scaling up of the technology outside the project sites.

4. PROJECT RESULTS

Implementation of the project activities started in January 1, 2018, following the project time plan. The major activities implemented between January 2018 and September 2019 and their outcomes are discussed below.

4.1. Initial Vermi-Worms Culturing

The first stage of the pilot project was culturing red worms (*Eisenia fetida*). Culturing centers were established at three institutes (Mekelle University, Wukro St.Mary's College and Wukro Agricultural Poly Technique College) and three Farmers' Training Centers (Rurba-Feleg, Tahtay Adikisandid and Adiha) (Figure 1). The culturing resulted in more than 250,000 worms, which is enough for more than 150 beneficiaries at the rate of 1500 worms per farmer household.

Figure 1. Established Vermi-culturing shade at Mekelle University

4.2. Training of women headed households

The second stage was training of 96 women farmer household heads together with 39 development agents/experts for five days (Table 2). These trainees were selected by each district and kebele (lower administration) officials. The criteria for selection of women headed households were: i) they should be household heads (no husband); ii) economically poor and, iii) with access to worm feed/composting material and irrigated farm plots.

Table 2. *Number of trained women headed farmers and extension workers*

Place (site)	Farmers	Extension workers
Ruba-feleg	25	6
Tahtatay-Adikisandid	34	2
Mesanu	5	2

Ayanlem	5	1
Gemad	5	2
Tsaedanaele	5	2
Adiha	17	4
Institutions (staff members of Mekelle University, Wukro St.Mary's & Wukro TVET)		20
Total	**96**	**39**

Trainees were equipped with both theoretical (20%) and practical (80%) skills on conventional compost making, vermi-worm culturing, vermi-worm management and use, vermicomposting and tea composting, and their application methods to soils. To assist the training and the post-training follow-up, a vermi-composting manual was developed in the local language (Tigrigna) and distributed among development agents, experts and officers (Figure 2).

Figure 2. Vermi-culturing- and composting training manual (left) and participants' training (right)

Each theoretical training included discussion on: i) the different types of composts and their sources (based on research results); ii) the different types of worms which help improve soil fertility (based on research results and experience); iii) the benefits (economic, physical, environmental and social) and drawbacks of the different worms (based on research results); iv) suitable environment for vermi worms, and challenges which they can face (based on research results and experience from other areas); v) worm bin and shade construction types, methods, material type and source (based on local experiences and research results); vi) suitable crops for which the vermi-compost product can be used.

Each practical training included three sections: i) field visit to organic farms which use conventional compost and vermi-compost as inputs; ii) conventional and vermi-compost (solid and tea compost) preparation and use; iii) group work on composting material identification, worm shade construction, worm bin preparation, worm handling and management, compost preparation and management/use, and technical and financial planning for compost and vermi-compost set-up at each beneficiary's house. Figure 3 shows the vermi-culturing, vermi-composting and practical application of vermi-composts.

Figure 3. Trainees during vermi-culturing, vermi-composting and product application.

Each training session was supported by group work and discussion (Figure 4). The group work aimed at helping trainees to be able to identify suitable composting materials at their locality, worm shade construction methods, worm bin preparation methods, worm handling and management techniques, compost preparation and management/use, and preparing technical and financial plan to implement the technology at each beneficiary's house.

Figure 4. Trainees during group work

4.3. Vermi-worm culturing/composting and production

4.3.1. *Vermi-worm culturing*

Each trained household constructed worm shades and bins from locally available materials with continuous follow-up /supervision of the trainers and development agents of each village (Figure 5). Most of the beneficiaries constructed a 2 m by 2 m (4 m^2) area and 2 m height worm shade from fertilizer bags and wood using family labor to protect the worms and the bin from direct contact with rain, wind, sun and animals. Others used parts of previously constructed shades in their house compound. Furthermore, all beneficiaries prepared a 2 m by 1 m (2 m^2) area and 60 cm height worm bin to culture the worms and produce vermi-compost. Each trainee was equipped with 2 kilos of worms and cast (equivalent to 1500 red worms). The worms were fed with locally available materials such as kitchen wastes, farm residues (e.g. non-marketable vegetables), fresh animal manure and farm weeds to culture the worms and transform these wastes into fertilizer.

Figure 5. Worm shades (left) and feeding (right) at Ruba-Feleg village in part

4.3.2. *Vermi-compost production and income grained*

4.3.2.1. *Income from worm and compost sell*

Farmers produced 300 to 800 kg of vermi-compost equivalent to 3000 to 8000 birr (around 107 to 286 US Dollars). 17 women headed households each sold 1 to 33 kg of vermi-worms, equivalent to 250 to 8300 birr or around 9 to 296 US Dollars (Table 3). Three women in Ruba-Feleg also sold an additional 500 kg of both vermi-and conventional compost equivalent to 4,000 birr or around 143 US Dollars to graduate students for research purposes.

__Table 3.__ Income gained from worm selling (1 USD ≈ 28 birr) by individuals

Village name	No. of women who sold worms	Income gained	
		Birr	USD
Tahtay Adikisandid	5	500 – 3500	18 - 125
Aynalem	1	500	18
Ruba-Feleg	4	500 – 5000	18 - 179
Adiha	7	250 – 8300	9 - 296
Total	**17**	**31,300**	**1,118**

4.3.2.2. *Income from Gesho (Rhamus prenoids) Production*

Farmers (e.g. Mrs. Medhin Assefa, from Tahtay Adikisandid village) stated that vermi-compost treated *Rhamus prenoids*/Gesho leaves (marketable part for local beer making called Sewa) were deep green with high vegetative growth compared to untreated plots (Figure 6). Accordingly, Mrs. Medhin Assefa is harvesting 3 kgs of Gesho a week (price = 70 – 300 birr per kg or 2.5 – 11 USD/kg) from vermi-compost treated plots while it was less than 0.5 kg a week from untreated plots. Hence, she is getting an income of 210 to 900 birr (7.5 to 32 USD) a week (depending on the season) from vermi-compost treated plots as compared to only 35 – 150 birr (1.25 to 5 USD) a week from untreated plots.

Figure 6. Rhamus prenoids/Gesho treated with Vermicompost (left) and control (right) at Adikisandid village

4.3.2.3. *Effect on Bread Wheat (Triticum aestivum), Maize (Zea mays) yield and disease tolerance*

Farmer's wheat demonstration using vermicompost and farm yard manure (from 4 m^2 plot area each) showed that vermicompost doubled the production (from 2.5 to 5.0 t ha^{-1}) through an increased number of seeds per head and reduced weed growth. The produced vermi-compost (Figure 7) in the lowland agro-ecology has also resulted in good Maize grain yield and vegetative growth. The women farmers perceive that vermi-compost reduced infestation by hazardous weeds (e.g. striga), insects (e.g. stock borer) as well as plant diseases such as rust. Maize grown on vermi-compost treated plots were deep-green while those on the chemical fertilizer treated farms were yellowish. Vermicompost treated Maize also tolerated the incidence of rust disease as well as stock borer better than maize grown on chemical fertilizer treated farms.

Figure 7. Color of Maize grown on vermi-compost treated plots (left) and chemical fertilizer treated plots (right)

The cob size and number were also compared. The vermicompost treated plots had both the highest cob size as well as cob number with two or three cobs per plant while only one cob per plant on the chemical fertilizer treated plots. The cob size on the vermicompost treated plots was roughly 1/3 larger than the chemical fertilizer treated plots, as can be seen in figure 8.

Figure 8. Cob size of Maize grown on Vermi-compost treated plots (left) and Chemical fertilizer treated plots (right)

Vermi-compost treated maize farms had the highest cob weight and biomass as compared to the chemical fertilizer (DAP) treated ones. Three plants from each of the three size category (large, medium and small) were taken for plant biomass and cob weight and number measurement (Table 4). Vermi-compost increased maize yield by 305% and maize biomass by 101.2%.

Table 4. *Effect on Maize biomass and grain yield (e.g. from woman Farmer Amitey' farm)*

Treatment	Cob weight (g/plant)	Cob number /plant	Biomass (g/plant)
Vermi compost treated farm			
- Large sized	342	2	990.8
- Medium sized	393	2	694.4
- Small sized	277	1	323.9
Average	**337.3**		**670**
Chemical fertilizer (DAP) treated farm			
- Large sized	103	1	471.3
- Medium sized	80	1	282.3
- Small sized	67	1	245.2
Average	**83.3**		**333**

4.3.2.4. *Effect on Orange quality*

The presence of deep green leaves and good quality orange fruits were observed on compost treated plots (Figure 9). Vermi-compost treated Orange trees had new shoot growth while a yellowish color and stunted growth was observed on non-treated plots. As stated by the beneficiary farmers, disease affected oranges are able to revive after vermi-compost addition as compared to the untreated ones.

Figure 9. Vermicompost treated (left) and untreated (right) Orange tree at Adiha village

4.3.2.5. *Effect on Teff (Eragrostis tef) yield*

Three treatments (Vermicompost at 5 t ha^{-1}, chemical fertilizer/NPS (Nitrogen, Phosphorus and Sulfur) at 200 kg ha^{-1} and no fertilizer) with three replicates were tested at farm level (Luvisols, 4 m^2 each plot area). Teff, the commonly grown crop in the area, was grown as test crop (Figure 10). The crop growth was observed under vermicompost treatment followed by NPS fertilizer. The average teff productivity from Vermi-compost applied plots was 2.0 t ha^{-1}, while the productivity from the chemical fertilizer treated plots and the control were 1.75 t ha^{-1} and 1.25 t ha^{-1} respectively.

Figure 10. Experimental results comparison among Vermi-compost, NPS and no fertilizer

4.3.3. *Training on Soap making from Aloe Vera species (Barbados aleo)*

A team of experts, extension/development agents, and farmer representatives evaluated the performance of the project beneficiaries (based on vermi-culturing, vermi-compost production, technology demonstration and income gained from the technology) and ranked them as very good, good, poor and failed. 14 women with very good performance (4 from Adiha, 4 from Tahtay Adikisandid, 4 from Ruba-Feleg and 2 from Ayanlem villages) were rewarded with a one day training on soap making from Aloe Vera (locally available plant species) at Wukro St.Mary's College (Figure 11). The objectives of the training were to: i) encourage the continuity of household's involvement in vermicomposting; ii) improve the sanitation of household beneficiaries; iii) further diversify income sources for the household beneficiaries. The total cost per piece taking the cost of oil (2 birr/piece), caustic soda (1.25 birr/piece) and labor (3.0 birr/piece) into account is 6.25 birr (0.22 USD).

Figure 11. Aloe Vera plant grown in the area (left) and Soap made out of it (right)

The beneficiaries felt encouraged to continue the organic farming activity and advise neighbors to follow their footprint, which resulted in 8 new adopters of the vermicomposting technology. The trained farmers were able to use the home made soaps during their daily activities which was previously difficult due to no financial capacity to buy soaps from the market. Some of the beneficiaries (e.g. Mrs. Kahsu Gebretsadikan from Tahtay Adikisandid and Mrs. Samrawit Moges from Ruba-Feleg) sold soaps at the local market and got a total of 2400 birr (equivalent to 86 USD). The income gained from selling of homemade soap at local markets (at the rate of 30 birr/piece) helped the women headed households to further diversify their income-sources and support their family needs.

4.4. Experimental site setup for vermi-compost application rate and their economic significance determination

Four experimental plots with seven treatments and five replications were implemented in three agro-ecologies (lowland, midland and highland) on major crops (wheat, maize, apple and salad). Both soil and agronomic parameters were evaluated. The economic significance of each treatment was also analyzed taking the cost of agricultural inputs (chemical fertilizer and vermicompost), and labor into account. The major research topics were: i) effect of vermicompost on soil physico-chemical properties, nutrient uptake and maize (*Zea mays* L.) yield and yield components in Kolla Tembien District, Tigray Ethiopia (M.Sc thesis by Solomon Mebrahtom); ii) effect of vermicompost on elected soil physico-chemical properties, and bread wheat (*Tirticum aestivam*.) productivity in the mid and highlands of Tigray, Ethiopia (M.Sc thesis by Berhe Abraha); iii) Residual effect of vermi-compost on selected soil properties and salad yield (by team of experts); iv) effect of vermicompost at different rates on soil properties and apple fruit growth on Cambisols in Tigray, Northern Ethiopia (B.Sc graduate seminar by Tarik Gebrekiros); v) effect of different feed types on the growth and reproductive performance of *Eissenia fetida.*

4.4.1. *Effect on maize yield and soil physico-chemical properties*

The study was initiated to determine the optimal rate of vermicompost required for maize production, and to examine the effect of different vermi-compost rates on selected soil physic-chemical properties such as texture, pH, extractable electric conductivity (ECe), cation exchange capacity (CEC), total nitrogen (TN), available P and exchangeable bases (K, Mg, Ca, and Na) and nutrient uptake of Nitrogen (N) and Phosphorus (P). Hence, a field experiment was carried out in 2018 during the main cropping season at farmer's field in Adiha village (Kolla Tembien district). The experiment (Figure 12) had seven treatments arranged in a randomized complete block design with five replications. The treatments were five rates of vermicompost (VC) (0, 2.5, 5, 7.5 and 10 t ha_{-1}), the recommended rate of N and P (46 N and 46 P_2O_5 kg ha_{-1}), compost at rate of 10 t ha_{-1} and control. Similarly, plant tissue samples were taken to analyze N and P crop uptake. Marginal rate of return was also estimated for each treatment.

Figure 12. Maize experiment at Adiha village (Lowland)

Our study results showed that vermicompost (VC) application significantly improved the soil physico-chemical properties. Bulk density significantly decreased while moisture content increased as the rate of VC increased. Application of VC at 10 t ha^{-1} decreased bulk density by 23.5%; while soil moisture content increased by 77% compared to the control. The studied soil chemical properties such as organic carbon (OC %), TN (%), CEC (Cmol (+) kg^{-1}), and available P (mg kg^{-1}) had the highest value upon application of VC at 10 t ha^{-1} (Table 5).

Table 5. *Effect of vermicompost on selected soil chemical properties*

Treatment	CEC (cmol(+) kg-1)	pH	ECe (mmhos/cm)	OC (%)	TN (%)	Exchangeable base (cmol(+) kg-1) Ca	Mg	Na	K	AvaP (mg kg-1)
Control	**7.60d**	7.40	1.71	**0.66c**	**0.04ed**	**2.60e**	**1.00d**	**0.14f**	**0.10e**	**2.43e**
46 N kg ha-1 + 46 P_2O_5 kg ha-1	7.90d	7.35	1.72	0.63c	0.04e	3.16d	1.10d	0.21e	0.21d	2.46e
10 t ha-1 C	11.52c	7.32	1.69	1.22ab	0.07bc	4.40c	1.80c	0.33d	0.31c	3.28d
2.5 t ha-1 VC	10.50c	7.38	1.69	0.99b	0.06cd	4.08c	1.28d	0.22e	0.24d	3.08d
5 t ha-1 VC	13.50b	7.44	1.67	1.01b	0.08bc	5.80b	2.78b	0.41c	0.41b	3.92c
7.5 t ha-1 VC	16.60a	7.57	1.67	1.27a	0.09b	7.58a	3.24a	0.45b	0.42ab	5.61b
10 t ha-1 VC	**17.20a**	7.63	1.66	**1.33a**	**0.13a**	**8.10a**	**3.46a**	**0.47a**	**0.46a**	**6.38a**
Mean	12.12	7.44	1.69	1.01	0.07	5.11	2.10	0.32	0.31	3.88
P-value	0.001	0.59	0.99	0.001	0.001	0.002	0.001	0.001	0.001	0.001
CV	8.09	3.99	11.57	12.01	14.71	5.33	8.47	2.33	6.89	6.17

Means followed by the same letters are not significantly different (P≤0.05) according to Turkey Test; Av. P = Available phosphorus, CEC = Cation exchange capacity, Ca= calcium, Mg= magnesium, K= potassium, Na= sodium, P_2O_5 *= Di phosphate penta oxide t= tone; ha= hectare; CV= Coefficient of variation;*

Application of different rates of vermicompost also significantly affected most of the crop parameters tested such as crop phenology, growth, yield and yield components (Table 6). The lowest maize grain yield (1600 kg ha^{-1}) was recorded from control plots with no vermicompost treatment; while the highest (4277.8 kg ha^{-1}) was from plots which received 10 t ha^{-1} VC.

Table 6. *Mean of biomass yield (BY), grain yield (GY) and stover yield (SY) of maize as affected by different rate of VC, compost and recommended NP*

Treatment	BY (kg ha^{-1})	GY (kg ha^{-1})	SY (kg ha^{-1})
Control	**13000.0$_e$**	**1600.00$_f$**	**11400.0$_e$**
46 N kg ha^{-1} + 46 P_2O_5 kg ha^{-1}	15800.0$_{cd}$	2993.33$_d$	12806.7$_{cde}$
10 ton ha^{-1} Compost	18100.0$_{bc}$	3651.11$_{bc}$	14448.9$_{bc}$
2.5 t ha^{-1} Vermicompost	14000.0$_{de}$	2406.67$_e$	11593.3$_{de}$
5 t ha^{-1} Vermicompost	17800.0$_{bc}$	3593.33$_c$	14206.7$_{bcd}$
7.5 t ha^{-1} Vermicompost	19300.0$_{ab}$	3804.44$_b$	15495.6$_{ab}$
10 t ha^{-1} Vermicompost	**21600.0$_a$**	**4277.78$_a$**	**17322.2$_a$**
Mean	17085.7	3189.52	13896.2
P-value	0.01	0.01	0.01
CV	7.8	2.85	9.60

Means followed by the same letters are not significantly different (P≤0.05) CV= Coefficient of variation.

However, the highest net benefit (34404.4 birr or 1229 USD) was obtained from plots treated with 5 t ha^{-1} VC over the control (18504 birr 661 USD), recommended NP (28443.4 birr or 1016 USD) and 10 t ha^{-1} conventional compost (33661.6 birr or 1202 USD). Hence, 5 t ha^{-1} is recommended as an optimal rate for maize production.

4.4.2. *Effect of bread wheat yield and soil physico-chemical properties*

The field experiment was conducted to assess the effects of different vermicompost application rates on selected soil physico-chemical properties and yield of bread wheat in two districts, Kilteawlaelo and Atsbiwemberta (Figure 13). Seven treatments comprising of four vermicompost rates (2.5 , 5.0, 7.5 and 10 t ha^{-1} of Vermicompost - VC), 100% recommended rate of inorganic NP (46 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}), 10 t ha^{-1} conventional compost and control replicated five times were arranged in randomized complete block design on sandy loam textural soils in both districts. A bread wheat variety namely 'Picaflor' was sown at a rate of 125 kg ha^{-1} as an experimental crop.

Figure 13. Wheat experiment at Adikisandid village (Midland)

Our results indicated that application of 7.5 and 10 t ha^{-1} vermicompost significantly improved most of the soil physicochemical properties. Soil physical properties such as soil moisture content increased by 140% upon application of 10 t vermicompost ha^{-1} compared to the control and 100% NP. Similarly, soil organic carbon, available Phosphorus, soil ex. Cations (Ca and K) and total nitrogen showed a significant increase (Table 7).

Table 7. Changes in soil physico-chemical properties under vermi-compost addition

Treatment	Adi-kisandid (midlands)						Ruba-Feleg (highlands)					
	Bulk density (g cm^{-3})	WHC (%)	K (cmol (+) kg^{-1})	Av.P mg kg^{-1}	TN (%)	OC (%)	Bulk density (g cm^{-3})	WHC (%)	K (cmol (+) kg^{-1})	Av.P mg kg^{-1}	TN (%)	OC (%)
Control	1.47_{a}	8.94_{e}	0.91_{f}	5.15_{e}	0.14_{e}	0.57_{e}	1.42_{a}	14.6_{d}	0.70	5.15_{e}	0.07_{e}	1.04_{b}
2.5 t VC	1.46_{a}	12.86_{d}	1.21_{e}	5.24_{de}	0.15_{de}	0.78_{de}	1.39_{ab}	15.9_{d}	0.98	5.24_{de}	0.08_{de}	1.27_{b}
5 t VC	1.41_{b}	16.3_{c}	1.26_{de}	5.83_{c}	0.16_{cd}	1.21_{cd}	1.36_{bc}	18.6_{c}	1.05	5.83_{c}	0.09_{cd}	1.26_{b}
7.5 t VC	1.39_{b}	19.72_{b}	1.59_{b}	7.01_{b}	0.17_{ab}	1.94_{b}	1.34_{cd}	21.6_{ab}	1.37	7.01_{b}	0.11_{ab}	2.13_{a}
10 t VC	1.33_{c}	21.46_{a}	1.77_{a}	7.35_{a}	0.18_{a}	2.70_{a}	1.31_{d}	22.5_{a}	1.51	7.35_{a}	0.11_{a}	2.77_{a}
NP(100 kg ha^{-1})	1.45_{a}	12.4_{d}	1.37_{cd}	5.51_{d}	0.17_{bc}	1.30_{cd}	1.40_{ab}	13.4_{d}	1.15	5.51_{d}	0.10_{bc}	1.04_{b}
10 t CC	1.4_{b}	17.68_{c}	1.49_{bc}	5.44_{d}	0.17_{ab}	1.62_{bc}	1.35_{cd}	19.2_{bc}	1.18	5.44_{d}	0.11_{ab}	1.26_{b}
LSD (5%)	0.02	1.42	0.14	0.27	0.01	0.54	0.04	2.59	0.13	0.27	0.01	0.7
CV (%)	1.2	7.0	22.3	3.5	4.5	28.7	2.5	11.1	2.5	3.5	7.7	35

Note: Means followed by the same letter within a column are not significantly different from Each other at P = 0.05, LSD = List significance difference

Application of 10 t ha^{-1} vermicompost also significantly increased wheat grain yield by 100% compared to the control (Table 8). Grain yield increased by 51% and 48% under application of the highest rate of vermicompost (10 t ha^{-1}) over plots treated with the recommended NP (100 kg ha^{-1}) and conventional compost (10 t ha^{-1}) respectively in the midlands (Adi-kisandid). Similarly, wheat grain yield in the highlands (Ruba-felg) increased by 48% and 51% over plots treated with the recommended NP and conventional compost respectively. A similar increase in biomass yield was recorded at both sites under application of 10 t ha^{-1} vermicompost.

Table 8. *Mean of biomass yield (BY) and grain yield (GY) of wheat bread as affected by different rate of VC, compost and recommended NP*

Treatment	Adi-kisandid		Ruba-Feleg	
	Biomass	Grain yield	Biomass	Grain yield
Control	6260_{e}	2082_{e}	5044_{e}	1925_{d}
2.5 t VC	7300_{d}	2541_{d}	6756_{d}	2260_{d}
5 t VC	7980_{cd}	3539_{c}	7157_{cd}	3089_{c}
7.5 t VC	10020_{b}	4234_{b}	9096_{b}	3766_{b}
10 t VC	11220_{a}	4912_{a}	10205_{a}	4440_{a}
NP (100Kg/ha)	8280_{c}	3249_{c}	7633_{cd}	2998_{c}
CC	7840_{cd}	3320_{c}	7853_{c}	2938_{c}
LSD (5%)	709.2	328.9	888.0	523.6
CV (%)	6.5	7.4	8.9	13.1

Note: Means followed by the same letter within a column are not significantly different from Each other at P = 0.05

Furthermore, application of 10 t ha^{-1} vermicompost was found economically beneficial compared to the other treatments. The net benefit obtained from application of 10 t ha^{-1} vermicompost (62841.5 - 72105.2 birr or 2244 – 2575 USD) was higher than the control (24946.5 - 31102.2 birr or 891 – 1111 USD), compost (41735.3 – 46312 birr or 1491 – 1654 USD) and NP (44841.3 - 50142.9 birr or 1601 – 1791 USD) treated plots. Hence, the recommended rate for wheat bread is 10 t per ha.

4.4.3. *Residual effect of vermi-compost on salad yield and selected soil properties*

The residual effect of the different treatments was also evaluated under irrigation (2019 irrigation season) using lettuce as a test crop. The lettuce largest in size was taken from each treatment (of one block out of five) to compare the effect of the treatments (Figure 14). Moreover, 35 composite soil samples were collected from the top 20 cm soil for analysis of physical and chemical soil-properties.

Figure 14. Treatments ranking

The highest salad performance was obtained from the 10 t ha^{-1} Vermicompost treatment (plot 10), while the lowest was obtained from chemical fertilizer treatment (plot 14). Hence, the detailed recommended vermicompost rate for salad is 10 t ha^{-1}. The detailed agronomic assessment results for each treatment is shown in Table 9.

Table 9. Agronomy and yield of Lettuce as affected by Residual Vermi-compost treatments

Parameters	Plot 8 (7.5 t ha-1)	Plot 9 (5.0 t ha-1)	Plot 10 (10 t ha-1)	Plot 11 (10 t ha-1 conv. compost)	Plot 12 (Control)	Plot 13 (2.5 t ha-1)	Plot 14 (Chemical)
Plant height (cm)	38	33	39	33	31	37	16.2
Head diameter (cm)	25	26	30	26	20.8	19.5	16
Root length (cm)	16	10	13	12	10	15	10
Stem diameter (cm)	4.1	9.9	4.5	4.5	3.4	4	2.8
Total biomass (kg)	0.24	0.4	0.46	0.20	0.14	0.16	0.09
Above ground biomass (kg)	0.2	0.3	0.40	0.17	0.12	0.13	0.07
Non-marketable (kg)	0.03	0.04	0.02	0.01	0.03	0.02	0.02

4.4.4. *Effect on apple fruit growth and soil properties*

Another experiment on the optimal vermi-compost application rate for fruit-tree growth and productivity was evaluated using apple fruit (Galaxy) as a test crop (Figure 15). The following 10 treatments were considered: zero compost (control), 0.5 kg VC, 1.0 kg VC, 1.5 kg VC, 2.0 kg VC, 2.5 kg VC, 3.0 kg VC, 3.5 kg VC, 4.0 kg VC and 4.5 kg VC replicated three times (total = 30 apple trees). The parameters measured from both vermi-compost, soil and tree were: i) initial vermi-compost properties (pH, EC, OC, N, P, K, and Moisture content); ii) soil properties (pH, EC, OC, N, P, K, Bd and moisture content), and moisture monitoring; iii) apple tree parameters (tree height, tree diameter, and number of branches).

Figure 15. Experimental Apple trees (left) and vermi-compost application (right)

The experimental results showed that both soil properties and apple growth increased with increasing vermi-compost application rate. The highest mean moisture content (34.54%) was recorded at the highest vermicompost rate (4.5 kg/plant). The increase in VC application rate also led to increased apple growth. Vermicompost at the rate of 4.5 kg/plant increased apple mean length (by 9.25 cm), diameter (by 4.0 cm), and bench diameter (by 2.2 cm).

4.4.5. *Effect of different feed types on the growth and reproductive performance of vermi-worm Eissenia fetida*

For successful culturing of the vermi-worm, *Eissenia fetida* (red worm), identification and ranking of suitable feed type is very important. Hence, six feed types (cabbage, banana leaf, salad, food waste and tomato) including the control (cattle manure) which are commonly found in urban and rural areas were selected and studied. Each treatment was replicated three times. In each worm bin, 100 red worms were introduced. After three months of culturing, three compost samples (from 40 cm by 40 cm area) were taken from each bin (Figure 16) for collecting data on: worm number, worm diameter, worm length, worm weight, cocoon number and chemical properties (pH and EC) of the soil.

Figure 16. Feed experimental treatment bins (left) and vermi-compost sampling (right)

The experimental results indicated that the highest worm length (9.08 cm), worm number (532) and cocoon number (218) was found on the cabbage feed type compared to the control which was 6.98 cm, 61 and 53 respectively. This implies that feeding cabbage not only facilitates worm growth and reproduction, but also increases conversion efficiency of waste to useful products (compost). The pH of the produced vermi-compost also increased with 1-1.5 units compared to the control on all feed types except the tomato feed type (< 1 unit increase). The highest pH was recorded on the food waste (7.43), while the lowest was on the control (6.03).

4.5. Women headed households' perception of vermi-composting technology

Information on the perception of women headed households on the benefits and challenges of the vermi-composting technology to their livelihood was also collected. For this purpose, 35 women project beneficiaries representing the project sites were randomly selected and interviewed following a semi-structured questionnaire. The output of the interview was documented on videos (4.6 Giga bite) in local language and distributed to beneficiaries and the funding organization.

The interview results indicated that all participants accepted the technology. The major benefits stated are summarized as follows: i) the produced vermi-compost improves crop productivity through improved soil fertility; ii) it contains more crop nutrients compared to other fertilizer types including chemical fertilizer; iii) it is easy to handle or manage by any family member; iv) it is a cheap technology as the culturing and composting is done with available resources (family labor and local materials); v) it helps reduce the cost for purchasing chemical fertilizer as most of the beneficiaries either totally or partial replaced chemical fertilizers by vermi-compost; vi) continuous compost production as the worms multiply quickly; vii) unlike chemical fertilizer, the produced vermi-compost can be used to any crop and soil type in both liquid and solid forms; viii) no associated human and crop health impact as there is continuous aerobic waste decomposition by the worms; ix) it protects the plant/crops from diseases (e.g. rust), insects (e.g. stock borer) and weeds (e.g. striga/witchweed); x) it improves household sanitation through continuous waste removal as worm feed.

Regardless of the benefits, the following challenges were also reported: i) the worms need continuous follow-up as they are susceptible to different enemies such as termites and rodents; ii) market linkage need to be improved to get more benefit out of worm selling.

4.6. Scale-up of the technology outside the project sites

Two mini-workshops were held during the project period. The first mini-workshop was held from October 5 to 7, 2018 with the aim of: i) evaluating the implemented activities and achievements of the AgriFoSe2030 pilot project in the last nine months; ii) to introduce the AgriFoSe2030 pilot project with different stakeholders (public, GOs and NGOs); iii) to share the achievements of the project activities with new beneficiaries and stakeholders to facilitate technology scale-up. A total of 143 stakeholders' representatives (existing and new beneficiaries, experts, and researchers, Wukro St.Mary's College, Wukro Agricultural Poly Technique College, Maichew Agricultural Poly Technique College and Raya University) participated in the first workshop (Figure 17).

Figure 17. Visit to vermicompost treated cabbage and experimental wheat at Adi-kisandid village

The second mini-workshop was held on the 25th of August (2019) at Adiha village (Figure 18), one of the seven AgriFoSe2030 pilot project sites, with the theme 'Mekelle University - AgriFoSe2030 Supported Project for Women Headed Household's Vermi-composting and Vermi-culturing Outputs Experience-sharing Visit at Adiha Village (Kolla Temben District)'. The objectives of the visit were: i) to evaluate the project activities and outputs in the last 21 months; ii) to share farmers' experiences among stakeholders on the benefits of vermi-culturing and vermi-compost for improved food security.**32** delegates from all AgriFoSe2030 pilot project sites and different organizations participated in the experience sharing visit.

Figure 18. Stakeholders' experience sharing visit at Adiha village

The vermi-compost project activities and outputs were also presented in: i) **Research, Technology and Innovation** regional conference organized by the Tigray National State Science and Technology Bureau (May 21st, 2019); ii) **Urban Solid Waste Management Challenges and Opportunities in Tigray**, a seminar organized by the Directorate of Urban Greening and Beautification in collaboration with The Tigray Region President Office and Mekelle University Future Urban Lab (May 22nd, 2019); **iii) National Consultative Workshop: Let us listen to the Voices of the Grass-Root People and be part of the Solution through our Agricultural Research and Development Agendas**' organized by Mekelle University (CoDANR), Tigray Bureau of Agriculture and Rural Development (BoARD), Tigray Farmers' Association Tigray, and PLUM Ethiopia (July 1, 2019). Our project, in the national consultative workshop was represented by two women headed households (Mrs. Samrawit Moges from Ruba-Feleg village and Mrs. Kahsu Gebretsadkan from Adikisandid village). Both women participants presented their vermicompost and homemade Aloe Vera soap products (Figure 19).

Figure 19. Produced vermicompost and Aloe Vera soap displayed at the national consultative workshop

The mini-workshops, stakeholders' experience sharing visits and seminars led to an increased interest of different organizations such as the GIZ-SLM, the Tigray National State Science and Technology

Bureau (BoST), the Tigray National State Urban Greening and Beautification Directorate and Mekelle University Industry Community Linkage Directorate Offices to scale-up the technology to other areas in the region.

As a result, with a financial support for trainees from GIZ/SLM, and technical support from AgriFoSe2030, 24 experts from 12 rural districts of Tigray (Alamata, Ofla, Endamekhoni, Raya-Azebo, Alage, Saharti-Samre, Degua-Tembien, Kola-Tembien, Ahferom, Adwa, Laelay-Maichew and Tahtay-Maichew) were given training on how to teach the technology to urban families. Moreover, a collaborative training was given to urban households from four cities with the objectives of reducing urban solid waste accumulation through vermi-composting and composting (Table 10). An awareness creation training was also given to 329 experts from the entire region (Tigray) in two groups (one group in Axum and the other group in Adigrat cities). Our collaboration also extended to the neighboring region Afar (Kuneba district) in collaboration with the Participatory Ecological Land Use Management (PELUM Ethiopia).

Table 10. *Technology scale-up areas, beneficiaries and collaborations*

Scale - up areas	Beneficiaries (No.)	Collaboration
Mekelle City	80	AgirFoSe2030 +Tigray BoST
Wukro Town	30	AgirFoSe2030 + Mekelle University + Wukro St.Mary's College
Adigrat City	35	AgirFoSe2030 + Mekelle University
Abi-Adi Town	30	AgirFoSe2030 + Mekelle University
Afar region (Kuneba)	12	AgriFoSe2030 + PELUM Ethiopia
Total	**187**	**Five collaborative institutions**

Some urban dwellers started to grow vegetable crops such as salad and switchyard using the introduced vermi-compost technology (Figure 20).

Figure 20. Vegetable crops grown in Mekelle City using Vermi-compost

As part of the efforts to scale-up the technology to urban areas, the following major activities were accomplished: i) inviting media to document and disseminate the project achievements (e.g. EBC and DW Television); ii) organizing experience sharing workshop (Figure 21). A one day workshop with 76 participants from 12 cities, institutes and development projects working in Tigray was organized in collaboration with the Tigray Bureau of Science and Technology. The workshop aimed at: a) organizing information on the possibilities for vermicompost technology scale-up; b) identifying challenges and opportunities of the technology; c) identifying potential stakeholders for future development of the technology and similar technologies.

Figure 21. Participants during onsite visit to introduced Vermi-compost technologies in Mekelle city

The overall project activities (from both rural and urban areas) were broadcasted on Ethiopian Television (link: ***https:youtu.be/7d58Rob73r0***); Dimtsy Weyane Television (DW TV) (link: http://www.dmtsiweyane.com/ti/node/19217), Ethiopian News Agency, FM102 (DW Radio), Mekelle University Corporate (Mekelle University Website) and Wukro town Municipality website.

The scale-up approaches in this project yielded a growing interest of individuals (farmers and urban residents) to adopt the technology. A demand is also coming from government organizations (Bureau of Agriculture and Rural Development, and Tigray Urban Greening and Beautification Directorate), youth and women associations from the region to help reach more households in the entire region, both urban and rural.

5. BARRIERS TO SCALING UP

Regardless of the various advantages obtained from the vermi-composting technologies to women headed households in both rural and urban areas, the scalability of the project to the entire region can be hampered by the following factors:

- Policy and development planners, experts, extension agents, researchers and academicians' knowledge on organic farming (particularly vermi-composting and vermi-culturing) is still very low, hence, technical and financial support for the scaling up of VC is still limited.

- Experts and extension agents are more interested in chemical fertilizers as the response of farmers to these fertilizers is quick. Less effort is, therefore, needed for scale-up compared to the organic fertilizer. Organic fertilizers production, particular vermi-compost, requires strong and regular follow-up, on-field demonstrations and are bulky to transport compared to chemical fertilizers to treat similar farm size.

- As farm level research and demonstrations on organic fertilizers, including vermi-compost, is limited in Ethiopia and other developing countries, more effort and time is required to convince farmers and other stakeholders to scale-up the technology.
- The characteristics and feeding behaviour of the local worms in different agro-ecologies is not sufficiently studied. Hence, on-farm research is required on the characterstics and feeding behaviour of local worms in the entire region compared to the introduced red-worm to define which is the most beneficial to use.
- Even though the introduced red-worms can survive under different agro-ecologies and weather conditions, their efficiency varies. Different strategies and pilot projects, therefore, need to be set-up on each agro-climatic zone, which requires local level understanding to identify suitable management strategies.
- The vermi-compost quality and worm productivity depends on the feed type which in turn depend on agro-climatic zone. However, there is no study on the suitable feed sources for vermi-culturing and compost quality assessment under different feed types in each agro-ecology. This would require extra time and finance to set-up the experiment.
- The application rate of the produced vermi-compost varies by soil and crop type as well as the vermi-compost quality (chemical properties). Hence, it is difficult to set-up a blind recommendation for major-agro-ecologies, and requires extra time and finance to come up with better recommendations for the entire region.

6. CONCLUDING REMARKS AND WAY FORWARD

6.1. Concluding remarks

The major activities implemented during the project's two years time, and their associated outputs are summarized below:

- Vermi-worms (*Eisenia fetida*) culturing centers, enough to culture more than 250,000 worms, were established at six places in the project site.
- 96 women farmer household heads and 39 development agents/experts were trained for five days.
- Experimental researches were established to evaluate the effect of vermicompost on maize, wheat, salad and apple. Moreover, suitable feed type for vermiculturing were evaluated.

It is clear that project beneficiaries are able to generate additional income of 9 to 296 US Dollars from vermi-compost production and vermi-worms selling. Furthermore, farmers' farm demonstrations revealed increased crop productivity as the result of vermi-compost application. For example, vermi-compost doubled wheat productivity over farm yard manure, increased maize yield by 305% and maize biomass by 101.2% over chemical fertilizer, and increased teff productivity by 14.3% over chemical fertilizer.

Vermi-compost addition increased soil fertility and crop yield of maize, wheat and apple. The highest net benefit for maize was obtained from plots treated with 5 t ha_{-1} vermicompost, while application of 10 t ha_{-1} vermicompost was found most economically beneficial for wheat.

The project beneficiaries considered the technology useful as: i) it improves soil fertility and crop productivity; ii) it reduces the cost of purchasing chemical fertilizer; iii) it is easy to handle or manage by any family member; iv) it improves household sanitation through continuous waste removal as worm feed; v) there is continuous compost production as the worms multiply quickly; and vi) it protects the plants from diseases (e.g. rust), insects (e.g. stock borer) and weeds (e.g. striga).

Notwithstanding the benefits, the following challenges were also reported: i) the worms need continuous follow-up as they are susceptible to different enemies such as termites and rodents; ii) there are market linkage problems to get more benefits out of the selling of worms.

To scale-up the pilot project outputs, different methods were followed. Mini-workshops were organized and project outputs presented in different workshops and seminars with the objectives to: i) evaluate the project activities and outputs; ii) share farmers' experiences among stakeholders on the benefits of vermi-culturing and vermi-compost for food security improvement. The outcome was some governmental and non-governmental organizations showed an interest to collaborate with our project to scale-up the technology to the entire region (both rural and urban areas). Hence, a joint training was given to experts and households in a few rural and urban areas as well as in the neighboring region (Afar). The overall project activities (from both rural and urban areas) were broadcasted on Ethiopian Television; Dimtsy Weyane Television (DW TV), Ethiopian News Agency, FM102 (DW Radio), Mekelle University Corporate communication and Wukro town Municipality websites.

Despite the various advantages obtained from the vermi-composting technology to women-headed households in both rural and urban areas through improved agricultural productivity and household waste management, there are barriers to scale up the project to the entire region. Some of the barriers include lack of knowledge about the technology by stakeholders which leads to less technical and financial support to the scale-up, limited capacity of policy and development planners to support VC technology, priority given to chemical fertilizers by extension agents, and limited farm level research and demonstration on the technology.

6.2. Way forward

The Tigray Bureau of Agriculture and Rural Development (BoARD) has requested the University of Mekelle to help implement various research and development activities in the region in relation to the vermi-compost project. These are summarized as follows:

- Establishing vermi- culturing centers on selected sites/districts to reach the different farmers training centers and farmers in the region;
- Capacity building of soil fertility experts in the region;
- Agro-ecology based research for best feed selection for better vermi-worm culturing;
- Quality and quantity of vermi-worms identification to be used as feed for fish and chicken;
- Selecting inputs for better conventional compost preparation at farmers' level;
- Agro-ecology based produced conventional compost and vermi-compost quality assessment;
- Develop manuals in Tigrigna and Amharic language for vermi-compost and conventional compost preparation.

More demand is also coming from urban areas of Tigray for solid waste management and improved livelihood of the urban poor through producing vermicompost (worm and compost selling) besides environmental sanitation. The special focus is on organizing and training youth and women headed households to work on composting and vermi-composting (using urban solid wastes as input) to create jobs, diversify income sources and food while keeping their town/city clean.

The project activities in both urban and rural areas should also be supported with home-garden to diversify sources of income and bring food- and nutritional security. This could include training of women-headed households on vegetables, spices and fruits management and processing, and supporting them with inputs such as seeds, seedlings and water saving technologies in addition to the vermi-composting technology.

To sustain the project activities and reach more people, a national or international organic farming workshop with a special focus on vermi-composting is needed. The workshop should have the following objectives: i) bringing international people on board to share experiences; ii) publish all related papers selected for oral presentation as special issue on the journal of the drylands (a local journal based in Mekelle University).

Regular follow-up of women headed household project beneficiaries is required to sustain and scale-up the project outputs. Moreover, there should be a link with market. Hence, vermi-composting value chain development for the entire region is necessary to sustain agricultural productivity through organic farming, including the vermi-compost technology.

7. REFERENCES

Aira, M., Monroy, F., Dominguez J & Mato, S. 2002. How earthworm density affects microbial biomass and activity in pig manure. *European Journal of Soil Biology*, **38**: 7–10.

Alhassan, I.S., Kuwornu, J.K.M., Osei-Asare, Y.B., 2018. Gender dimension of vulnerability to climate change and variability Empirical evidence of smallholder farming households in Ghana. International Journal of Climate Change Strategies and Management 11 (2): 195-214. DOI 10.1108/IJCCSM-10-2016-0156.

Bezabih Emana, Hadera Gebremedhin & Nigatu Regassa. 2010. Impacts of Improved Seeds and Agrochemicals on Food Security and Environment in the Rift Valley of Ethiopia: Implications for the Application of an African Green Revolution. Drylands Coordination Group Report No. 56 02.

Bisen US, Chauhan RK, Singh AK, Singh M, Ghosh BC and Bera B, 2017. Development of Vermicompost tea cultivation at high altitude. Eco.Env. & Cons. 23 (1): 464 – 469.

De Brito, A.M.A., Gagne, S & Antoun, H. 1995. Effect of compost on rhizosphere microflora of the tomato and on the incidence of plant-growth promoting rhizobacteria. *Applied and Environmental Microbiology*, **61**:194-199

Federal Democratic Republic of Ethiopia, Ministry of Agriculture [MoA], 2015. Agricultural Growth Program II (AGP II). Program Design Document. Addis Ababa, Ethiopia. https://www.google.com/#q=agp+ii+ethiopia

Flato, M., Muttarak, R., Pelser, A., 2017. Women, Weather, and Woes: The Triangular Dynamics of Female-Headed Households, Economic Vulnerability, and Climate Variability in South Africa. World Development 90: 41–62. http://dx.doi.org/10.1016/j.worlddev.2016.08.015.

Hati, Daksha, 2001. 1000 Wriggling Worms and Rural Women. The Deccan Herald, 26th June, 2001, India.

Scheuerell, S., Mahaffee, W. 2002. Compost Tea: Principles and Prospects for Plant Disease Control. *Compost Science and Utilization,* **10**: 313-338.

Visvanathan C., Tränkler J., Joseph K., Nagendran R. 2005. Vermicomposting as an Eco-tool in Sustainable Solid Waste Management, Asian Institute of Technology, Anna University, India.

World Bank. 2007. World Bank Fact Index Country Report: Ethiopia. *www.worldbank.org/ en/country/ethiopia/overview.*