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THE EFFECT OF COMPOST ON SOIL FERTILITY ENHANCEMENT AND YIELD INCREMENT UNDER SMALLHOLDER FARMING - A CASE OF TAHTAI MAICHEW DISTRICT - TIGRAY REGION, ETHIOPIA

DISSERTATION

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1. THE PROBLEM

1.1 The rationale and justification of the study

Agriculture is the main economic activity of Ethiopia. It is dominated by smallholder farming (MoFED, 2002; CSA, 1998). The contribution of smallholder peasant agriculture to the country is very high. It accounts for about 45% of the GDP, 85% of the exports and 80% of the total employment (EPA, 1997b). However, agricultural productivity is continuously challenged by land degradation, which is manifested in various ways. For example, footpaths develop into gullies, soils become thin and stony, topsoil is gone etc (Stocking and Murnaghan, 2001).

The decline in soil physical, chemical and biological properties is revealed in many parts of the densely populated highlands of Ethiopia. For example, in Tigray nitrogen and phosphorus are highly deficient (Mitiku et al, 2003). Nitrogen in the cultivated surface soils was 0.07-0.13 percent of Melbe area of Tigray (Tegene, 1996). Moreover, the soil depth in many areas of Ethiopia is less than 20-30 cm. This means that it is reaching the lower limits of productivity of the arable land and has lost much of its capacity to retain moisture; with consequent decline in agricultural yield (Stocking and Murnaghan, 2001; Elias, 2002; World Bank, 2007). The annual grain production loss estimate due to burning of dung as fuel than using for soil fertility improvement is estimated to 550,000 t per annum while due to accelerated erosion the loss is around 40,000 t by 1990. This will be accelerated into 170,000 t in 2010, if not controlled (EPA, 1997b).

The Ethiopian government has been issued the Environmental Policy of Ethiopia (EPA, 1997a) to protect the natural resource degradation and improve the soil fertility management. Under the Soil Husbandry and Sustainable Agriculture section (3.1(c)) of the policy explains “to promote the use of appropriate organic matter and nutrient management for improving soil structure, nutrient status and microbiology in improving soil conservation and land husbandry”; (d) “protect the physical and biological properties of soil through management practices for the production of crops and livestock to the proper balance of chemical and organic fertilizers, including green manures, farm yard manures and compost”; (e) “promote effective ground cover for erosion control”.

The Conservation Strategy of Ethiopia has set strategies for the implementation of improving soil, crop and animal husbandry for sustainable agricultural production based on the Environmental Policy of Ethiopia. To mention the appropriate points in the Conservation Strategy such as section 4.1.1 (a) “Build on indigenous system of soil management to develop and promote improved technologies for increasing the quantity and improving the quality of Soil Organic Matter, soil structure, soil nutrients, and soil flora and fauna, and in particular exploit the complementary effects of chemical and organic fertilizer sources such as farm yard manures, green manures, compost and biological nitrogen fixation in order to improve soil quality and structure, minimize soil pollution and increase crop production.” 4.1.2 (c) “Shift the present focus of agricultural development and extension on maximizing crop yield utilizing high cost technologies that requires imported agricultural inputs to one of producing yields, which will meet most or all of farmers’ production objectives through the judicious use of locally available and/or imported inputs (EPA, 1997b).”

However, due to the high market prices and weak delivery of mineral fertilizer, a sharp drop in the prices of harvested products especially during harvest season (Müller-Sämann and Kotschi, 1994; Tegene, 1987) or unreliable rainfall farmers use no or less amount of mineral fertilizer. The consumption in the country is between 7-8 $kg.ha^{-1}.yr^{-1}$ (MOARD, 2007; Elias, 2002) as compared to the 48 and 97 $kg.ha^{-1}.yr^{-1}$, respectively in Kenya and worldwide (Pender et al., 1999). So far, most of the mineral fertilizers used are in irrigated fields (Aseffa, 2005). However, application of mineral fertilizer is not sufficient to effectively restore the productivity of the cultivated soils in the highlands (Mitiku and Fassil, 1996; Tegene, 1987). This is because maintaining the right level of organic matter and potassium is also an equally important requirement for the improvement of soil productivity and crop yield (Tegene, 1987). Most farmers are highly inclined into the local soil fertility management practices because subsistence agriculture demands high labor and low capital. This is also high survival and risk avoidance strategies for the peasant farmers (Tegene, 1987).

The country’s long-term economic development strategy is Agricultural Development-Led Industrialization (ADLI) with a goal to achieve rapid and sustainable economic growth by improving the productivity of the agricultural sector and building up on agriculturally based industrial sector, which is labor-intensive and utilizes local raw materials (EPA, 1997b).

The Institute for Sustainable Development (ISD) has been working in Tigray Region since 1996 in ecological land management to reverse the land degradation problem, improve soil fertility and yield based on the ADLI policy. The use of compost is becoming a very important sustainable alternative for many smallholder farmers, who are unable to buy mineral fertilizer to increase their yield. Compost has been started to spread through out the country since 2003/4. For example, in Tigray Region it has spread into 25 percent of the farmers (Araya and Edwards, 2006; SSNC, 2008). Since the Tigray Project of ISD is based on the Environmental Policy of Ethiopia and on the Conservation Strategy of Ethiopia this study is based on the experience of ISD since it started its impelemetation. But the nutrient content of compost and composting material and its effect in the future of smallholder agriculture needs to be assessed.

Therefore, the significance of this study is to assess the effect of compost application in smallholder farming without upsetting their usual living. Its results are useful for farmers to come up with a policy briefing for experts and policy makers for a better attention in the government strategy.

1.2 Hypothesis

The study has the following hypotheses to be tested during the research period:

i. The soil status of the plough layer soils of the study area are at very low level for crop production.

ii. All farmers can find sufficient biomass for compost making.

iii. The compost management and application has important effect on farmers' income.

iv. Compost results in an improved balance of nutrient compared to mineral fertilizer.

v. Smallholder farmers can be sustainable with low input agriculture.

1.3 Objectives

The aim of this study is to obtain valid data about the use of compost in the smallholder farming in the Tahtai Maichew Woreda, Tigray Region - Northern Ethiopia, and to derive recommendations. Through out the research process the following activities will be addressed to test the above hypothesis.

1. Determination of the soil fertility status.
2. Assess, if biomass for compost making is sufficiently available at any time of the year.
3. Check, if compost improves nutrient in soil, yield and farm income.
4. Determination of farmers' compost application amount.
5. Determination of sustainability in current farmers' practice.

1.4 Organization of the thesis

The motivation for this research and the major objectives addressed in this research are explained briefly in this section. The subsequent chapters are organized as follows:

Chapter 2 provides the literature review. The main focus of the literature review is on the soil fertility situation of tropical Africa in general and northern Ethiopia in particular. The agricultural system and soil fertility management practices of smallholder farmers especially compost are the main highlighted. This is because farmers are mainly shifting into compost. Therefore, the study is focused in the effect of compost.

Chapter 3 provides a description of the study area and the research methodology. The description of the study area focuses in the biophysical, local soil fertility management situation and the agricultural system of the study area. In the methodology all processes come across the study such as compost preparation, sample collection, laboratory analysis, etc are explained here.

Chapter 4 presents the results. The main results are about the present soil fertility status of the study area; compost production and biomass availability; quality of composting materials and compost; the effect of compost in soil, yield and socio-economy of farmers; the nutrient situation of the different inputs and outputs based on the crop types is addressed; the situation of marketing and use of mineral fertilizer in the district. The other aspect assessed is the sustainability of smallholder farming under low-input agriculture.

Chapter 5 discusses the major findings and outlines the main conclusions. It mainly focuses four points. 1. The realities of the soil fertility of the study area. 2. The compost production capacity of the smallholder farming and compost quality enhancement. 3. The effect of compost on soil, yield and income. 4. The nutrient balance situation of the different inputs and outputs as affected by treatments. 5. Sustaining the smallholder farming under the present agricultural situation.

Chapter 6 outlines the main conclusions and draws major policy implications and discusses issues for future research.

2. STATE OF THE ART

2.1 Soil fertility problem

2.1.1 Soil fertility situation in Ethiopia

Over 50 percent of the highlands in general and cropped areas of Ethiopia are in an advanced stage of land degradation (Elias, 2002). This is because of the continuous cultivation at least since the 13th century (Tewolde Berhan, 2006). Therefore, soil organic matter (SOM) content and nutrients are generally lower, where land degradation is more severe (Elias, 2002; Tegene, 1998). It leads to poor soil structure consequently to water erosion (Sivakumar and Stefanski, 2006). Therefore, and soils in many areas of the country especially in Tigray become shallow and stony (Stocking and Murnaghan, 2001).

Tigray is a region with higher land degradation (Hagos et al., 2002). Farmlands are extremely deficient in nitrogen, available phosphorous and organic matter (Tesfay, 2006; Mitiku et al., 2003). The study by Mitiku et al. (2003) reported that 94% of the land has a very low level organic carbon, 76% had extremely low and another 21% had very low levels of nitrogen (N) content and 98% low phosphorus content. However, with 30% of the plots being high and 37% medium, the available potassium is better supplied than nitrogen and phosphorous, with only 33% of the plots having low available potassium content (Mitiku et al., 2003; Mitiku and Fassil, 1996). This is an indication of potassium is less commonly limiting (Mitiku and Fassil, 1996). This shows that the soils are reaching the lowest limits of productivity and has lost much of its capacity to retain moisture (Stocking and Murnaghan, 2001; Elias, 2002; World Bank, 2007).

2.1.2 Soil fertility situation in Tigray

Only few researchers such as Mitiku (1997) and Hunting (1975) has been carried out studies on the soils of Tigray. But there is no systematic soil survey undertaken for the whole of Tigray Region. There are also spot level studies conducted by Aseffa (2005), Nyssen et al. (2008) and others. Based on the researches and the map of the WBISPPO (2002) the major soils of Tigray are identified as Cambisols, Luvisols, Rendzinas, Lithosols (Leptosols), Fluvisols, Nitosols, Arenosols, Vertisols, Xerosols, Regosols and Andosols. But no one has put the soils in spatial coverage for the region.

The soils identified so far vary in their characteristics (depth and fertility) from within and between the soil types. Many researchers reported that Tigray Region is highly degraded (Hagos et al, 2002; Virgo and Munro, 1977). Virgo and Munro (1977) reported that the result of the "empirical methods and suspended sediment measurements indicate high rates of regional soil loss (17-33 $t.ha^{-1}.yr^{-1}$), accounted for by seasonally high rates of rainfall erosivity, steep terrain and poor land use. Application of the universal soil loss equation to arable lands indicates potential annual soil losses are 400 t/ha on Vertisols and 200 $t.ha^{-1}$ on Cambisols." Therefore, the soils are reaching their lowest soil fertility status (Stocking and Murnaghan, 2001). The plough layer of most soils, except Vertisols, of the studies undertaken by Nyssen et al (2008), Aseffa (2005), Mitiku (1997) and Virgo and Munro (1977) show textures of the study area are sandy-loam, sandy-clay-loam or loam. These textural characteristics are evidences for the higher soil removal of soils from nearby hillsides.

Most of the reports of the soil characteristics of Tigray indicated their lower soil fertility status. However, many of the soil types referred except Lithosols (Lepthosols), Rendzinas and limited Vertisols of Hagere Selam area, all the soils are deeper than one meter (Aseffa, 2005; Mitiku, 1997; Virgo and Munro, 1977) (Table 2.1). Mitiku et al. (1997) reported that the soil depths of their research are 42 percent (less than 75 cm), 37 percent (75-100 cm) and 21 percent (greater than 100 cm) of their 300 sample plots.

Vertisols cover large part of the country, about 10 percent of Ethiopia (12.7×10^6 hectares) an d it accounts for nearly 23% of the total arable land used for crop production (Debele, 1985). More than half of the Vertisols (7.6×10^6 ha) are found in the Central Highlands with an altitude of more than 1500 m above mean sea level (Welderufael and Weyessa, 2009). The Vertisols of Ethiopia are found on the extensive basalt plateau (FAO, 2001).

The Vertisol soils of the Hagere Selam area of Central Tigray are Pellic Vertisol, Haplic Vertisol and Calcaric Vertisol. They contain 1.1-1.6 percent organic carbon, 0.09-0.16 percent Nt and 39.1-57.9 cmol(+) kg^{-1} soil (Van de Wauw et al., 2008). Most Vertisols have a high cation exchange capacity (CEC). The CEC of the soil material (in 1 M NH_4OAc at pH 7.0) is commonly between 30 and 80 cmol(+)/kg of dry soil; the CEC of the clay is of the order of 50 to 100 cmol(+)/kg clay (FAO, 2001). The OC of the Chromic Vertisol in Quiha by Virgo and Munro (1977) is within this range but CEC (28) is much lower. On the other hand the OC of Gormedo area is higher than the others i.e., 2.6 percent (Mitiku, 1997). The findings of the research on the Vertisols of Melbe area, Tigray, reported the percentage of total nitrogen in the surface soils was 0.07-0.13 in the cultivated soils while 0.20-0.27 in the uncultivated ones (Tegene, 1996).

Table 2.1 - The major soils in Tigray with their average depth (cm), texture (tex.), OC (%), CEC (cmol(+)/kg-1 soil), TN (%) and Olsen-P (ppm)

Soil unit (FAO)	Series	Dep.	Tex.	OC	CEC	TN	P	Auth.
Lithosols	Dindera	30	SCL	-	-		-	4
Leptosols	Teghane	30	CL	0.98	13	0.10	7.4	2
Vertisols	Humera	200	C	1.2	42		19.0	4
Vertisols	Gormedo	115	C	2.6	29		5.0	4
Chromic Vertisols	Quiha	150		1.2	28**		-	5
Pellic Vertisols	Ginchi	>100	C	0.55		0.05		3
Pellic Vertisol	H. Selam	140	C	1.1	50.0	0.09	8.5*	1
Haplic Vertisol	H. Selam	90	C	1.1	45.1	0.09	14.0*	1
Calcaric Vertisol	H. Selam	80	C	1.6	39.1	0.16	11.1*	1
Fluvisols	Lahama	160	SL	2.4	20		1.4	4
Luvisols	Tabeldi	200	SCL	0.4	20		7.0	4
Luvisols	Romanat	130	CL	1.4	25		27.0	4
Luvisols	Teghane	190	CL	1.4	14.6	0.12	10.28	2
Cambisols	Yemad	144	SCL	1.1	12		8.6	4
Cambisols	Senda	125	SCL	1.0	16		2.0	4
Cambisols	Teghane	120	C	2.35	18.6	0.23	21.6	2
Eutric Cambisols	Quiha	90+		0.3	14**		-	5
Chromic Cambisols	Hawzien	110		0.4	6.3**		-	5
Skeletic Cambisol	H. Selam	68+	C	1.7	30.6	0.15	12.0*	1
Skeletic Cambisol	H. Selam	170	C	2.1	39.0	0.19	55.8*	1
Vertic Cambisol	H. Selam	180	CL	1.5	30.2	0.12	20.6*	1
Gleysols	Kesafi	120	L	-	27		-	4
Arenosols	Menchebu	180	SL	1.0	13		1.8	4
Rendzinas	Mosebu	45	C	3.3	41		2.3	4
Xerosols	Kalla	100	SL	2.0	22		4.0	4

Key: Dep. - depth; Auth. - author(s); 1. Van de Wauw et al., 2008; 2. Aseffa, 2005; 3. Welderufael and Regassa, 2009; 4. Mitiku, 1997; 5. Virgo and Munro, 1977. OC: organic carbon, CEC: cation exchange capacity, P: phosphorus, where * P_{av} -mg/100 g; ** meq/l. SCL = sandy clay loam, C= clay, SL = sandy loam, L = loam, CL = clay loam

Luvisols in Tigray are very deep soils ranging from 130 cm in Romanat to 200 cm in Tabeldi (Aseffa, 2005; Mitiku, 1997). Most of the soils are clay-loam, sandy-loam and sandy-clay-loam texture. Organic carbon contents are at low level, but vary widely from the lowest 0.4 percent in Tabeldi to the highest 1.4 percent in both Romanat and Teghane (Table 2.1). The total nitrogen is 0.122 percent, which is at low level. Available phosphorous varies very much from 7.0 to 27.0 (Olsen-P (ppm)) (Table 2.1). The cation exchange capacity of the Luvisols show they are 14.6, 20 and 25 cmol (+) kg^{-1}, which are showing respectively low, medium and high potential fertility level of the soils (Landon, 1991).

Cambisol in Tigray is characterized by deep soil. The plough layer soil varies from clay to clay-loam and sandy-clay-loam soils. Their organic carbon ranges from the lowest 0.3 percent in Quiha to 2.35 percent in Teghane. Total nitrogen is also between 0.12 percent in Hagere Selam to 0.227 percent in Teghane. The later lie at the medium level (Landon, 1991). Available phosphorous and cation exchange capacity (CEC) are very variable. Available phosphorous ranged from 2.0 in Senda to 55.8 (cmol(+) kg^{-1}) in Hagere Selam while CEC from 6.3 in Hawzien to 39.0 (Olsen-P (ppm)) in Hagere Selam (Table 2.1).

Most of the textures of the Luvisols and Cambisols are dominated by clay-loam, sandy-clay-loam and silt. This indicates the soils are deposited from the nearby hillsides by erosion of the erratic rainfall. However, generally the Luvisols and Cambisols of Tigray have favorable infiltration characteristics than Vertisols (Virgo and Munro, 1977).

Regardless of the soil type all studies indicate pH is weakly alkaline to moderate alkaline reactions between 6.0 and 8.8 (Van de Wauw et al., 2008; Mitiku et al., 1997; Tegene, 1996; Virgo and Munro, 1977). The soil reaction of Vertisols vary from weakly acid to weakly alkaline. According to FAO (2001) higher pH values (8.0-9.5) were measured on Vertisols with much exchangeable sodium. Even though the pH values (1:2.5 soil:water) do not have precise significance but some generalizations can be made.

According to the rating of Landon (1991) the organic carbon of the Vertisols, Luvisols and Cambisols in Tigray are at a low level. The nitrogen lie in the very low and low range. There is a medium level in the Cambisols of Hagere Selam. Available P of the

Cambisols and Luvisols vary from deficient in Senda area to adequate in many places. However, CEC (cmol(+) kg^{-1}) shows the soils have higher fertility potentials (Table 2.1).

2.1.3 Nutrient situation

Many studies point out the widespread processes of nutrient mining and soil fertility decline (Scoones and Toulmin, 1998; Shepherd et al., 1996). Throughout the smallholder farming systems of Africa negative nutrient balances of nitrogen and phosphorus are reported (Ncube et al., 2009). Although the main sources of nitrogen in soil are the breakdown and humification of organic matter (Landon, 1991; Saleem, 1998) but they are retarded due to the continuous cultivation and soil degradation (Bationo and Mukwunye, 1991; Jones and Wild, 1975). Farmers remove the crop residues, the main NPK export, to feed their animals without adding enough nutrients to the soil (Dechert et al., 2005; Elias et al., 1998).

This situation requires restoring nutrients for a better production. Jones (1972) suggested only 3-year fallow to restore the soil organic carbon, NPK and Mg that were depleted in a 3-year growth period while Harris (1998) generally indicated an extended resting period. But this is likely impossible in many places in Africa especially in Ethiopia. Aseffa (2005) reported that fallowing, for natural soil fertility replenishment, has almost completely disappeared from agricultural practice in Tigray. This is because farmers are forced into non-fallowing intensive cultivation (Bationo and Mukwunye, 1991; Saleem, 1998; Snapp et al., 1998).

However, the nutrient balance estimate for Ethiopia varied very mcuh, which varies from the -47 kg N, -7 kg P and -32 kg K $ha^{-1}.yr^{-1}$ (Stoorvogel et al., 1993) to -122 kg N, -13 kg P and -82 kg K $ha^{-1}.yr^{-1}$ (Haileslassie et al., 2007; 2005). While the field scale study by Elias et al. (1998) for the mixed farming in Southern Ethiopia N and P were more of equilibrium or positive. The plot level study by Hengsdijk et al. (2005) reported only -27 N $ha^{-1}.yr^{-1}$. While the study by Aseffa (2005) in Teghane Atsbi area of Tigray reported depletion between -65.5-(-115) kg N $ha^{-1}.yr^{-1}$, 0-(-5.8) kg P $ha^{-1}.yr^{-1}$ and -34.6-(-112) kg K $ha^{-1}.yr^{-1}$. The nutrient depletion in Ethiopia has several causes such as the limited applications of organic fertilizer like crop residues and manure, and the socio-economic problems in the mineral fertilizer (Aseffa, 2005).

The negative nutrient balances indicated above are not only in Ethiopia they are also experienced in other African countries. For example, the study in Nakuru Disrict of Kenya indicated that the NPK balances in cropping activities were negative (Onwonga and Freyer, 2006). The nutrient balance of the studies carried out in Kenya range in -71-(-112) kg N, +3-(-3) kg P and -9-(-70) kg K $ha^{-1}.yr^{-1}$ (Van den Bosch et al., 1998; Smaling et al., 1993).

Partial or full nutrient balance studies at any level have large variations between farms, plots and across land-use and little variation between districts (Van den Bosch et al., 1998; Onwonga and Freyer, 2006). In many studies both nutrient balance analyses show important results but partial nutrient analysis leaves some important nutrient pathways like inputs through deposition, sedimentation and outputs like leaching, erosion, or gaseous losses in the calculation (Haileslassie, 2007; 2005; Dechert et al., 2005). Studies suggested inputs are the most important flow that determines values of partial balances (Haileslassie et al., 2005). But vary under different cereal crops and locations. Homestead plots, where farmers mainly apply organic fertilizer and plant such as maize, permanent and vegetables crops are reported positive balance while teff, barley, sorghum, millet and oat had negative balances (Haileslassie et al., 2005).

2.2 **Smallholder farming systems**

2.2.1 Rain-fed agriculture

Over 85 percent of the total population of Ethiopia are rural and they dependent on mixed farming (Tewolde Berhan, 2006). It is a country of small-holder farmers characterized by fragmented plots and dependence on rain-fed agriculture (World Bank, 2007; Aseffa, 2005). The land-use in Tigray region is changing due to the increasing population and continuous cultivation. Over 50% of the highlands of Ethiopia are now in an advanced stage of land degradation (Mulugeta, 2005), destroyed by gullies and the sedimentation of silt virtually devoid of organic matter (Tewolde Berhan, 2006). But it is not a recent phenomena because the whole of the highlands of Ethiopia were deforested and under crop cultivation at least since the 13th Century, if not thousands of years before, but the slopes were terraced and the uncultivated areas were wooded (Tewolde Berhan, 2006).

In the history of Ethiopian civilization, agricultural development in the northern highlands of Ethiopia particularly in Tigray has undergone a series of revolutionary developments in crop and livestock production. Tigray at large is identified as a high erosion and moisture deficiency part of the country (Virgo and Munro, 1977; Tegene, 1996). It is classified in the World Bank (2007) as a drought-prone area with inadequate and unreliable rainfall.

Even though the opportunities to generate the required production for wider economic growth are limited (World Bank, 2007) the farmers have existed for thousands of years with this fragmented and small landholding system supported by their traditonal practices (Tewolde Berhan, 2006; Araya and Edwards, 2006). However, they have abandoned fallowing and cultivation is extended onto the very fragile steep slopes (Tegene, 1987).

2.2.2 Agricultural production

In the Tigray region the productivity of the soils reduced and consequently leads into the decline in agricultural productivity (Belete, 2003; Engdawork, 2002). At present, farmers use mineral fertilizers to correct deficiencies of the soil fertility and increase production but treating soils with nitrogen and phosphorus fertilizers alone is not enough to restore effectively the productivity of the cultivated soils in the high lands (Mitiku and Fassil, 1996).

Making and applying compost, however, is one of the options and it is widely used by rural communities to improve the soil fertility and raise their yields from agricultural. In many parts of Tigray crop production was often equivalent or even better than the mineral fertilizers used (Araya and Edwards, 2006; Edwards et al., 2007). In Ethiopia grain production is increasing higher than the land expansion i.e., grain production increased by 4.75 and 6.71 percent while land expansion by 2.33 and 0.86 percent in Ethiopia in general and in the Tigray Region in particular respectively (CSA, 2009). This could be by different means than due to the land expansion.

2.3 **Soil fertility management**

Many researchers belief in the hopelessness of the recovery of soil such as Mulugeta (2005) reviewed that the soil is heavily degraded and it would thus take centuries to recover. But evidences show smallholder farmers are maximizing returns from their limited land and capital, minimize production risks, diversify sources of income, provide food and increase productivity (Aseffa, 2005). This is because Ethiopian farmers are endowed with diverse systems of soil fertility improvement suited to the various agroecologies of the country and sustain family livelihood. The longer years of this mixed farming goes side by side with local soil fertility management practices (Aseffa, 2005; Hagos et al., 1999) such as animal manure, crop residues, crop rotation, mineral fertilizer, compost etc to cope with declining soil fertility, which differ among farmers and among locations (Elias, 2002).

2.3.1 Manure

Since time immemorial animal manure is the prime source of the soil fertility management to improvement way for many farmers of Ethiopia. Traditionally, it is used as fertilizer to ameliorate soil fertility depletion in any parts of Africa in general and Ethiopia in particular. For example, the study conducted by Elias (2002) reported that 87 percent of Kindo Koisha (Southern Ethiopia) farmers apply animal manure. This is because applying animal manure has residual effect in the soil (Tegene, 1998; Elias, 2002). The effect vary based on the amounts applied. However, it is dependent on the availability of livestock and family labor for transporting into their fields (Elias, 2002). But today it is also extensively used as source of household energy (Aseffa, 2005).

2.3.2 Crop residues

Crop residues include the above-ground biomass of plants remaining in the field after grains, tubers and other products have been collected. The crop residues are incorporated into the soil and /or left as mulch (Elias, 2002). It is a way of directly recycling nutrients into the soil taken by the plants from the soil earlier. It is used for soil protection and soil fertility improvement (Smith and Elliott, 1990). Normally in Ethiopia crop residues are removed for animal feed (Araya and Edwards, 2006; Elias, 2002). But according to a study by Elias (2002) about 42 percent of farmers in Kindo Koisha apply crop residues for improving their soil fertility. While others immediately plough fields to protect roaming of animals due to the free range grazing practices (Araya and Edwards, 2006).

2.3.3 Mineral fertilizer

In order to increase agricultural yields, the government of Ethiopia has launched an extension package which gives more attention to high external inputs and high yielding varieties (Yohannes, 1999; Elias, 2002). The introduction of mineral fertilizers to Ethiopia started in the 1970s by the Ministry of Agriculture through Wolaita Agricultural Development Unit (Elias, 2002). The national recommended application rate for Ethiopia is 100 kg of diammonium-phosphate (DAP) and 50 kg Urea per hectare (Elias, 2002). But the real experience is showing that farmers are applying only smaller amounts of mineral fertilizer between 7 and 10 $kg.ha^{-1}$ annually (MOARD, 2007; Elias, 2002; Pender et al., 1999).

By 1995 only two-third of the rural households in Ethiopia have been using mineral fertilizer at this lower rate (Pender et al., 1999). Most of the mineral fertilizer is used in irrigated fields (Aseffa, 2005). However, many farmers are reluctant to use chemical fertilizer. This is because it is the limited capacity of the farmers to purchase and fear of debt (Elias, 2002), unreliable rainfall (World Bank, 2007) and the ever increasing cost of mineral fertilizer (Elias, 2002). The sharp drop in the prices of harvested products is also another reason (Müller-Sämann and Kotschi, 1994; Tegene, 1987).

2.3.4 Integrated nutrient management

Drechsel et al. (2001) reported that the application of recommended mineral fertilizers do not improve the negative nutrient balance due to the higher nutrient removal from the soils. It is because inputs (natural and man-made) are only possible to partially compensate the removal (Bationo et al., 1998). Many researches recommend integrated soil amendment practices because single application or practices could not reverse the existing problem (Eichler-Lobermann et al., 2007). It increases the level of soil organic matter, the efficient utilization of nutrients with minimum nutrient losses and integration of appropriate technologies (Onwonga and Freyer, 2006).

Integrated nutrient management practices are survival and risk avoidance strategies of farmers. The existing cultural and social institutions of communities makes labour demanding systems appropriate (Tegene, 1987). Farmers are highly linked to their innovative practices in bringing new and productive farming systems such as creating proper synergy by mixing compost and mineral fertilizer (Harris, 1998). Such as the study by Channappagoudar et al. (2007) and Manyong et al. (2001) compost and animal manure amended with mineral fertilizer gave higher yield than mineral fertilizer or compost alone.

The study by Mugwe et al. (2007) in Kenya showed that combining 30 $kg.ha^{-1}.yr^{-1}$ inorganic N fertilizer with legume plants (*Tithonia, Calliandra and Leucaena)* or cattle manure obtained a significantly higher yield of maize as compared with the application of legume plants, organic and inorganic fertilizer alone. This is an indication of achieving better yield out of all options from the varieties of technologies for farmers' choices to improve their yield match with their complex agricultural system. For example, the Sudano Sahelian zones of West Africa, indigenous SWC increased sorghum yield by up to 1500 $kg.ha^{-1}$ agroforestry improved up to 30% of N required by crops by planting leguminous hedgerows (Bationo et al., 1998). A study by Dakora and Keya (1997) showed that about 43-581 kg N $ha^{-1}.y^{-1}$ can be fixed through leaf pruning of legume trees such as *Sesbania sesban* can provide up to 448, 31 and 125 $kg.ha^{-1}.yr^{-1}$ N, P and K respectively.

2.3.5 Recycling organic matter

The mixed farming practices of Ethiopian farmers is a system of removing biomass from one place and feeding human and animal in another place. This requires to return the biomass to their origin. Recycling of organic matter is also one way of re-importing nutrients from near by urban areas, which were removed as food staff from the rural setting.

These have different potential alternatives for diverting organic waste into compost (Smiciklas et al., 2008). There are other different additional sources of biomass for compost making such as: recycling of organic materials are clearing waste disposals (Erhart et al., 2007) and irrigation waste and poultry (Eusuf Zai et al., 2008). These are important indicators for the need of effective organic waste management and closing the natural ecological cycles (Erhart et al., 2007). Because compost making is bringing waste management alternatives, which decrease disposal costs and recycle nutrients for maintaining and improving soil quality and crop growth (Smiciklas et al., 2008).

2.4 Compost

The generalized definition of compost is as follows "compost is a recycled or decomposed organic waste from different crop residues, animal and human manure and wastes and sludge being stabilized by the work of macro- and micro-organisms through aerobic, semi-aerobic and anaerobic biological processes inside a pit and/or on a surface" (Katovich et al., 2005; Elias, 2002; Abawi and Widmer, 2000; Roulac, 1996; Taddesse and Abdissa, 1996).

2.4.1 Expansion, quality and application rate

Compost is becoming widely used by many farmers in the Sub-Saharan Africa to improve soil fertility and crop production (Mugwe et al., 2007). By 1995 compost has been expanded into 11 percent in Southern Ethiopia (Elias, 2002) while by 2005 it has been using by about 25 percent farmers in Tigray (SSNC, 2008; Araya and Edwards, 2006). In Kenya such as Embu District about 91 percent of the farmers use farmyard manure, which is good potential for compost making, and in Vihiga 75 percent has been using compost (Amudavi, 2005; Mati, 2005).

Dry matter application rates of compost aree variable from the lowest 10 and 11.2 $t.ha^{-1}.yr^{-1}$ (Manna et al., 2001; Smiciklas et al, 2008) in the semiarid part of India to over 134 $t.ha^{-1}.yr^{-1}$ in the Illinois, US (Smiciklas et al, 2008). The equivalent amounts of macro-nutrient for the 10 and 11.2 $t.ha^{-1}.yr^{-1}$ compost as the lowest application is vary very much from 60, 13 and 17 $kg.ha^{-1}$ of NPK respectively while the highest application of compost, which is 134 $t.ha^{-1}$ compost, gives 1,478 (N), 540 (P) and 940 (K) $kg.ha^{-1}$ (Table 2.2). These applications are much higher than the usual macro-nutrient applications through organic and inorganic fertilizers.

Table 2.2 - Compost application rates ($t.ha^{-1}.yr^{-1}$) and their corresponding nutrients ($kg.ha^{-1}.yr^{-1}$)

Application rate (t/ha)	Nutrient application $kg.ha^{-1}.yr^{-1}$			Place and soil type	Authors
	N	P	K		
10.0	60	13.1	16.7	India	Manna et al., 2001
11.2	123.2	44.8	78.4	Illinois, USA	Smiciklas et al, 2008
16.0	143	-	-	Austria - Luvisol	Erhart et al., 2007
22.4	246.4	89.6	156.8	Illinois, USA	Smiciklas et al, 2008
23.0	205	-	-	Austria - Luvisol	Erhart et al., 2007
33.6	369.6	134.4	235.2	Illinois, USA	Smiciklas et al, 2008
44.8	492.8	179.2	313.6	Illinois, US	Smiciklas et al, 2008
67.2	739.2	268.9	470.4	Illinois, USA	Smiciklas et al, 2008
134.4	1478.4	537.6	940.8	Illinois, USA	Smiciklas et al, 2008

Studies show composts contain about 12-20 percent organic carbon (Young, 1989; Asmelash, 2001), which are sources of energy for bacteria, fungi, eartheworms and other organisms in the soil. They break-down dead plant and animal remains by releasing carbon dioxide, water and mineral salts, including nitrates, phosphates, etc., which are the nutrients for growing plants (Young, 1989; IIRR, 1998; Asmelash, 2001). The nitrogen content of compost is reported as high as 15.3 $g.kg^{-1}$ (Wahba, 2007).

A carbon:nitrogen (C/N) ratio <21 is compost maturity indicator (Getinet et al., 2008; Darlington, 2003). From a study by Manna et al. (2001) in the semi-arid tropics of India C:N ratios of 8-22. Some times 7.7 C/N ratio are reported (Marchesin et al., 1988). Compost with a higher C:N ratio is not recommended for application because C:N ratio >15 is an indication of limited N availability due to immobilization (Gutser et al., 2005; Forster et al., 1993). In matured compost the lowest C:N ratio, below 6-7 (Gutser et al., 2005) is an indication of materials to be humified and stable. They are suitable for field application (Manna et al., 2001; Darlington, 2001).

Improving N and C:N ratio of compost is related to the proportion of the green plants and dry materials used for the compost-making. The optimum C:N proportion of different composting materials is 30:1 (Getinet et al., 2008; Young, 1989; Richard, 1996). According to Richard (1996) when composting has high carbon materials additional nitrogen (mineral fertilizer) may be required to reduce the C:N ratio to the optimal range. It facilitates the establishment of micro-organisms for the quick decomposition of biomass into compost (IIRR, 1998; Cyber-north, 2004). Generally dry materials (woody materials or dead leaves) have higher C:N ratios while green materials usually have lower C:N ratios (Young, 1989; Cyber-north, 2004). This is because the dry, coarse materials such as straw, wood chips, etc. are high in C and low in N while the green materials such as grass clippings, fresh plant material, kitchen scarps and manure, are high in nitrogen and low in carbon. Animal wastes are also more N rich than plants (Cyber-north, 2004).

2.4.2 Biomass availability

There are different sources of compost. Animal manure, which is one of them, is an integral component of soil fertility management practices but crop responses in the farmers fields vary because of the differences in the quality, rates and frequency of application (Snapp et al., 1998). However, poultry manure with 20-24, 6-16 and 14-17 $g.kg^{-1}$ of N, P and K respectively (Lekasi et al., 2001; Ahn, 1970) while the data from the study by Nandwa and Bekunda (1998) reported that poultry manure have average 48 $g.kg^{-1}$ N and 18 $g.kg^{-1}$ P. On the other hand with 5 N $g.kg^{-1}$, 3 P $g.kg^{-1}$ and 3 K $g.kg^{-1}$ the farm-yard manure has the lowest nutrient content (Tegene, 1998; Channappagoudar et al., 2007).

A study in Kenya reported that barley straw has 7, 0.4 and 25 $g.kg^{-1}$ of N, P and K respectively (Lekasi et al., 2001). Other studies show the N content of plants vary from 2 - 60 $g.kg^{-1}$ of a dried material (Baruah and Barthakur, 1997). The study by Elias (2002) showed leaves of *Croton macrostachyus* and *Erythrina abyssinica* have high content i.e., 40 $g.kg^{-1}$ and 33 $g.kg^{-1}$ nitrogen and 3 $g.kg^{-1}$ and 2 $g.kg^{-1}$ phosphorous respectively.

The quality of compost is a reflection of the nutrient contained in the different biomass used for compost (Nandwa and Bekunda, 1998; Campbell, 2000) and the method or duration of composting (Hadas et al., 1996). Briggs and Twomlow (2002) reviewed that methods of heap/pit affect compost quality. Snapp et al. (1998) reported that storing manure improperly such as urine may result into volatilization of N (Lekasi et al., 2001; Haris, 2002). For example, a three month storage of manure was resulted in 59% nitrogen loss (Kwakye, 1980). Regular turning of compost reduced N content into 12 $g.kg^{-1}$ from the 14 $g.kg^{-1}$ non-turned (Lekasi et al., 2001). Proper shading increased OC content. Feeding animals on concrete floor increased NP and OC content than feeding on soil floor (Lekasi et al., 2001). The best quality dung and manure comes from farmers where considerable care has been taken in collecting and storing dung (Harris, 2002). Sheep fed on cowpea (*Vigna unguiculata*) leave resulted in large amounts of urine N, more prone loss by volatilization of ammonia, unless managed well, (Powell et al., 1994). According to Nzuma and Muwira (2000) use of bedding straw reduced losses of ammonia by up to 80 percent.

2.4.3 Production capacity of compost

The compost production capacity of farmers vary very much. It varies from farmer to farmer mainly dependent on the animal holding (Tulema et al., 2007; Drechsel and Reck, 1998). This is because animal feed waste and animal manure are available best to the farmers who own cattle (Kikafunda et al., 2001). According to Manyong et al. (2001) more livestock holding encourages familes to use organic manure and owning domestic animals is common in Africa. For example, Lekasi et al. (2001) reviewed from their survey conducted in Kiambu, Kenya, that 77-85 percent of the households keep dairy cattle. The availability of biomass in Ethiopia is estimated to 22.7×10^6 $t.yr^{-1}$ of dry-manure, 12.7×10^6 $t.yr^{-1}$ crop-residue and various other organic by-products (Tulema et al., 2007). While the study by Devi et al. (2007) reported that recyclable resources in Ethiopia are abundant. They estimated the total amount available as 1.6×10^{11} $t.yr^{-1}$ (compost/vermicomposting), 8.5×10^9 $t.yr^{-1}$ (poultry manure) and 1.8×10^{10} $t.yr^{-1}$ (FYM). While the required amounts for the total agricultural land per year is 3.25×10^{10} $t.yr^{-1}$ (compost/vermicomposting), 3.2×10^9 $t.yr^{-1}$ (poultry manure) and 9.7×10^7 $t.yr^{-1}$ (FYM) (Devi et al., 2007). This is mainly because Ethiopia is the highest in livestock population in Africa (Zinash, 2001).

Stroebel (1987) reported that one zero-grazed cattle produces 1-1.5 $t.yr^{-1}$ manure (Nandwa and Bekunda, 1998) while another study by Laegreid et al. (1999) reviewed that one cow can give manure 4, 10 and 5.5 $t.yr^{-1}$ as liquid, slurry and stable manure respectively. The study by Harris (1998) reported that manure production at Kano, northern Nigeria, range from 2-15 t over two years. But Howard (1943) has estimated 22-26 $t.yr^{-1}$ of compost from one cow from its crop residues and dung from stable floor mixed with soil. But these estimates are very wide to compare and unclear.

Biomass availability in moisture stress areas is dependent in the biomass management. For example, farmers keep manure accumulated in cattle pen until it is cleaned or used for composting (Miner et al., 2001). Manure management increases not only the quantity but also the quality of the manure (Lekasi et al., 2001). But the production capacity varies based on the animal holding. However, so far the production capacity of compost is not studied at family level.

2.4.4 Effect of compost on soil characteristics

According to Bationo and Mukwunye (1991) addition of organic materials have beneficial effects on the soils' chemical and physical properties. The study by Epstein et al. (1976) reported that in 240 $t.ha^{-1}$ application of sludge and sludge compost that moisture differences between the treatments (control, sludge and sludge compost) were not significant through out the growing season. While the result of the study by Ouedraogo et al. (2001) reported that there was no significant difference as short-term effect in soil organic matter content between the 5 and 10 $t.ha^{-1}$ compost application and no-compost. Again Epstein et al. (1976) reported the organic carbon content of 80 $t.ha^{-1}$ compost application and the unamended soil did not increase. However, 240 $t.ha^{-1}$ sludge compost application increased 2 percent organic carbon (Epstein et al., 1976).

The above shows that effective result is dependent on applying higher amount or long-term compost application. Other evidences such as the study by Nandwa and Bekunda (1998) held in Kabete, Kenya, indicated P levels were maintained or increased only in treatments where mineral fertilizer P inputs were applied. Another study by Smiciklas et al. (2008) reviewed that highest available P and K from 44.8 and 134.4 $t.ha^{-1}$ of compost application achieved better than the control. The effect of compost in CEC is almost similar to NPK that the study by Ouedraogo et al. (2001) reported that a higher amount of compost application has significant difference between 0 and 10 $t.ha^{-1}$ compost application rates but not between the 0 and 5 $t.ha^{-1}$ compost. Garcia et al. (1991) reported that CEC increase in 30-180 $t.ha^{-1}.yr^{-1}$ compost application. Wahba (2007) also reported organic matter and CEC changed after two years at 20 $t.ha^{-1}$ compost application.

Generally higher rates of compost applications significantly raised organic matter levels, and available P and K, and yield (Smiciklas et al., 2008). Garicia et al. (1991) also reported significant changes of soil P, K and CEC in 30-180 $t.ha^{-1}$ compost application in four harvesting seasons. The ten year study conducted in Austria with 9, 16 and 23 $t.ha^{-1}$ compost application revealed that soil organic nitrogen concentration and soil organic carbon were significantly higher than in the untreated control (Harti and Erhart, 2005).

The study by Epstein et al. (1976) reported that nitrogen for all treatments with 40 and 80 $t.ha^{-1}$ rate compost applications decreased with time while the nitrogen for the 240 $t.ha^{-1}$ sludge compost treatment was significantly higher. Legume crops can improve nitrogen better through biological fixation. For example, Kikafunda et al. (2001) reviewed that using nitrogen fixing legumes are possible solution to the nitrogen problem for the resources constrained by smallholder farmers. Studies investigated for N fixation by above ground of faba bean showed to be 10 to 350 kg N ha^{-1} in Australia, 85-181 kg N ha^{-1} in the Europe and 54–133 kg N ha^{-1} in the Middle East (Rochester *et al*., 1998), and 76 to 125 kg N ha^{-1} in Portugal (Carranca et al., 1999).

2.4.5 Effect of compost on yield

Due to the high land-degradation improving agricultural production in the Sub-Saharan Africa is a challenge (Snnap et al., 1998; Stoorvogal et al., 1993; FAO, 1986). The research by Eghball and Power (1999) and Mugwe et al. (2007) showed that lowest yields were in the control fields. Another example is the study by Nandwa and Bekunda (1998) showed that constant declining of yields by over 70% in 17 years i.e., from 3.8 $t.ha^{-1}$ to 0.9 $t.ha^{-1}$ from no-input experiment. It is not only the yield but also the kernel weight and harvest index in control plots are inferior to any type of input application than in the composted plots, especially at the 10 $t.ha^{-1}$ compost rate (Ouedraogo et al., 2001).

On the other hand researches are showing application of inputs are achieving better yields. Garcia et al. (1991) reported that yield increase is proportional to the amount of compost used while Eghball and Power (1999) reviewed that manure or compost can produce corn grain yields equal or greater than the mineral fertilizer when application rate is based on correct N or P availability. The study by Ouedraogo et al. (2001) in Burkina Faso reported an increase of sorghum yield by 45% and 300% from the 5 and 10 $t.ha^{-1}$ compost application respectively over the no-compost plots. The study by Diop

(1999) showed applying compost increased 45% yield of millet in Senegal. These are clear indications that soils need inputs to increase their yield, which is reflected by the low agricultural production of the smallholder farms (Mugwe et al., 2007; Sanchez et al., 1997) and shows that it has reached where farms give low yields if there is no or inadequate input applications (Odhiambo and Magandini, 2008).

2.5 **Compost in sustaining yield and socio-economy of the smallholder farmers**

Nowadays sustaining agricultural production has become a central issue through agricultural management. But overcoming the complex problem of smallholder farming system is impossible under single recommendation (Jama and Pizzaro, 2008; Stoorvogel et al., 1993). Therefore, the concern centers on the need to develop technologies and practices that are affordable, socio-economically reliable and effective to improve their food production under their own choices (Pretty, 2008; Saleem, 1998; Smaling et al., 1993).

Many researchers reviewed lots of reasons that farmers are frustrated in using mineral fertilizer such as subsidy removal (Snapp et al., 1998), the ever increasing price of mineral fertilizer became beyond the purchasing power of farmers (SSNC, 2008; Mugwe et al., 2007; Araya and Edwards, 2006; Müller-Sämann and Kotschi, 2004; Elias, 2002; Nandwa and Bekunda, 1998). Increase cost of production leads to a lower agricultural return by reducing family income (Sanchez et al., 1997). About 75% of the contacted farmers in South Africa could not afford the required quantities of fertilizers (Odhiambo and Magandini, 2008).

Therefore, farmers are inclined into locally available resources and technologies such as compost, animal manure, SWC and planting multipurpose trees than using mineral fertilizer. For example, compost does not need money but labour, which is locally available in each farming family. It is easily understood technology (Tegene, 1998). The labour requirement is mainly for digging compost pits (Briggs and Twomlow, 2002), which serve for many years once constructed. But for many farmers labor is not major obstacle because labour shortage can also be minimized by group work (Diop, 1999), and the labor need for turning over of compost can be minimized if the compost is well started (Diop, 1999). The other sustaining advantage in northern Ethiopia crops planted with mineral fertilizer fail when rain quite early (Araya and Edwards, 2006; SSNC, 2008). This is because soils are shallow and crops are succeptible to the moisture problem (Tegene, 1998).

Ouedraogo et al. (2001) reviewed that many farmers understand the role of compost in improving soil quality and sustaining yield. The study by Zvomuya et al. (2006) reported the cumulative biomass yield of composted fields were significantly higher than control, non-composted manure and mineral fertilizer yields. The study held in Kabete, Kenya, also showed that treatments with only mineral fertilizers initially out-yielded the no-input and FYM treatments but later tend to decline rapidly (Nandwa and Bekunda, 1998). Another similar result was reported by Bhandari et al. (2002) that lack of sustainability under high input agriculture that rice yield has stagnated and declined during the Asian Green Revolution. Moreover, another result of this research revealed that wheat suplemented with FYM show high and stable yield unlike the inorganic NPK treatments, which showed significant yield decline over 14 years.

Generally, the frustration of the smallholder farmers is to escape possible crisis when the prices of their farm products are too low or lost in the unpredictable rainfall situation (Tegene, 1998; Knowler, 2004; Araya and Edwards, 2006; World Bank, 2007; Chianu et al., 2008; Carr, 2001). This is because input costs continue to rise while the return from agricultural products fall (Ong'wen and Wright, 2007). For example, Gruhn et al. (2000) reported the domestic prices of mineral fertilizer in Africa are such that one kg of nitrogenous fertilizer can cost between 6 and 11 kgs of grain. That is why some times farmers complain that using mineral fertilzer is a waste of money (Harris, 1998). While the study conducted by Devi et al. (2007) in 2005-2006 in Ethiopia showed that the cost of organic farming was 40.6% less than that for inorganic farming.

Farmers are looking for socio-economic independency at local level, which is better income without being trapperd into debt problem (Somda et al., 2002; Kikafunda et al., 2001). Therefore, it is an indication of social sustainability and community empowerment with diverse and resilient communities with in which local population can access services and meet their needs at their own decision (Ong'wen and Wright, 2007). These all integrated activities sustain not only the soil and agricultural yield for families but also save the scarce foreign exchange of countries by reducing the mineral fertilizer importation (Bationo and Mukwunye, 1991).

3. STUDY AREA DESCRIPTION AND METHODOLOGY

3.1 Study area description

3.1.1 Study area selection

Tahtai Maichew District is one of the districts in the Tigray region, where rainfall is erratic and unreliable in most years. It is selected based on the following criteria:

1. the sustainable agriculture program (of using compost) of the Institute for Sustainable Development is expanding at district level. And
2. the researcher frequently visits and has good relation with the community, local administration and experts.

Table 3.1 - Study area selection criteria

R.N.	Item	Site selection preference							
		K	**MZ**	**AN**	**EZ**	**MS**	**AS**	**HA**	**MA**
1	Acceptance of the sustainable development program	Y	Y	Y	Y	Y	Y	Y	Y
2	Plots without being applying compost	Y	Y	Y	Y	Y	Y	Y	Y
3	Know-how about compost	Y	Y	Y	Y	Y	Y	N	Y
4	Volunteer to prepare compost	Y	N	Y	N	Y	N	N	N
5	Volunteer to apply compost	Y	Y	Y	Y	Y	Y	Y	Y
6	Accessibility from the main road	Y	Y	Y	Y	Y	Y	N	N
7	Volunteer farmers to offer their land for 3 years	Y	N	Y	N	Y	N	N	N
8	Good communication with local administration and experts	Y	Y	Y	Y	Y	Y	Y	Y
9	Area under rainfed cereal crops	Y	Y	Y	Y	Y	N	Y	N
	Score for YES	**9**	7	**9**	7	**9**	6	5	5

Key: Y – yes, N – no, AN - Adi Nefas, AS - Akab Se'at, EZ - Etan Zere, HA - Hadush Adi, K - Kewanit, MA - Mai Atsmi, MS - Mai Siye, MZ - Mai Zagra. Therefore, the sites shown with bolded number 9 were accepted for the study.

Selection of farmers and sites were also undertaken based on

- assessing communities where compost have not been applied in their fields before 2005 i.e., until soil samples were taken.
- identifying smallholder farmers, who started preparing compost. And
- searching volunteer farmers, who can offer part of their land for trial for three years and be used based on the design and plan of the researcher.

Based on the above criteria, six farmers, in three sites with best scores were selected for the experimentation (Table 3.1).

3.1.2 Geographical location

Ethiopia is a landlocked country found in the horn of Africa. It is bordered by Eritrea in the North, Sudan in the West, Kenya in the South, Somalia in Southeast and East, and Djibouti in the East. It is located within the tropics between 3°24` and 14°57` N; and 32°42` and 48°12` E (Hagos *et al*., 2002; Fig. 3.1). The total area of the country is 1.13 million km^2 (EPA, 2003). It is divided into nine regional states, one City Council and one City Administration.

Tigray region is one of the Administrative regions of the country. It is found in the most northern part of the Northern Highlands of Ethiopia, stretching from 12^{0}15'to 14^{0}57'N and 36^{0}27' to 39^{0}59'E (Aseffa, 2005). The region is bordered in the north by Eritrea, in the west by Sudan, in the south by Amhara Regional state, and in the east by Afar Regional state (Figure 3.1).

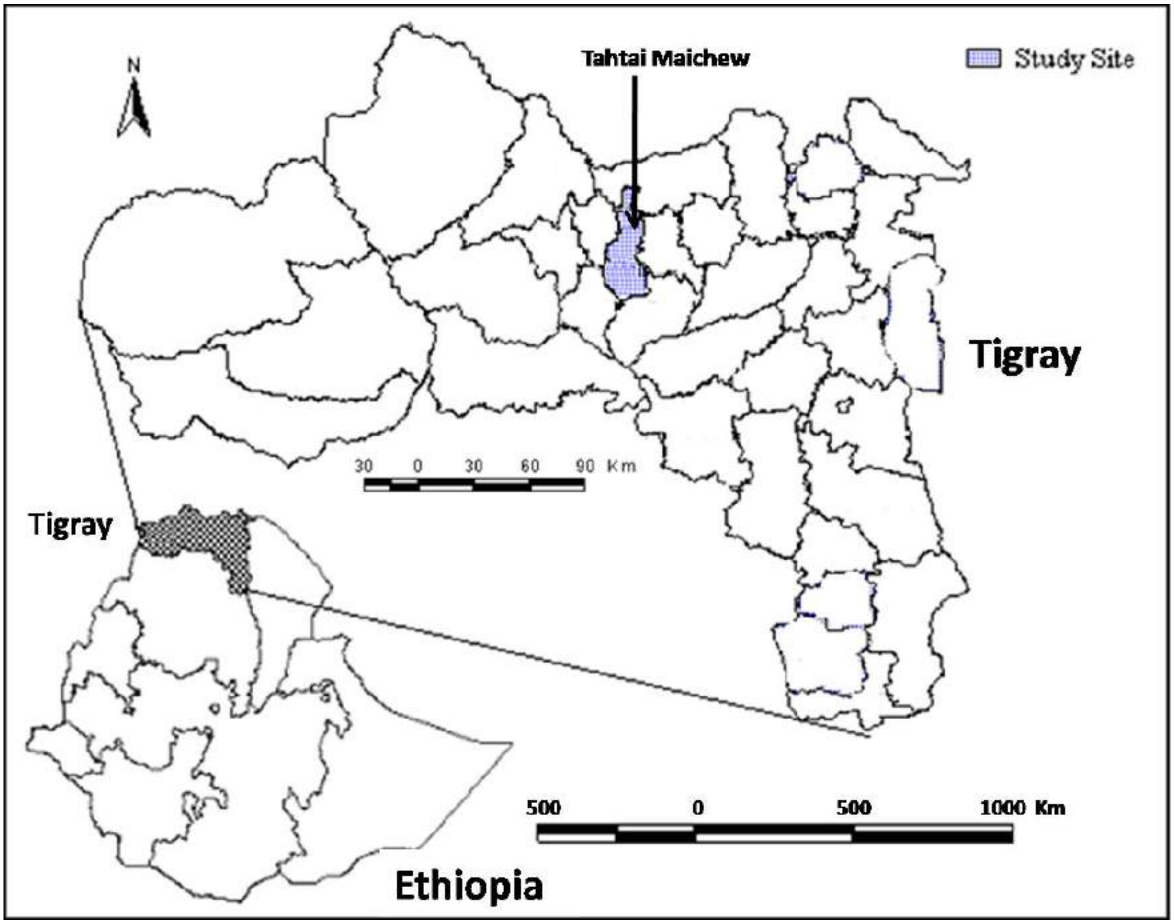

Fig. 3.1 Location map of the study area

The study was conducted in three small villages called Kewanit, Mai siye and Adi Nefas. They are located with in the Tahtai Maichew District (*Wereda*). The district capital town is called Wuqro Marai. It is found in the central zone of Tigray Region. All the villages and the capital town of the district are found within 8-26 Km range from Axum town. As part of the northern highlands of Ethiopia, the study sites are found in the Nile Basin. The watersheds of the Kewanit and Adi Nefas are in the Tekezze river while the Mai Siye to the Mereb river.

3.1.3 Relief

As part of the Northern highlands, the relief of Tigray is rugged and dissected by valleys and gullies (Hunting, 1976). The altitude ranges from <500 m above sea level (asl) in the eastern lowlands, to about 4,000 m in the southern highlands (Aseffa, 2005; Figure 3.3). Tahtai Maichew District is found in the altitude of 1500-2500 m asl as Weina Dogua (Mid-altitude) climatic region. While the study area sites (Adi Nefas, Kewanit and Mai Siye) are found within the altitude of 2049–2229 m asl at footsteps of the nearby hills. This marked variation in altitude results in a distinct variation in spatial distribution of the temperature and the rainfall. In addition, the non plain topographic landscape and agro-climatic diversity poses huge development challenges in the country (World Bank, 2007).

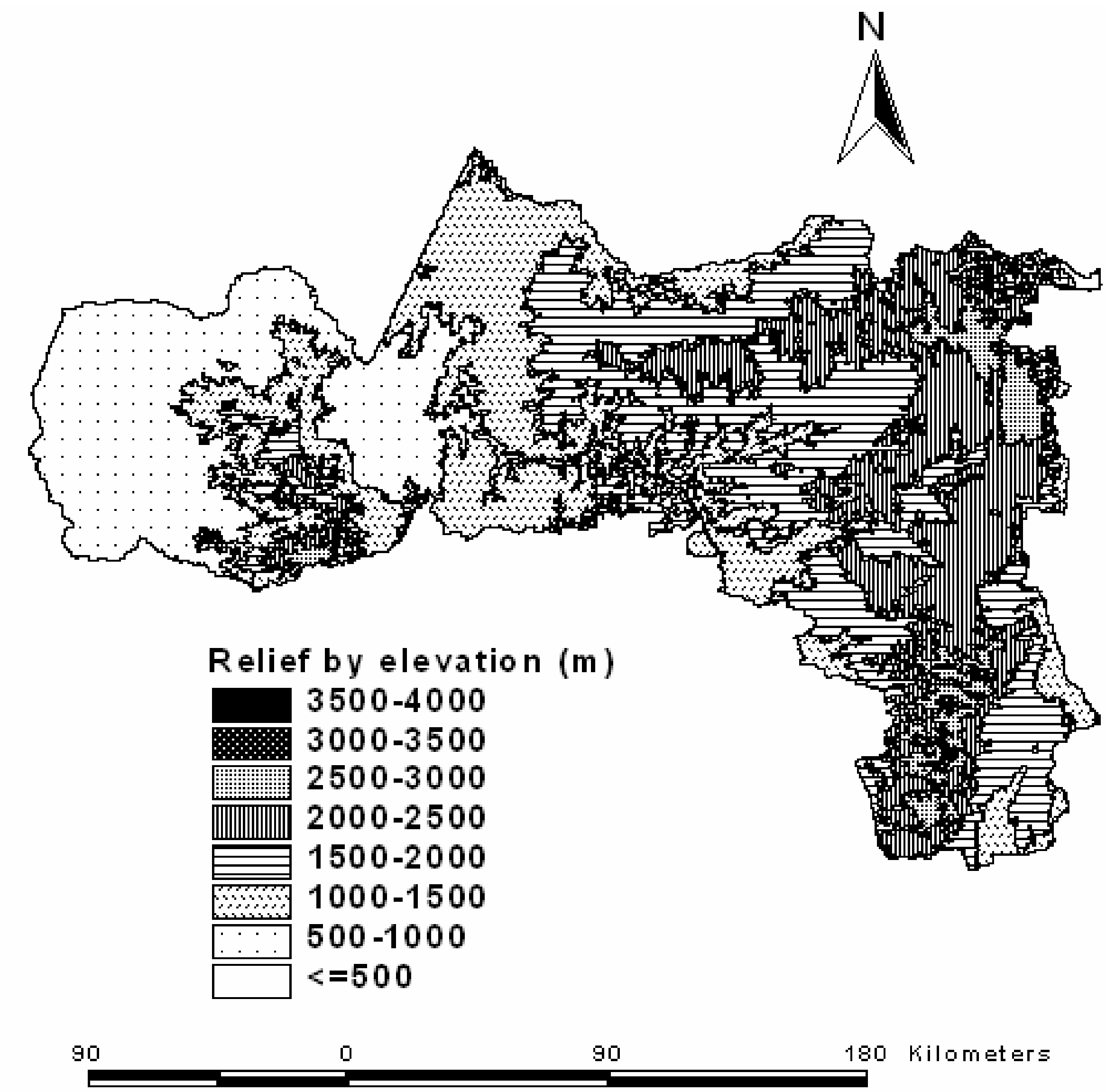

Figure 3.2 - Relief of Tigray by elevation (m above sea level) (WBISPPO, 2002)

3.1.4 Rainfall

Average annual rainfall of the Tigray Region varies from 200 mm in the eastern lowlands to over 1800 mm in the western highlands (Aseffa, 2005). Rainfall is erratic and variable. The central Tigray plateau comprises of semi-arid highlands with mean annual rainfall of about 500 to 700 mm (Tegene, 1996). In most parts of Tigray Region 46-73 percent of the rainfall is confined into only July and August months (Tegene, 1996; TBPED, 1998).

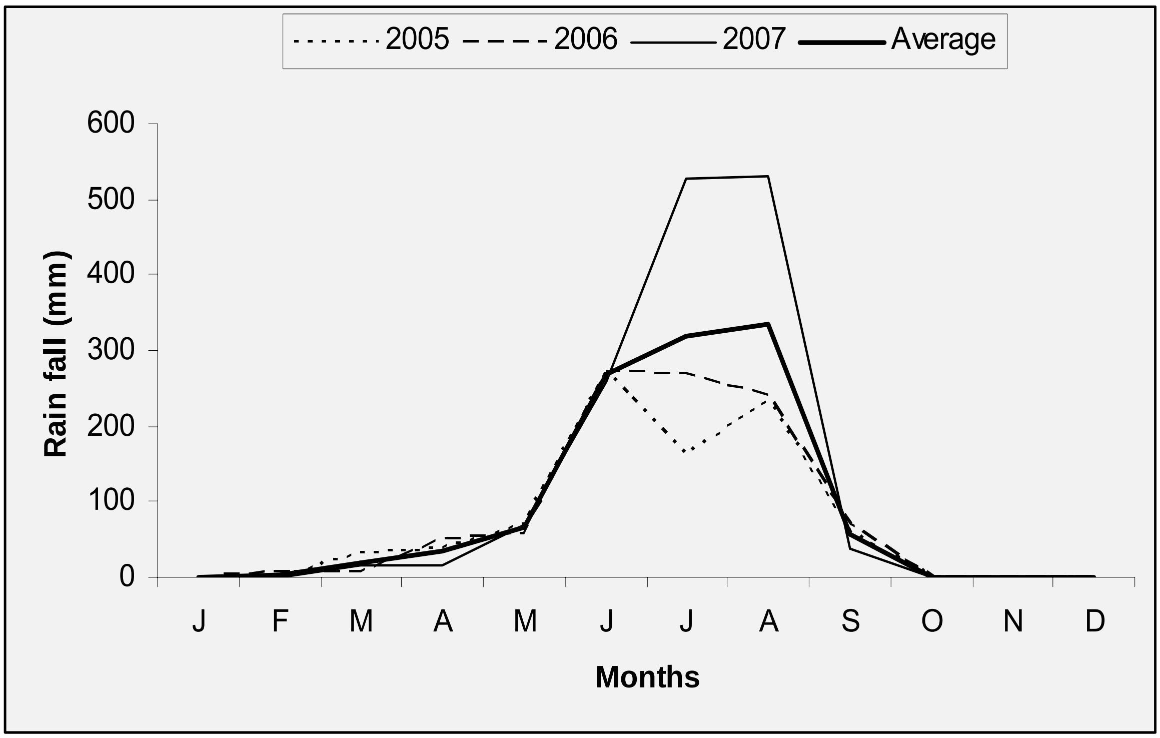

Figure 3.3. Rainfall in Wuqro Marai town between 2005 and 2007
Source: Tahtai Maichew District Agriculture and Rural Development office

The annual rainfall amount greatly varies from 864 to 1459 mm recorded in Wuqro Marai, the district capital town of Tahtai Maichew District. Even though the rainfall is high its distribution is concentrated into three summer months (June to August). These three months account for 77-90 percent of the annual rainfall (Figure 3.3; Annex 2). Nyssen et al. (2008) reported their evidence in Hagere Selam (2650 m) part of Tigray rainfall seems sufficient for agriculture from March (Figure 4) but it is uncertain till June (Figure 3.4). For the Hagere Selam uplands, the average growing period for agricultural production (LGP) is 162 days (Goebel and Odenyo, 1984). The delay in the on-set of the rainfall is one problem for crop maturity in the study area.

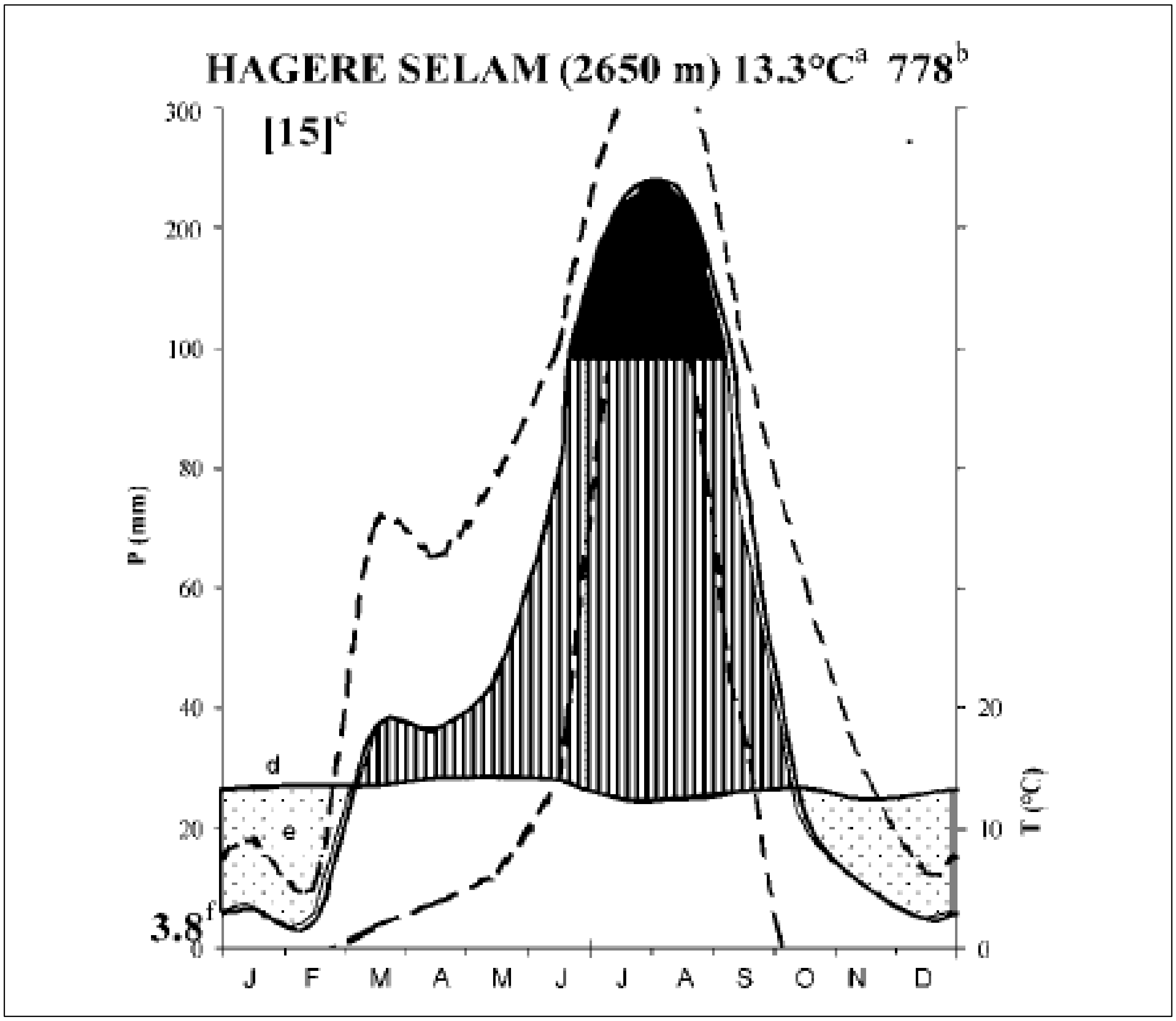

Figure 3.4 - Ombrothermic diagram for Hagere Selam (Tigray).
"Monthly precipitation (P) is indicated with ±1σ. The lower dashed line stands for 84 per cent probability of exceedance of average monthly rain. Note change in y-axis scale above 100 mm; a: mean temperature; b: mean yearly rain; c: number of rain observation years; d: mean monthly temperature; e: month where P<2T; f: lowest monthly minimum temperature. Precipitation and temperature data from National Meteorological Services Agency (1973–1982 and 1996–2000)." Source: Nyssen et al. (2008).

3.1.5 Soils

So far, no systematic soil survey has been carried out for the whole of Tigray region. However, on the basis of the world soil resources reference, the soil distribution of Tigray has been mapped (WBISPPO, 2002; Section 4.1). Two extensive surveys have been conducted in the central highlands of Tigray by Mitiku (1997) and Hunting (1975) and the major soils identified in these surveys include Cambisols, Luvisols, Rendzinas, Lithosols (Leptosols), Fluvisols, Nitosols, Arenosols, Vertisols, Xerosols and Andosols.

3.1.6 Farming systems and land-use-land cover situation

Mixed farming that combines crops and livestock characterizes the country and the region in general and the study area in particular. The landscape in Tahtai Maichew district is mostly occupied by mountains and cliffs (37.87%) followed by cultivated field, which covers 32.4% of the district area. Forests are disappearing, except for small patches covered with bushy stands especially in church yards and protected areas. The woodland areas together account about 12 percent of the district. The district has very small (only 0.60 percent) potentially cultivable land but not cultivated (Table 3.2).

Table 3.2 - Land cover/land use types of the study wereda

Land cover/ land use	**Total area (ha)**	**Area (%)**
Cultivated land	18 618	32.40
Cultivable but not cultivated	343	0.60
Protected natural vegetaion	4 095	7.13
Rehabilitated land	2 994	5.21
Bad (useless) land	2 974	5.17
Sandy land	5 069	8.82
Mountain and cliffs	21 766	37.87
Village/settlement	1 609	2.80
Total area	**57 469**	**100.00**

Source: Tahtai Maichew District Agriculture and Rural Development Office, 2007

Most of the cultivated fields are dissected by gullies. Cultivated fields are uncovered because farmers collect all types of biomass for human and animal food and feeding respectively. The remnant biomasses are roamed by cattle due to the free-range grazing practices in the country in general. However, recently introduced physical and biological soil and water conservation practices are changing the face of the cultivated and uncultivated areas.

3.1.6.1 Farm size holding

The overall average cultivated land holding in the study area is 0.8 ha/ family. About 38 percent of the respondents own half hectare and 28 percent 0.75 hectare. 10 percent of the respondent farmers own one hectare and another 10 percent own greater than one hectare. While another 14 percent own only 0.25 hectare per family (Table 3.3). The variation in the size of the land holding depends on the fertility level of the soil or access to irrigation. Farmers who receive fertile land and access to irrogable water own smaller land size than the farmers receive infertile and which does not get access to irrigation.

Table 3.3 - Land holding size (*Tsimdi*=1/4 ha) and fragmentation. Data collected from the district through questionnaire in Tahtai Maichew district in October 2006.

Farm size	Number of pieces					**Total**
	1	2	3	4	≥5	**# (%)**
<1 *Tsimdi*	-	-	-	-	-	**0 (0)**
1 *Tsimdi*	7	6	2	1	0	**16 (14)**
2 *Tsimdi*	11	21	10	0	1	**43 (38)**
3 *Tsimdi*	2	20	2	7	1	**32 (28)**
4 *Tsimdi*	0	7	2	1	2	**12 (10)**
>4 *Tsimdi*	0	1	5	3	2	**11 (10)**
Total	**20 (17.5)**	**55 (48)**	**21 (18)**	**12 (10.5)**	**6 (5.0)**	**114 (100)**

Source: Field survey assessment, 2006

Most of their land holdings are in more than one pieces. About 48 percent of the respondent farmers own farms allocated on two pieces of separate locations. Another 18 percent of the farmers have their farm in three pieces and only 17.5 percent farmers have their land in one plot but their farms are less than or equal to half a hectare (Table 3.3).

3.1.6.2 Traditional soil fertility management

Many farmers use different types of soil fertility management practices to improve their soil and increase crop yields. But today fallowing and shifting cutivation are not practiced in the smallholder farmers of the study area. According to the responses of the farmers, over 92 percent do not consider fallowing in their farming practices (table

4.33). Instead intensive-cropping is practiced because of the high demand for land. Hence. most farmers use crop rotation instead of fallowing (Table 3.4).

Table 3.4 - The trend of the different traditional soil fertility management practices used by smallholder farmers

R.N	Local practices	Past	Present	Remark
1	Fallow	High	Less	It is practiced throughout the country but it is almost not used except in lowlands.
2	Crop rotation	High	High	Still strong used though out the country.
3	Animal manure	High	High	Still strong used though out the country.
4	Damping ash and household waste	Med ium	High	In cities, towns and rural homesteads.
5	Burning soil (*GAY* local name)	High	Low	Still used and give good production for 2-3 years. But the soil needs rest minimum for 5 year.
6	Burning crop residues	High	High	In many lowland areas of the country especially farms with termite occurrences.
7	*KRIT- GEDEBA*	High	High	It is a physical construction such as terraces to protect from soil erosion. It is practices through out the country.
8	Diverting fresh flooding and silt into fields.	High	High	Still strong in Wello, Afar and Tigrai. It is mainly used when rain start late and stops early, which is in May and September respectively. Also practiced when the main rain seems insufficient for crops.
9	Shifting pen - domestic animals stay 3-7 days in a farm.	High	High	Still strongly used in the lowlands especially Wer'e and Sheraro areas in Tigrai.
10	*Bisbash* (compost)	-	Increasing	Increasing throughout the country.
11	Shifting cultivation	High	Low	Almost not practicing except in some parts of Southwest Ethiopia.
12	*Zniq*/ *Wahrar* - inter-cropping	Less	Increasing	Now spreading throughout the country.
13	Leaving crop residues in cultivated field	Low	Increasing	New introduction by ISD project in many parts of the country.
14	Importing fertile soil from somewhere	Less	Less	By innovator farmers.
15	Growing multipurpose trees	Low	Increasing	New introduction by ISD within and around farm boundaries but spreading throughout the country.
16	Making threshing fields with in farm plots	High	Still higher	Throughout the highland of the country.
17	Making drainage	Less	Increasing	It is practices in Vertisol and water logged areas of the country.
18	Chemical fertilizer	Less	Increasing	Throughout the country.

Crop rotation and animal manure amendment are commonly used by many farmers. Farmers prefer old animal manure (more than one summer aged) for application. This is justified by easy nutrient release for crops and less weed seed holding potential. Farmers use different types of manure including the most valuable manure used in an infertile land is from chicken. But it is very difficult to collect sufficient amount because the number of chicken in a family is few and usually there is no proper living space prepared in the rural family. The next and highly used in infertile lands is manure from goats. Farmers do not recommend using chicken manure in flooded fields because they can be easily washed away by flooding through water.

The physical and biological soil and water conservation practice known as *KRIT-GEDEBA* is also practiced. It is practiced by making terraces with stones including plant residues such as maize, sorghum, tree branches, aloe vera, grass, etc. It is practiced through out the hilly parts of the country. But now due to the serious land degradation it is spreading all over the country.

There is a controversy in the definition of compost (*BISBASH*) for many farmers. Even though they do not use the name compost for many farmers it is not different from the old animal manure mixed with some other organic waste.

At early times intercropping was not well used except mixing oil crops with teff. But now it is spreading in to many cereal crops such as oil crops with teff, finger millet, etc. Another is mixing finger millet with sorghum. Recently tomato with many crops (faba bean, finger millet, maize, etc.) is being practiced. But intercropping is highly used in fruits and vegetables.

3.1.6.3 Cropping pattern

The main crops grown in the study area include barley (*Hordeum vulgare*), wheat (*Triticum spp.*), tef (*Eragrostis tef*), sorghum (*Sorghum bicolor*), finger millet (*Eleusine coracana*), maize (*Zea mays*), horse beans (*Vicia faba*), field peas (*Pisum sativum*), chickpeas (*Cicer arietinum*) and lentils (*Lens culinaris*). In the farming practices of Ethiopia legume crops are often grown in rotation (TBPED, 1998).

In Tahtai Maichew district the following seven main crops are in production: teff, maize, wheat, finger millet, faba bean, sorghum and barley. They cover for over 99 percent of the cultivated land and 87 percent of the total production in the three years experiment period (2005-2007). The other crops occupy only 0.60 percent of the cultivated land

and 12.78 percent of the total production (Table 3.5). Due to the heavy rain in 2007 summer, faba bean, teff and wheat fields were affected by logging mainly in clayey soils. Therefore, most of these crops are shifted in to chick pea. It can be seen this crop is very much higher in 2007 than the other years. This is because chick pea is a crop sown at the end of the summer i.e. September.

Table 3.5 - Total agricultural production (pdn - $t.yr^{-1}$) and total cultivated land (ha^{-1}) in Tahtai Maichew Wereda 2005 - 2007

R.N	Crop type	2005		2006		2007	
		land	pdn	land	pdn	land	pdn
1	Maize	2 859	1 598	4 017	8 733	2 548	4 986
2	Sorghum	1 304	2 301	1 987	3 268	849	175
3	Finger Millet	1 779	3 039	2 423	3 877	2 299	4 195
4	Sorghum	253	304	271	328	639	1 339
5	Tef	7 771	9 110	4 441	5 462	4 166	6 032
6	Wheat	1 333	2 063	978	1 499	5 978	2 893
7	Barley	958	2 038	956	1 405	1 173	1 944
8	Faba bean	1 285	1 786	2 152	2 841	2 743	3 692
9	Field pea	131	164	225	288	778	1 282
10	Flux	40	16	60	31	91	45
11	Noug	20	8	75	53	169	85
12	Lentil	30	15	5	3	71	50
13	Cowpea	55	28	30	178	98	79
14	Fenugreek	-	-	8	4	11	6
15	Chick pea	135	81	120	84	325	260
16	Grass pea	165	99	372	223	242	218

Source: Tahtai Maichew District Agriculture and Rural Development Office

Through out the three years experiment period, teff occupied the largest farm land and obtained the highest production. This is because it is the best staple food, which is highly used in every socio-cultural celebrations and daily food. By 2005, 2006 and 2007 it occupied about 43, 24.5 and 23 percent of the cultivated land, and 34, 19 and 21 percent of the production respectively (Table 3.5).

3.2 Experimental approach

3.2.1 Assessing compost application rate

There were three types of compost prepared in Tigray in general and in the Tahtai Maichew district in particular. These are: 1. Farm residue compost, 2. Weed (*Parthenium hysterophorus*) compost, and 3. Urban waste compost. Compost application rate of farmers were assessed first. Land holding of farmers were identified based on local practices. Land is measured by *KERT* or *TSIMDI*, which is quarter of a hectare. It is equivalent with one labor day of a pair of oxen. Farmers apply different amounts of compost per unit area depending on the type of soil and crop intended to cultivate. The compost was identified by measuring the size of the compost pits and then the compost was weighed after sieving. All farmers used one pit of compost for ¼ hectare of land. Therefore, the average application of compost by farmers' standard in the Tahtai Maichew District for the soil was assessed to be 3.2 $t.ha^{-1}$ i.e., 3,200 $kg.ha^{-1}$ yr^{-1}. Hence, this is considered as farmers' standard in Tahtai Maichew District in the present research work.

3.2.2 Experimental design and field layout

The experimental plot design used is based on randomized complete block design (RCBD), which is distinguished by the presence of homogeneous blocks of equal size and each of which contains all the treatments (Jayaraman, 2000). There were six farmers' fields as blocks in three locations: Kewanit, Adinifas and Mai Siye *Tabias* (county) respectively indicated as L1K, L2A and L3MS of Tahtai Maichew District (Table 3.6). They are used as replications with four treatments as 4 subplots in each site i.e. two fields in each location. The six fields are at the following altitudes: L1K1 (2049m), L1K2 (2051m), L2A1 (2165m), L2A2 (2229m), L3MS1 (2081m) and L3MS2 (2085m).

Figure 3.5 - Lay-out of the experimental block design

L1K1 37P0463166 UTM 1559214			**L2A1** 37P0452154 UTM 1560525			**L3MS1** 37P0456305 UTM 1563845	
C	MF		C	MF		C	6.4 t ha^{-1}
3.2 t ha^{-1}	6.4 t ha^{-1}	**^ N**	3.2 t ha^{-1}	6.4 t ha^{-1}		3.2 t ha^{-1}	MF
L1K2 37P0463127 UTM 1559188			**L2A2** 37P0451170 UTM 1561297			**L3MS2** 37P0456332 UTM 1563714	
3.2 t ha^{-1}	6.4 t ha^{-1}		MF	C		MF	6.4 t ha^{-1}
C	MF		6.4 t ha^{-1}	3.2 t ha^{-1}		C	3.2 t ha^{-1}

Key: **L1K1** - Kewanit - Gebreyesus *Walka*; **L1K2** - Kewanit Gebreyesus *Ba'ekel*; **L2A1** - Adinefas Abadi; **L2A2** - Adinifas Tsige; **L3MS1** - Mai Siye Embaye, and **L3MS2** - Mai Siye Nursery

One block in each site consists of four subplots i.e. treatments with the same size and alignment on the slope less than 2 percent in all locations. The size of a single subplot in the block was 2mx2m with 0.5m boundary between the plots. They were separated from each other from displacement of seeds and inputs carried away by run-off that mix each other. To see the natural tolerance of the crops, weed and pests were controlled by hand with out using chemical inputs.

The four treatments under the study were:

1. control/check plots were without any type of input.
2. national recommended rate of mineral fertilizer (100 kg DAP and 50 kg Urea) per year ha (Elias, 2002) i.e. 40g of DAP & 20g of Urea were applied for each 4m^2 size plot.
3. compost with farmers' standard. It is 3.2 t.ha^{-1}.yr^{-1} i.e., 1.28 kg of compost was applied as broadcast form in each sub-plot with an area of 4m^2 (i.e., 3,200

kgx4m^2)/10,000m^2) during seeds sowing and incorporated with in the plough layer soil.

4. compost with double to the farmers' standard amount (6.4 t.ha^{-1}.yr^{-1}) compost. The amount of compost was 2.56 kg (i.e., 6,400 kgx4m^2)/10,000m^2) per 4m^2 area plot. It was applied in a broadcast form during seeds sowing and incorporated with in the plough layer.

In order to see the mulching effect, crop residues were left in the experimental plots until the next planting season, all plots were kept closed from roaming by cattle. This would help the soil's natural fertility renewal process against the removal of the crop residues practiced in the highlands of Ethiopia.

3.2.3 Cropping system

All traditional farmers' practices such as crop rotation were considered. The three crops were sown following the farmers' traditional practice i.e., crop rotation: *Eragrostis tef, Hordeum vulgare,* and *Vicia faba* were planted consecutively following their sequence in the first (2005), second (2006) and third (2007) years of trial period. But the treatments were kept permanent over the three years (Table 3.6).

Table 3.6 - Sowing and harvesting dates of the crops for the different tillage systems

Year	**Treatment**	**Crop type**	**Sowing date**	**Harvesting date**
2005	Control	Teff	22 July	19 November
	MF (DAP and Urea)			
	3.2 t.ha^{-1}.yr^{-1} compost			
	6.4 t.ha^{-1}.yr^{-1} compost			
2006	Control	Barley	24 June	22 October
	MF (DAP and Urea)			
	3.2 t.ha^{-1}.yr^{-1} compost			
	6.4 t.ha^{-1}.yr^{-1} compost			
2007	Control	Faba bean	20 June	26 October
	MF (DAP and Urea)			
	3.2 t.ha^{-1}.yr^{-1} compost			
	6.4 t.ha^{-1}.yr^{-1} compost			

The planting dates varied depending on the crop type and the onset of the rain. Sowing dates were always with in the traditional farmers' time, and it is mainly between the end of June and July, and the harvest time between October and November (Table 3.6). Early maturing local varieties of seeds were sown based on the seeding rate of majority of farmers. Seeding rate varies very much depending on the soil types, the crop variety and the rain intensity. Depending on the farmers' situation analysis, seeding density of the different crops were decided based on the medium fertility soil type (*Ba'ekel* soil is taken as medium fertility soil) of the study sites. The seeding densities are measured by *TANIKA* (cups) per *TSIMDI* (quarter of a hectare). Therefore, an average of the famers practice in relation to the seeding density of the government recommendation given through the extension service was used for the experimentation.

- Teff *(Eragrostis tef)* - the seeding density for teff was 50 kg.ha^{-1}.
- Barley (*Hordeum vulgare*) - the seeding density for barley was 180 kg.ha^{-1}.
- Faba bean (*Vicia faba*) - the seeding density for faba bean was 200 kg.ha^{-1}.

Therefore, the amounts of seeds used were of 20 g, 72 g and 80 g per 4 m^2 area subplot, for teff, barley and faba bean respectively. Application was done by broadcasting method in all experimental plots.

3.2.4 Compost preparation

There were three types of compost identified that farmers used to prepar in the study area. They are: **1.** farm residue compost; **2.** weed mainly *parthenium* compost, and **3.** urban (irrigation) waste compost. But over ¾ of the farmers use the farm residue compost. This is because of its accessibility. Therefore, compost was prepared from farm residue in farmers' house-yards. But it was done after selecting target farmers for experiment and experts and providing sufficient training in compost preparation.

The compost preparations were:

3.2.4.1 Farm residue compost

All the farm residue (**FR**) composting materials, such as dry and green materials, water, urine and animal manure were collected before the pit filling day. The lengthy farm residues and green materials were chopped into pieces before putting into the pits. To make it easily understood by farmers, the available dry and green materials were mixed at a rate of 3:1. Farm residues are mainly straw, grass and stalk of field crops as left-over from animal trough. Green materials that refers to grass, weed, leaves or tree branches mainly from dominant plants easily available in their surroundings. Animal manure are mainly cattle, goat/sheep, chicken droppings, equines etc (fresh and old dung). The household litters (including food items, vegetable wastes and ash) are also used as both and dry based on their moisture holding.

For the quick start of microbial activity, all sides of the walls of the pit was painted with semi-liquid mixture of dung, water and human and animal urine. About 15 cm height layer of the mixed dry and green materials were put first and a mixture of diffeent animal manure with about 5 cm height was added. Then good amounts of water was sprinkeled to wetten the dry matter. Again dung slurry was spread. Lastly some fertile soil was added over the whole layer. This process has repeated four times to fill a 1mx1.5mx1.5m pit. Lastly the heap was covered by a mixture of soil and dung and wide leaves were added in order to protect from sun and wind.

It was kept under semi-aerobic condition. After one month it was turn-over and the moisture was again maintained. It was turn-over for the second time. At the end of the third month it was ready for use. It has to stay in the pit until June/July, sowing season for all crops.

3.2.4.2 *Parthenium* compost

The *Parthenium hysterophorus* weed (**P**) compost preparation was in a Farmers' Training Center of Selam Bikalsi Tabia of the Alamata District in Southern Tigray, which is one of the parishes highly infested by *Parthenium hysterophorus* weed. This is because most farmers use this weed as composting material.

Four pits with a 1.5mx1.5mx1.0m size were prepared for compost making. Even though Parthenium *hysterophorus* was the main component other types of biomass were used in different pits. These were as follows.

1. 100% of the biomass used was green *Parthenium* - all the biomass was chopped into pieces before putting into the pit. Then the pit was filled step by step by

sprinkling enough water. But this was without animal manure and dung being added.

2. **P1** - About 75% of the biomass was at 1:1 ratio of the green and dry *Parthenium* mixed. The plants were cut into pieces before putting into the compost pit. The rest 25% was biomass like plant materials, animal manure, fresh and old animal dung, urine and water. The pit was filled step by step by adding enough water.
3. **P2** - 100% of the biomass used was dry *Parthenium* weed. The plants were cut into pieces before putting into the compost pit. Without animal manure, dung and other composting materials being added. The pit was filled by adding enough water.
4. **P3** - About 50% dry *Parthenium* and the rest 50% green *Parthenium* weed. The plants were cut into pieces before putting into the compost pit. There was no other composting material added except water, which was added during the compost filling.

Due to the water shortage in the area the composts were not turned over.

3.2.4.3 Urban waste compost

The urban waste compost (**UW**) comprised about 70 percent fruit, vegetable and food waste from residential houses. About 15 percent were house litter like grass, papers, ash, etc. The rest 15 percent includes water, animal dung (fresh and old), old compost and fertile soil.

3.3 Sampling and collection of data

3.3.1 Socio-economic data collection

Socioeconomic data was collected from smallholder farmers using field observation, interview, discussion and structured questionnaires comprising of both closed and open ended questions. The questionnaire and focused interview were undergone to generate specific information on farmers' knowledge of soils, local soil classification practices, land-holding size, soil fertility decline and management practices, compost preparation techniques, availability of biomass, compost application rate, input utilization, prices of biomass and grain, etc including narrative interviews on farmers' experience with composting and with gathering biomass.

Reports and recorded data such as population size, land use and land cover data, rainfall data, production and input utilization data were obtained from the district officials.

3.3.2 Composting material identification and sampling

The composting materials used for compost making are identified through interviewing and group discussion with farmers. Since it was too much to list all types of plants under use, they were ranked according to the amount of biomass used for compost making. Then samples of the frequently used composting materials were collected in the study area and taken for laboratory analysis. Green materials were collected during the rainy season, dry materials during the dry season while animal manure were taken from cattle pen in the mornings. The above ground biomass samples of the top 26 frequently used plant types were collected. Five straw samples from farm residues; eight fresh plant samples from the dominant weeds; seven leave and tree branch samples from different plants taken fresh and six samples from animal manure were sampled for laboratory analysis.

To see the nutrient uptake difference and nutrient balance, other samples were also collected from the treatments as grain of barley and grain and straw of faba bean. Plant samples were collected in paper bags (Anderson and Ingram, 1993).

Then the plant, straw and grain samples collected were taken for a laboratory analysis of their NPK to the soil and plant analysis laboratory of the Tigray Agricultural Research Institute (TARI) of Tigray Region, Northern Ethiopia, in Mekelle town.

3.3.3 Amount of compost prepared and applied

The amount of compost prepared and used by farmers is identified by measuring the pit sizes. The weight of compost was also measured by local measurement called *SHEKHMI or QUMTA* (a sack is equivalent with 50 kg) and weighing to know the amount of compost prepared from six pits. QUMTA is easier for a farmer. Mostly farmers prepare a compost of one or two pits with a size of 1mx1.5mx1.5m. The total amount of compost from one pit is 16-18 Qumta or 800kg of compost. Therefore, it is identified that the application rate of compost at local level to be as one pit for one *TSIMDI/KERT*, which is equivalent to ¼ of a hectare, which is equivalent to application of 3,200kg (800kgx4) of compost.

3.3.4 Soil profile identification

To understand the general background of the soils of the study area six profiles were opened up to a depth greater than 150 cm. Two profiles in each site adjacent to the experimental plots. The sampling locations have been geo-referenced using Global Positioning Systems (GPS) (Table 3.5). Following the soil profiles description, samples were taken from each layer. The Soil Survey Handbook (Hodgson, 1974) was used as a guidance in the description of the soil profiles at the field level. Samples were taken from each horizon of the soil profiles. The soil samples were analysed for physical and chemical properties following standard procedures for each parameter.

3.3.5 Soil sampling

Plant and litter materials were cleaned from the surface before taking fresh soil samples. Soil core samples were taken to determine the bulk density and corresponding auger samples were taken for soil moisture determination. To obtain statistically representative samples from the area, composite samples were taken from each sub-plot to the plough layer level (Franzen and Cihacek, 1998). Five subsamples were collected in plastic bags (Anderson and Ingram, 1993) and spread the soil on a polythene sheet. Divide into four quadrants. The process was repeated until a sample of the required size is obtained.

Over the three years (2005-2007), soil samples were collected before sowing and immediately after harvest during the vegetation periods. The first soil samples were collected from the plots in April 2005 i.e. before the sawing. The second and third phases of soil samples were taken in the June and July 2006 and 2007 from the same area, where the first soil samples were taken. To see the impact of compost on the soil, samples were taken immediately after harvest, usually between October – November for all the three years.

3.3.6 Compost sampling

Compost samples (one in 2005, two in 2006 and two in 2007) were taken from the preselected representative farmers. It was collected every year during application or sowing season, which is mostly taken in the months of June and July. The composts were selected for sampling by farmers with their own criteria: well decomposed (darkbrown color and good smell) and no stones available in the compost. Sub-samples were taken as 1/3 from upper layer, 1/3 from middle layer and 1/3 from the bottom layer. To obtain a sample from the sub-samples, the composts were spread on a polythene sheet. Two pairs of subsamples of the same pit were collected in plastic bags. Mixing all together and divide into four quadrants. The process repeated until the sample of the required size is obtained.

The nutrient quality of the composts were determined through laboratory analysis in the soil laboratory of the "Water Works, Design and Supervision Enterprise" of the Federal Ministry of Water Resources, Ethiopia.

3.3.7 Crop performance and yield

Crop performance and yield components of the crops were recorded during the experiment period (2005-2007). Germination rate records, plant height, plant density, moisture content, color and vigor, weed situation, flowering stage, disease and pest infestation and maturity dates based on treatments were evaluated by consultation with farmers.

Crop yields were collected at the end of each harvest season i.e., between October and November each year. The harvest was treshed and weighed from each sub-plot (4 m^2) i.e., treatment based, and calculated as t/ha basis. Grain and straw samples were also collected during threshing in respective subplots. Loss of biomass during threshing before transported to farmers' homesteads was estimated. But it was not for grain because it was threshed in bags.

3.4 Data analysis

3.4.1 Compost and soil analysis procedures

The soil sample preparation for laboratory test includes proper registration, air-drying, grinding, sieving through 2 mm sieve and storage (Sahlemedhin and Taye, 2000). The analysis was conducted on ground and sieved (< 2mm) samples. The soil samples were used for physical and chemical property analysis.

3.4.1.1 Analysis of physical properties

To obtain the necessary physical data from the representative soil samples, the following methodologies were used. These are:

- To determine the level of stoniness on the farmers' fields the stone quantity assessment Chart by Hodgson (1976) was used.
- To determine the bulk density, soil samples were collected with 100 cm^3 volume cylindrical metal core samplers. The core samplers were weighed and then oven-dried at 105ºC and weighed again (oven dry weight). The bulk density was determined by dividing the weight of the dry soil over the volume of the corresponding core. The values are given in $g.cm^3$ (Anderson and Ingram, 1993; Schlichting et al., 1995).
- Particle size distribution was determined by the *Bouyoucos* hydrometer method (Bouyoucos, 1962). Then the relative amounts of sand, silt and clay were determined and the textural class calculated by using a soil textural triangle (Marshall and Holmes, 1981).
- The soil colors were described using the Munsell Soil Charts.

3.4.1.2 Analysis of chemical analysis

- A 1:2.5 soil-water suspension (10 g air dried soil:25 ml H_2O) was used for pH determination. This suspension was stirred three times every five minutes and left for 30 minutes before measuring by pH meter glass electrodes. Electrical conductivity is measured based on 1:2.5 extract from soil:H_2O suspension (Richards, 1954).
- The percentage organic carbon was determined by a modified Walkley-Black procedure (Smith and Welden, 1940). The organic matter was obtained by wet oxidation technique i.e., calculation of 1.724 x per centage of carbon (Black, 1965). It is based on the assumption that organic matter contains 58% organic carbon (Kleber and Stahr, 1997).
- The wet digestion of the Kjeldahl procedure was used to test for total nitrogen while Olsen's method was employed to determine available phosphorus (Olsen et al., 1954; Anderson and Ingram, 1993). Available K was extracted by

ammonium acetate extraction method (Sahlemedhin and Taye, 2000; Rowell, 1994).

- Cation exchange capacity and exchangeable bases were determined by the ammonium acetate method (Black, 1965).

3.4.2 Mineral analysis in plant biomass and grains

The N, P and K contents of the plants, straw and grain of different composting materials were analysed in the soil laboratory of the Tigray Agriculture Research Institute (TARI). The preparation of the plant material were through drying the green material at a maximum of 60^0C, grinded to pass through a 0.15 mm mesh and 10 g is taken for analysis (Anderson and Ingram, 1993).

The concentration of the total nitrogen in plant was determined by the Kjeldahl method. The organic nitrogen is oxidized into ammonium by acid hydrolysis with H_2SO_4 together with the reagent potassium sulfate to raise temperature and to hasten the rate of decomposition, copper sulfate and selenium powder were used as catalyst.

- The nitrogen present in nitric form remains unchanged. The modified method is based on the same principle but by addition of salicylic acid and sodium thiosulfate, the nitrates and nitrites are reduced into ammonia form of nitrogen. Then NH_3-N formed and the NH_3N that was originally present in the sample are fixed in the form of $(NH_4)_2SO_4$. After digestion, nitrogen can be determined from the solution that can be rendered alkaline by addition of NaOH enabling NH_3 to be volatilized and then trapped in boric acid during distillation and then titrated with standard acid.
- The plant analysis procedure for Phosphorous and Potassium concentration was done following ashing method. About 1.0 g of ground plant sample was dried out in aluminum dish over night at 105^oC in an oven. The ash was dissolved in concentrated HCl and diluted with de-ionized water. After addition of color reagent (molybdate-vandate-solution), the phosphorous concentration was measured by spectrophotometry and K by flame photometry.

3.4.3 Harvest index and kernel weight determination

Harvest index was determined by calculating the total grain weight to the total biomass weight and shown in ratio. It is calculated by crop and based on treatments. Kernel weight refers to 1000 grain weight, which is determined by counting and weighing 1000 grains. The counting was only for the grain of barley and faba bean because counting grain of tef was impossible. The counting and weighing of 1000 grain was conducted in the soil laboratory of the Federal Environmental Protection Authority of Ethiopia in Addis Ababa.

3.4.4 Cumulative productivity index

For the determination of the agronomic characteristics, one factor factorial model was applied on the yearly data. However, a model with one factor randomized complete block design combined over years was implemented for the grain and straw yields. Accordingly, each crop was considered as if it was sown in three consecutive years. In comparing the long-term agronomic performance of the treatments, Relative Productivity Index (RPI) (Teklu, 2005), which was defined as the ratio of the treatments mean grain yield to the mean grain yield of all the treatments (Eq. 1.1-1.3) has been employed to overcome the difficulty of comparing different crops. To see the continual effect of the treatments over years through:

$$RPI = \frac{\overline{y}}{\overline{Y}} \qquad 1.1$$

$$\overline{y} = \frac{\sum_{i=1}^{n} yi}{n} \qquad 1.2$$

$$\overline{Y} = \frac{\sum_{i=1}^{N} \overline{yi}}{N} \qquad 1.3$$

where y_i = yield of a treatment ($kg.ha^{-1}$)

n = number of replications

N= number of treatments.

3.4.5 Nutrient balance

The partial nutrient balance of the study considers only the most important inputs and outputs during the study period (Haileselassie et al., 2005 and 2007; Van Dung et al., 2008). These are: the inputs include mineral fertilizer (IN1), organic inputs (IN2) and biological N-fixation (IN4), while the outputs as harvested products (Out1) and residues removed (Out2). The others (atmosphoric deposition-IN3, sedimentation-IN5, leaching losses-Out3, gaseous losses-Out4, and erosion-Out5) are not considered due to their complexity in measuring and calculation.

The nutrient supply of the different inputs were calculated based on the input applied to respective crops. Such as:

- there was no input applied to the control plots in all the three crops.
- the plot with mineral fertilizer (IN1) (100 kg DAP and 50 kg Urea) supplies nitrogen and phosphorous inputs as: the 50 kg Urea contains 23 kg of nitrogen because urea contains 46 percent N. While DAP (diammonium phosphate) is 18-21 percent nitrogen ($(NH_4)_2HPO_4$) form and 20-23 percent phosphorous i.e., averagely 19.5 kg nitrogen and 21.5 kg phosphorous. Therefore, the total input of N and P are 42.5 and 21.5 kg respectively.
- the amount of NPK content of the 3,200 kg and 6,400 kg compost (IN2) were obtained by analysing the NPK content of the compost and calculated by the amount of compost applied in all crops.
- Input applications for all crops (teff, barley and faba bean) were the same but the N fixation (IN4) of faba bean was taken an average of other studies in Africa, Middle East and Australia. The N fixation of faba bean is extrapolated as 125 kg N ha^{-1}, which is calculated from overall average of 10-350 kg N ha^{-1} in Australia and 54-133 kg N ha^{-1} in the Middle East study by Rochester et al., (1998) and 76-125 kg N ha^{-1} of a study by Carranca et al., (1999) in Portugal. This applies for all treatments where faba bean is cultivated.

While the output was calculated based on the export through crop and straw from the different types of crops.

- First, the amount of grain and straw yield were measured.
- Second, the net straw that reach the farmers' house weighed after threshing. This is to know the amount of straw wasted during threshing.
- Third, the NPK content of the grain (Out1) and straw (Out2) were analysed in laboratory.
- Fourth, the total amount of NPK were calculated.

Finally the partial nutrient balances of the different crops were calculated by subtracting the export from the import.

3.4.6 Economic analysis

The price of chemical fertilizer and cost of production of compost is calculated as an average for the last 5 years (2003-2007). This is because five years is the minimum life span of a pit made by farmers and get an average cost of a chemical fertilizer. It is also to minimize exaggerations in the price of fertilizer, because the cost of chemical fertilizer is on increasing. The cost of compost and chemical fertilizer are considered in the production sites. All includes the labor days needed to prepare compost while the price of chemical fertilizer in the market at the time and the transport needed to reach home was also taken into consideration. Farmers consider the time taken to buy chemical fertilizer because it is not a door to door service. It needs a longer process when it is to be purchased on credit basis and the 15 percent interest rate. But they are not considered in the calculation. Spreading compost or chemical fertilizer in the field is also considered.

In this analysis, labor for ploughing, weeding and cropping of the plots considered equal for the four treatments. No chemical (herbicides and/or insecticides) used because the study wanted to see the natural tolerance of the crops with their respective treatments. The average market price of the grain and straw harvest were considered assuming that farmers sell their grains at local markets.

The net income of grain and straw yield is calculated based on the Partial Budget Analysis (Ehui and Rey, 1982) referring the local prices of the straw and grain based on the crop type and reduce their respective expenditures. The partial budget analysis, which lists only those items of income and expense that changes, allows different treatments against a control, estimate net returns and incremental costs for every treatment against the control (marginal rate of return) from an experimental data.

It is defined as NI = TR – TC (2.1)

Where NI= net income; TR= Total Revenue; TC= Total Cost;

TC = FC + VC (2.2)

Where FC= Fixed costs and VC= variable costs.

In order to properly screen among alternative technologies it evaluates the increase of changes in net income (ΔNI) as the difference between the change in total returns (Δ TR) and the change in total costs (Δ TC),

i.e. Δ NI = Δ TR - Δ TC = Δ TR - Δ VC - Δ FC = Δ TR - Δ VC, since Δ FC = 0 (2.3)

Assuming that capital is not a constraint, the technology with the highest Δ NI will be recommended. New technologies, however, typically require a package of increased inputs (capital costs). Thus, it is necessary to compare the extra (or marginal) costs with the extra (or marginal) net benefits. In this case, it defines:

MRR = Δ NI/ Δ VC (2.4)

where MRR is marginal rate of return and measures the effect on net return of an additional capital invested in a new technology, compared to the control.

3.4.7 Statistical analysis

The analysis of the experiments were were subjected to Analysis of Variance (ANOVA). Excel, SPSS, Sigmastat version 2.0 (Jandel Corporation) and SAS system softweres were used.

3.4.8 Estimation of missing values and/or outlier

In an RCBD when an experiment has one or more observations missing, the standard computational procedures of the analysis of variance are using the missing data formula technique *(*Jayaraman, 2000)*.* This estimate is used to replace the missing data or an outlier. A single missing value in a randomized complete block design is estimated as:

$$Y = (rB_o + tT_o - G_o)/((r-1)(t-1)) \quad (3.1)$$

Where y = Estimate of missing data

t = Number of treatments

r = Number of replications

B_0 = Total of observed values of the replication that contains the missing data

T_0 = Total of observed values of the treatment that contains the missing data

G_0 = Grand total of all observed values

The missing value is replaced by the computed value of y and the usual computational procedure of the analysis of variance is applied to the augmented data set.

4. RESULTS

Farmers have different practices in improving their soil fertility and is increasing their crop yield. Nowadays compost is one of the choices used by many farmers. But a chain of factors can affect compost use in smallholder farming systems. The first factor that determines compost use is availability of biomass in terms of quantity and quality. The ability of farmers to prepare compost for self consumption is also part of the first step determining factor. The second determining factor is the quantity and quality of compost. On the third step, the determining factor becomes the effect of compost on soil fertility, yield and economic benefit that can be easily detected by the farmers. The fourth step, the nutrient export by above ground biomass is seen as determining factor for long term sustainability of farming under different inputs especially compost amendment. Finally, the sustainability of the smallholder farming systems under the existing low input agriculture. Therefore, the following sections present these factors.

4.1 Soil fertility situation

4.1.1 Traditional soil fertility characteristics

Farmers generalized the soil fertility of the study area into three levels. These are: fertile, medium and infertile soils. The most common soil fertility criteria used by farmers are depth, colour and yield. Fertile soil is deep soil; macro-organisms are observed and give higher yield of both grain and straw. It is mainly the characteristics of *Walka* and *Ba'ekhel* i.e., clay and reddish soils respectively (Tables 4.1 - 4.3). While infertile soils are shallow or stony, less or no macro-organisms observed with less production capacity. This is the characteristics of *Hutsa* (sandy soil). Unlike shallow soils deeper soils retain moisture, crops grown deep rooted and not easily affected when rain stopped early. But some times farmers classify stony farms as fertile soil if they are deep. According to farmers stones are useful in protecting soil removal especially in hilly slopes.

Table 4.1 - Traditional soil fertility description

Fertile	Infertile
Fields are with minimum stones or gravel; gentle slope; not affected by erosion.	Stony or gravelly; highly affected by sheet or wind erosion.
More macro-organisms are observed in the soil. This is an indication of healthy soil.	Less or no macro-organisms observed in the soil.
Deep layer; mostly easy for ploughing. Fresh and moist looking when ploughed. Higher water percolation capacity.	Shallow layer; difficult to plough. Dry, when ploughed. Low water percolation capacity.
Generally blackish in color.	Generally light-red in color.
Soils are loose and not compacted which are good to plough. Has good aeration and root penetration.	Soils are tight and compacted difficult to plough. Has low aeration and root penetration.
The different stages of crops are good looking, i.e., from germination to harvest. Plants are deep rooted.	Plants are grown in the top layer of the soil.
Plant residues (ratoon-cane) especially sorghum and maize re-vegetate in the dry season.	Plant residues (ratoon-cane) dry immediately after harvest.

Table 4.2 - Traditional soil classification

R.N.	Local name of soil	Color	Characteristics of the soil type	Crop types grown
1	**BA'EKHEL (reddish soil) - these are easy to plough**			
1.1	BA'EKHEL	BULLA (light-yellow)	It is deep and fertile.	Suitable for all types of crops.
1.2	REQIQ (shallow) - BA'EKHEL	Light-yellow	It is thin and infertile.	All types of crops do not grow without any input to the soil.
2	**HUTSA (sandy soil) – these are easy to plough**			
2.1	HUTSA	Reddish-light	Easy to plough.	Crops with short roots do not grow well here while maize, legume crops, sorghum and finger millet grow better.
3	**WALKA (clay soil) – soils are heavy to work on**			
3.1	REGUED (deep) - WALKA	Black/dark	Water logging; cracks observed.	It is not convenient for deep rooted crops like sorghum. If drained it is good for the short rooted crops like teff. At the end of the main rainy season around September onion, grass pea, fenugreek and chick pea can grow. Vegetables can grow during dry season if irrigated.
3.2	MEQAYIHO WALKA	Reddish clay	Water logging.	It is good for the shallow-rooted crops like teff, barley, wheat, chick peas because they can be sown after mid of the rainy season and they are short growing season crops.
3.3	REQIQ (shallow) - WALKA	Black	Water logging.	Red teff is best here because it is fast maturing crop but if the rain continued its grains fall.
4	UGMA/LESDI	Reddish clay soil (loam)	Accumulated silt soil from highlands	It is very good for all types of crops. Good soil for continuous cultivation with out inputs.

Based on the above table the soil types of the study area are divided into three major groups. They are *Ba'ekhel, Hutsa and Walka* (Tables 4.2 and 4.3).

Ba'ekhel refers to any reddish or yellowish colored soil. It corresponds with the Regosol, Cambisol and Luvisol soils of the WRB (Table 4.3). It occupies about 27.6 percent of the cultivated land of the Tahtai Maichew District. Shallower (*Reqiq*) *ba'ekhel* soil needs input to achieve good harvest. If *ba'ekhel* soil is deep it is suitable for all types of crops. Ugma or Lesdi type of soil is loam soil formed by siltation. It is very fertile and is classified in this soil type.

Hutsa refers to any type of sandy soil. It is found mainly in lower flood plains. It covers around 10.7 percent of the district. This type of soil is characterized by high water percolation, easy to plough and crops are susceptible to moisture stress.

Table 4.3 - Traditional soil type under cultivated crops

R.N.	**Soil type**	**Area in percent**	**Correspond ence (WRB)**
1	Ba'ekhel (reddish soil)	27.6	Regosol, Cambisol, Luvisol, Leptosol and Phaeozem
2	Walka (clay soil)	61.7	Vertisol, Vertic Cambisol
3	Hutsa (sand)	10.7	

Source: Tahtai Maichew district Agriculture and Rural Development Office and adapted from Mitiku (1996) and Nyssen et al. (2008)

Walka refers to a clayey or black soil types. It corresponds with the Vertisols and Vertic Cambisols of the WRB (Table 4.3). It is mostly found in lower or plain lands. It covers an area up to 61.7 percent of the cultivated parts of the study district. They are characterized by water-logging. Mostly these soils are not used for both shallow- and deep-rooted crops such as teff and maized respectively. This is because of the short rainy season. But the *Meqayiho* (reddish) clay is used for shallow-rooted crops. It is because it partialy percolate water and it is less affected by water-logging.

4.1.2 The soil

Even though so far there is no systematic soil survey conducted for Tigray different studies identified the following major soil types. These are: Cambisols, Luvisols, Rendizinas, Lithosols (Leptosols), Fluvisols, Nitosols, Arenosols, Vertisols, Xerosols, Regosols and Andosols (Nyssen et al., 2008; Aseffa, 2005; WBISPPO, 2002; Mitiku, 1997; Virgo and Munro, 1977; Hunting, 1975

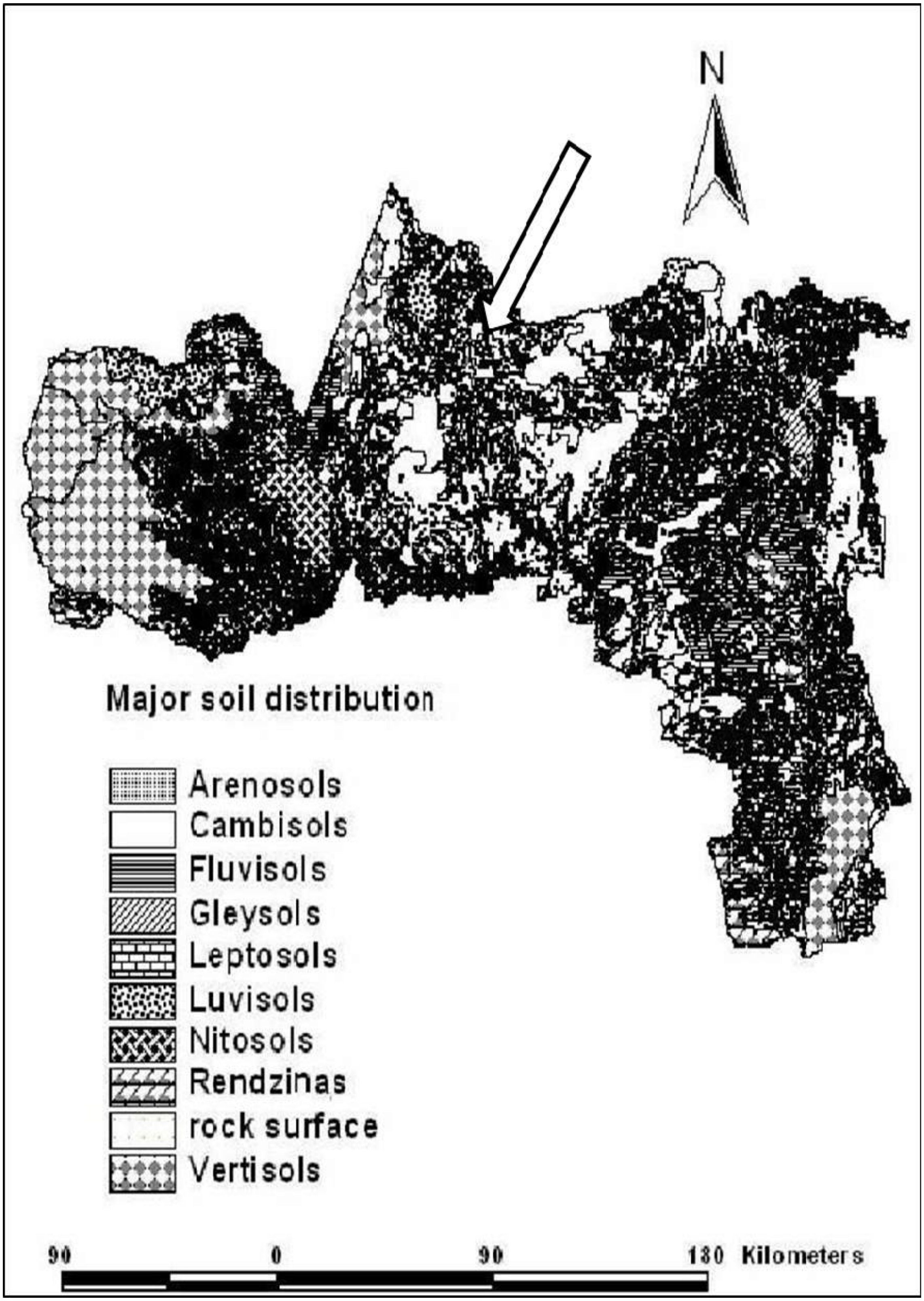

Figure 4.1 - Spatial distribution of major soils in Tigray (WBISPPO, 2002)

4.1.3 Profile description

The characteristics of the soil profiles (Profile 01- profile 06) of the study area lie in the WRB soil classification. They are identified as *Cambisols, Luvisols and Vertisols*. All profiles are found in a plain landscape. The description of the soil profiles of the study area are as follows:

4.1.3.1 The physical properties of the soils

All profiles indicate that the soils of the study area are deeper than one meter. Profile-03 (Endoleptic Cambisol) is only 110 cm and Profile-04 (Vertic Luvisol) is 132 cm. But the rest four Profiles (Profile-01 (Fluvic Vertisol), Profile-02 (Vertic Luvisol), Profile-05 (Vertic Cambisol) and Profile-06 (Vertic Cambisol)) are between 149 and 207 cm. The plough layers of almost all the soils are dominated by loam texture. Only Profile-01 has clay dominant topsoil i.e., about 52 percent and 44 percent silt soil. All the profiles contain more than 36 percent silt in their plough layer. Profile-05 is highly dominated by about 57 percent sand with 36 percent silt (Table 4.4). The soils are dominated by soil sediments derived from the adjacent hilly catchments.

The plough layer bulk density values of all profiles range between 1.05 and 1.34 $g.cm^{-3}$. It is only the Fluvic Vertisol (Profile-01) that has a high bulk density (1.34 $g.cm^{-3}$). The rest soils are in the range of 1.05-1.26 $g.cm^{-3}$. Generally the bulk densities of all profiles rise with depth (Landon, 1991). Profiles (03, 04 and 06) have a character of recently cultivated soils. The bulk density values of all the profiles do not have a sign of compaction problem (Landon, 1991).

Table 4.4 - Soil profile characteristics: depth, color, texture, T.C., BD ($g.cm^{-3}$), pH (H_2O), EC ($mS.cm^{-1}$), $CaCO_3$ (%), ESP (%)

Depth (cm)	Horiz.	Color	Texture (%)			T.C.	BD	pH	EC	$CaCO_3$	ESP
			Sand	Silt	Clay						
Profile 01 - Fluvic Vertisol (*calcaric*)											
0 – 20	Ap	2.5YR2.5/2	4.1	44.1	51.8	SiC	1.34	7.08	0.20	7.49	0.94
20 – 53	AB	5YR 3/2	0.9	34.2	64.9	C	1.26	7.05	0.12	12.79	0.99
53 – 81	Bk1	7.5YR 2.5/1	12.5	28.8	58.7	C	1.26	7.09	0.18	6.40	1.30
81 – 129	Bk2	7.5YR 2.5/1	15.9	5.0	79.1	C	1.24	6.89	0.12	11.22	1.38
129 – 169	Bk3	2.5YR 2.5/1	46.8	33.4	19.8	L	1.21	6.83	0.12	9.57	1.30
Profile 02 - Vertic Luvisol											
0 – 22	Ap	5YR 3/3	41.1	42.8	16.1	L	1.23	5.60	0.04	-	0.76
22 – 53	E	7.5YR 3/3	52.3	36.0	11.7	SL	1.28	6.35	0.05	-	1.08
53 – 88	B1	7.5YR ¾	37.0	40.6	22.4	L	1.25	5.90	0.04	-	1.51
88 – 122	Bk	7.5YR 3/2	50.6	28.6	20.9	L	1.35	6.54	0.07	5.35	0.73
122 – 149	C	7.5YR 3/2	32.0	49.6	18.3	L	1.30	5.90	0.04	-	0.91
Profile 03 - Endoleptic Cambisol (*calcaric*)											
0 – 20	Ap	5YR 4/4	33.2	48.8	18.0	L	1.05	5.42	0.05	-	1.15
20 – 60	B	5YR 3/3	49.6	46.2	4.2	SL	1.22	5.67	0.04	-	0.84
60 – 110	C	7.5YR 4/4	86.2	12.8	1.1	SL	0.82	6.59	0.07	11.35	0.70
Profile 04 - Vertic Luvisol (gleyic)											
0 – 18	Ap	5YR 4/3	29.3	44.9	2.8	L	1.10	5.79	0.01	-	0.99
18 – 43	AB	5YR 5/1	20.8	45.3	33.9	CL	1.45	5.86	0.10	-	1.89
43 – 68	B	5YR 5/3	36.8	35.2	28.0	CL	1.34	5.97	0.13	-	2.17
68 – 104	BC	5YR 5/6	26.6	33.1	40.3	C	1.37	5.92	0.11	-	1.35
104 – 132	Br	5YR 5/6	17.0	36.8	46.2	C	1.23	5.86	0.08	-	1.40
Profile 05 - Vertic Cambisol											
0 – 18	Ap	5YR 3/2	56.7	36.0	12.3	L	1.26	5.22	0.05	-	0.71
18 – 33	AB	5YR 3/3	52.5	36.1	11.4	SL	1.41	5.28	0.05	-	0.75
33 – 110	B	10R 3/2	35.9	37.8	26.3	L	1.34	5.42	0.04	-	0.68
110 – 159	BC	5YR 3/2	42.3	33.6	24.1	L	1.35	5.54	0.04	-	0.73
159 – 205	C	2.5YR 3/3	44.9	41.6	13.5	L	1.29	5.86	0.05	-	1.37
Profile 06 - Vertic Cambisol											
0 – 13	Ap	7.5YR 3/4	41.2	41.3	17.6	L	1.18	5.41	0.10	-	0.68
13 – 44	E1	7.5YR 3/3	28.0	42.8	29.2	CL	1.31	5.48	0.14	-	0.75
44 – 90	E2	7.5YR 3/2	38.1	26.2	35.7	L	1.43	5.80	0.05	-	0.76
90 – 139	B1	7.5YR 2.5/3	46.4	31.6	22.1	L	1.32	5.69	0.05	-	0.78
139 – 207	B2	10YR 3/2	43.4	33.1	23.5	L	1.39	6.95	0.08	-	0.61

Key: Horiz. - horizon; T.C. - textural class;

4.1.3.2 The chemical properties of the soils

The pH values show they are between 5.22 and 7.08 (Table 4.4). This shows us that the plough layer soils are marked by weakly alkaline to moderately alkaline reactions. The electrical conductivity of all the soils range between 0.2 to 0.01 mS cm^{-1}. There are only two (Fluvic Vertisol (Profile-01) and Vertic Cambisol (Profile-06)) profiles with 0.20 and 0.10 $mS.cm^{-1}$ respectively but the rest are below 0.05 $mS.cm^{-1}$ (Table 4.4).

Table 4.5 - The chemical properties (OM, OC, TN, C:N, CEC, P (mg. kg-[1]) and K (mg.kg^{-1}))

Depth (cm)	OM (%)	OC (%)	TN (%)	C:N	Exchangeable Base Cations (mmol/100g of soil)					P	K
					Na	K	Ca	Mg	Sum		
Profile 01 - Fluvic Vertisol (*calcaric*)											
0 – 20	2.82	1.10	0.06	18	0.51	0.54	36.40	16.69	54.14	22.40	221.24
20 – 53	1.52	0.88	0.07	13	0.55	0.39	36.40	19.26	56.60	6.40	155.83
53 – 81	1.43	0.83	0.04	14	0.68	0.42	34.20	18.40	53.70	18.50	160.94
81 – 129	1.91	1.11	0.07	15	0.74	0.31	34.20	17.98	53.23	43.60	128.94
129 – 169	1.67	0.97	0.04	12	0.86	0.38	43.20	18.40	62.84	39.00	156.17
Profile 02 - Vertic Luvisol											
0 – 22	1.41	0.82	0.04	21	0.33	0.25	27.40	8.56	36.54	8.20	101.51
22 – 53	0.88	0.51	0.04	13	0.45	0.17	21.40	9.42	31.44	6.10	101.34
53 – 88	0.53	0.31	NA	14	0.54	0.16	23.10	9.42	33.22	3.60	72.69
88 – 122	1.00	0.58	0.04	15	0.34	0.24	25.70	11.56	37.84	6.10	120.31
122 – 149	1.19	0.69	0.06	12	0.37	0.30	27.40	8.56	36.63	23.20	118.94
Profile 03 - Endoleptic Cambisol (*calcaric*)											
0 – 20	1.29	0.75	0.06	13	0.32	0.52	24.80	9.42	35.06	34.30	210.03
20 – 60	1.43	0.83	0.04	21	0.43	0.57	34.20	9.42	44.62	41.20	223.07
60 – 110	0.28	0.16	0.01	16	0.45	0.49	41.90	14.52	57.36	22.20	196.70
Profile 04 - Vertic Luvisol (gleyic)											
0 – 18	2.38	1.38	0.07	20	0.32	0.56	18.80	7.70	27.38	46.90	235.02
18 – 43	1.28	0.74	0.04	19	0.65	0.32	23.10	5.99	30.06	18.00	136.53
43 – 68	0.78	0.44	0.04	11	0.71	0.32	21.60	6.05	28.68	2.40	131.56
68 – 104	0.74	0.43	0.03	14	0.57	0.59	27.90	7.85	36.91	1.80	223.41
104 – 132	0.64	0.37	0.03	12	0.53	0.65	25.90	5.18	32.26	1.90	270.76
Profile 05 - Vertic Cambisol											
0 – 18	1.26	0.73	0.06	12	0.20	0.31	17.10	6.85	24.46	12.90	126.60
18 – 33	1.16	0.67	0.04	17	0.23	0.26	18.50	7.04	26.03	14.80	114.49
33 – 110	2.21	1.28	0.07	18	0.31	0.30	28.90	12.66	42.17	6.60	121.46
110 – 159	1.52	0.88	0.06	15	0.32	0.29	29.40	8.64	38.65	12.20	129.06
159 – 205	1.10	0.64	0.06	11	0.44	0.28	22.70	11.34	34.76	10.20	117.80
Profile 06 - Vertic Cambisol											
0 – 13	1.29	0.75	0.04	19	0.25	0.50	19.40	8.80	28.95	12.90	188.66
13 – 44	1.84	1.07	0.07	15	0.34	0.38	28.20	9.68	38.60	8.40	152.89
44 – 90	1.33	0.77	0.04	19	0.39	0.31	30.70	9.94	41.34	8.50	131.59
90 – 139	1.74	1.01	0.05	20	0.35	0.28	29.70	10.18	40.51	10.30	121.46
139 – 207	1.19	0.69	0.05	14	0.36	0.43	37.40	17.06	55.25	9.50	125.18

Generally the organic matter (OM) in the soils is at a medium level. In most of the soils OM is higher in the plough layer than the lower horizons. It ranges between 1.26 to 2.38 percent at the plough layer. The higher OM (2.38%) level is observed in Profile-04, which is Vertic Luvisol. The organic carbon contents of all the profiles are below 1.0 percent except Profile 01 and 04 (Table 4.5). The percentage of the nitrogen in the soil profiles is at very low level, which ranges from 0.04 to 0.07% (Table 4.5). Four of the six profiles (01, 02, 04, and 06) have C:N ratio of greater than or equal to 18. While the Profiles 03 and 05 have C:N ratios of 13 and 12 respectively. The high C:N ratios are indicating higher carbon content compared to their nitrogen content (Table 4.5).

Phosphorous (P) at the plough layer of the soils of the study area has wide range (8.2 to 46.9 $mg.kg^{-1}$). Only profile-02 has 8.2 mg P kg^{-1}. Other profiles 05 and 06 have 12.9 mg P kg^{-1} each. Profiles 01 and 03 are with 22.4 and 34.3 mg P kg^{-1} respectively. With 46.9 mg P kg^{-1} Profile 04 is the highest. Phosphorous is adequate in the 3 profiles (01, 03 and 04) for cereals, grasses, soybeans, and maize. The two profiles (05 and 06) are in the low level while the one (profile 02) is deficient (Landon, 1991) (Table 4.5).

The potassium levels at the plough layer of the soils are above 100 $mg.kg^{-1}$. Two profiles (02 and 05) are below 150 mg K kg^{-1} while the other one (Profile 06) is between 150 and 200 mg K kg^{-1} content. The other three profiles (01, 03 and 04) have above 200 mg K kg^{-1} (Table 4.5). According to the rating of Landon (1991) the plough layer of these soils are low in potassium. It is also dependent in the clay mineral present and on the level of exchangeable K (Landon, 1991).

The cation exchange capacity (CEC) for all profiles vary from (27.5-54.4 mmol 100 g^{-1}) 275 to 544 $mmol.kg^{-1}$. CEC is indicating an increase with depth. In all cases the exchangeable base cations are dominated by calcium followed by magnesium and sodium (Table 4.5). According to the rating of Landon (1991) the plough layer of Profile-01 is very high level while the rest are high in CEC but small quantity of lime and K fertilizer may be required.

Table 4.6 - Estimated NPK ($kg.ha^{-1}$) stock of different profiles in Tahtai Maichew, Northern Ethiopia

Profile	Soil layer (cm)	N	P	K
01	Plough layer (0-20)	1 605	60	590
	Root zone (0-169)	12 030	600	3 330
02	Plough layer (0-22)	1 080	20	275
	Root zone (0-149)	NA	170	2 405
03	Plough layer (0-20)	1 260	70	440
	Root zone (0-60)	3 212	270	1 530
04	Plough layer (0-18)	1 385	95	465
	Root zone (0-68)	4 175	165	1 400
05	Plough layer (0-18)	1 360	30	285
	Root zone (0-159)	13 395	210	2 635
06	Plough layer (0-13)	615	20	290
	Root zone (0-139)	9 320	175	2 560
Average	**Plough layer**	**1 220**	**50**	**390**

The estimated nitrogen stock at the plough layer shows it ranges between 615 and 1605 kg.ha^{-1}. The overall average is 1220 kg.ha^{-1}. Four of the profiles (01, 03, 04 and 05) are above the average while the other two are below the average. The highest is in the Profile-01 (Fluvic Vertisol) while the lowest is Profile-06 (Vertic Cambisol). The overall average phosphorous stock is 50 kg.ha^{-1} ranging between 20 and 95 kg.ha^{-1}. Three profiles (01, 03 and 04) are above the overall average. While the overall average potassium is 390 kg.ha^{-1}. Potassium ranges between 275 and 590 kg.ha^{-1}, in Profile-02 and Profile-01 respectively (Table 4.6). This NPK stock is very small in the continuous cultivation.

4.2 Compost production

Farmers make different types of compost from different types of biomass available in their surroundings. The major compost types identified and prepared by farmers so far are: farm residue compost, weed compost and urban-waste compost. The quality of compost farmers prepared and composting materials vary from each other.

4.2.1 Compost application by smallholder farmers

At present over 88% of the farmers consulted in the study area use compost. About 39 percent of them produce between 1 and 2 t compost annually (Figure 4.2; Annex 6). The average cultivated landholding of the study area is 0.8 hectare per family, which is fragmented into two or more pieces (Table 3.2). The average amount of compost sieved and weighed from one 1.0mx1.5mx1.5m pit is 800kg i.e., 16-18 *Qumta* (a traditional quantity measurement sack equivalent with 50 kg). Usually it is used in one plot of land, which is called *Tsimdi/Kert* (equivalent with 0.25 hectare). Therefore, the average application rate is calculated to be 3.2 t compost ha^{-1}.yr^{-1}.

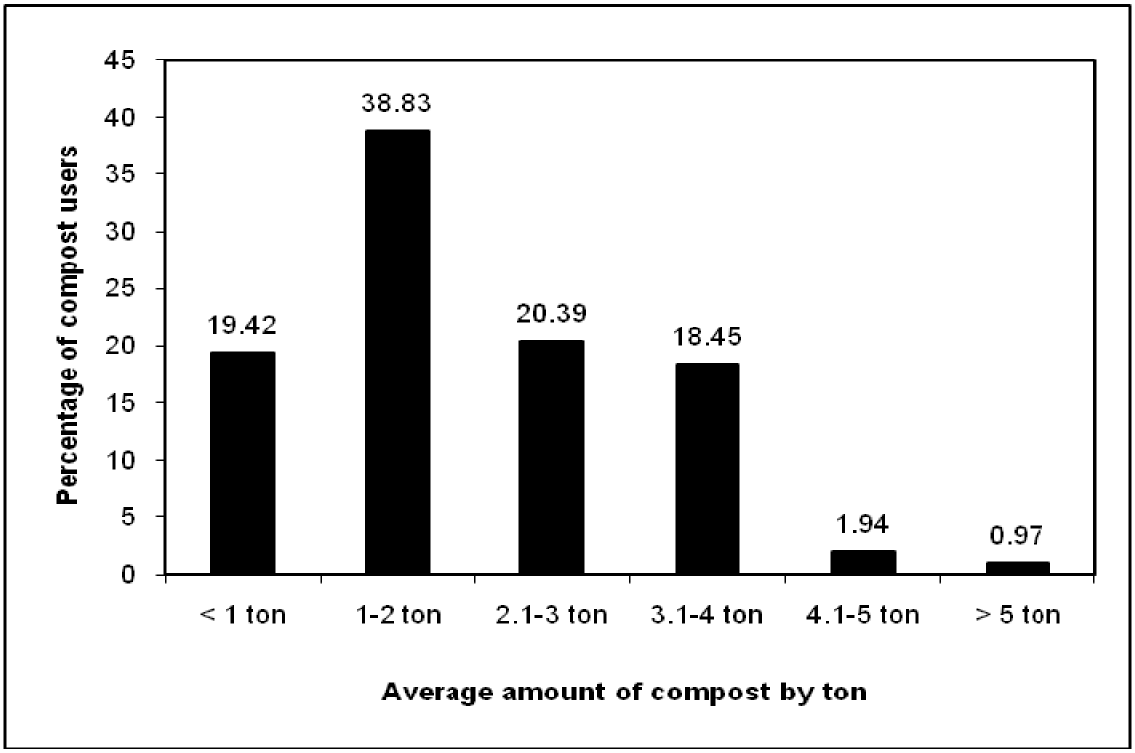

Figure 4.2 - Percentage of farmers (n=103) who use compost and amount of compost produced.

However, the amount of compost applied per unit area varies based on the type of the soil and crop. But generally more compost is applied in sandy soil and for higher plants, while less amount of compost is applied in clay soil and for smaller plants. For example, when a field is sown with teff, which is a very small type of crop, the application of compost is 2.8 $t.ha^{-1}$ in clay soil and 4.8 $t.ha^{-1}$ in sandy soil. On the other hand when a field is sown with barley, wheat or finger millet higher amounts of compost is applied than they apply for teff (Table 4.7). According to the farmers this is important application amount because they are getting better yield without lodging problem in the different crops.

Mineral fertilizer or compost application in the legume crops is not common. Even if farmers apply, it is a very small amount because they believe that it is enough (Table 4.7).

Table 4.7 - Average amount of compost applied per crop and soil type (t.ha^{-1}.yr^{-1}).

Crop type	Clay/ *Walka* – fertile	Reddish/ *Ba'ekhel* – medium fertile	Sandy/ *Hutsa* - infertile
Teff	2.8	3.2	4.8
Barley/ Wheat/ Finger millet	3.2	3.4	5.0
Maize/Sorghum	3.4	4.0	6.0
Any legume crop	No application rate is identified.		

Over 39 percent farmers of the study area mix compost and/or animal manure with mineral fertilizer. 24 percent of the farmers prepare and use only compost and another 13.5 percent use only animal maure in their fields. There are only 13.5 percent farmers who use mineral fertilizer alone in their fields. About 10 percent they do not use any type of input in their farms. It is because they have fertile fields, which does not need any input to be applied (Table 4.8).

Table 4.8 - Input application per number of farm plots at yearly level

R.N.	Plots applied per year	CO	AM	CO+AM+MF	MF	No input
1	100% of their plots	14 (34.1)	0 (0)	28 (41.8)	19 (82.6)	0
2	About ¾ of their plots	13 (31.7)	0 (0)	16 (23.9)	*4 (17.4)	0
3	About ½ of their plots	10 (24.4)	15 (65.2)	11 (16.4)	0 (0)	0
4	About ¼ of their plots	2 (4.9)	8 (34.8)	6 (9.0)	0 (0)	0
5	Some times	2 (4.9)	0 (0)	6 (9.0)	0 (0)	0
6	No application	0 (0)	0 (0)	0 (0)	0 (0)	**17 (100.0)
	Total	**41 (24.0)**	**23 (13.5)**	**67 (39.2)**	**23 (13.5)**	**17 (9.9)**

Key: Co - compost only; AM - animal manure only; MF - mineral fertilizer. *These are some times supported with crop rotation i.e., when they cropped their plots with legume crops such as faba bean. **These plots are fertile and supported by other soil fertility management practices.

About 66 percent of the farmers who use only compost apply it into 75-100 percent of their farmers every year. Among the farmers who mix compost and/or animal manure with mineral fertilizer the 66 percent apply into 75-100 percent of their farms every year. On the other hand 100 percent of the farmers using animal manure apply into partial (25-50%) of their farms every year. This is because if they apply animal manure once it can serve for more than one year. But both the mineral fertilizer users apply into 75-100 percent of their farmers every year. This is because farms frequently fertilized with mineral fertilizer requires application every year (Table 4.8).

4.2.2 Nutrient quality of compost materials

Different types of compost materials have different nutrient contents. They are grouped into four (Figures 4.2 – 4.5). These are:

4.2.2.1 NPK of farm residues

Farm residues are the type of biomass farmers rely on. They are left after cattle are fed. Their NPK content vary from each other. The average nutrient content of the farm residues is 4.3, 1.1 and 16 g.kg^{-1} of nitrogen, phosphorous and potassium respectively (Figure 4.3; Annex 5.1; Table 4.9). All composting materials have higher variations in their nutrient contents. For example, potassium with a standard deviation of 8.4 varies very much as compared with the 0.9 of the phosphorous content (Table 4.9). With 6.4 g.kg^{-1} the straw of barley is good in nitrogen. With 30 g.kg^{-1} and 17.2 g.kg^{-1} straw of barley and stalk of maize respectively holds higher in potassium content.

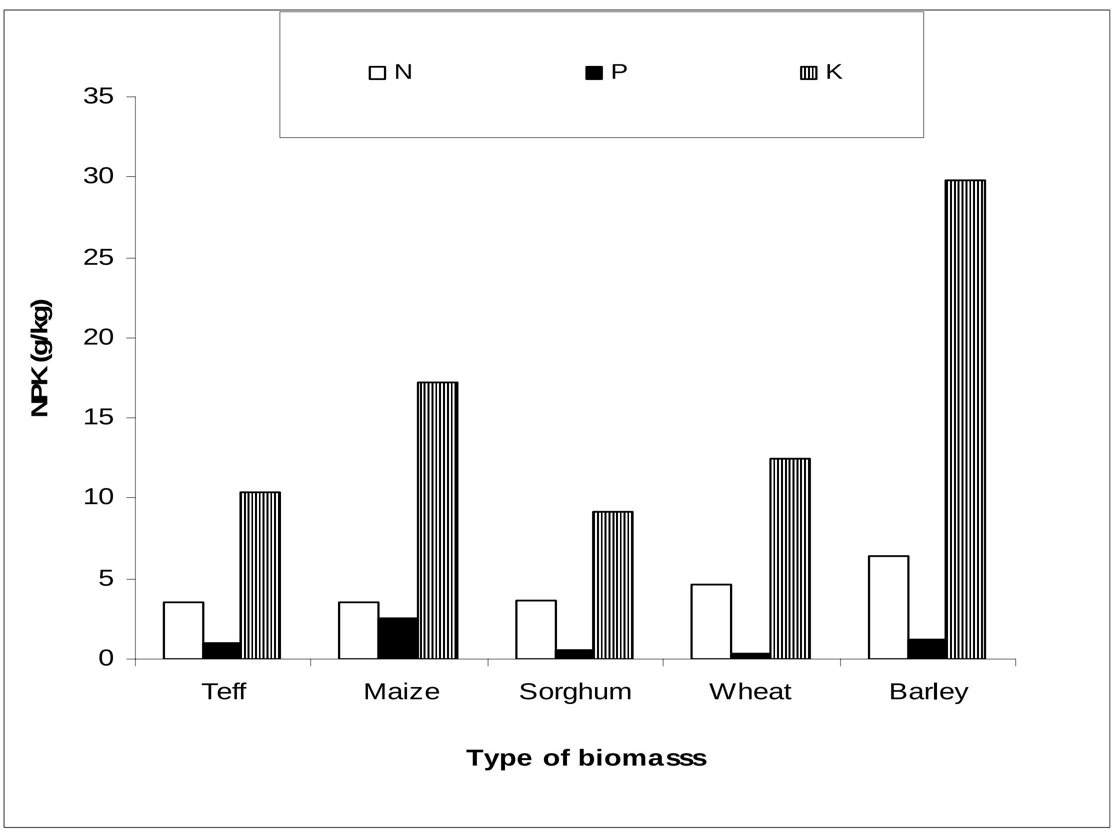

Figure 4.3 - The NPK content of selected farm residues (g.kg^{-1}).

4.2.2.2 NPK of weed biomass

Weed biomass is available mainly as left-over of animal feed except the *Parthenium hysterophorus*, Mestenagir (*Datura stramonium*) and Medafe (Argemone *mexicana*). Both the three weeds are not edible for animals. The average nutrient contents of the weeds are about 17.8 g.kg^{-1} (nitrogen), 1.9 g.kg^{-1} (phosphorous) and 23.3 g.kg^{-1} (potassium) (Figure 4.4; Table 4.9) but their nutrient content varies very much from each other. With 38.5, 37.3 and 22.8 g.kg^{-1} *Parthenium hysterophorus*, Mestenagir (*Datura stramonium*) and Medafe (*Argemone mexicana*) respectively contain high amounts of nitrogen. With 2.9, 2.8 and 2.5 g.kg^{-1} Tinigta (*Guizotia scabra*), *Parthenium hysterophorus* and Wazwazo (unidentified) respectively have higher phosphorous. Still *Parthenium hysterophorus* (51 g.kg^{-1}), Mestenagir (*Datura stramonium*) (39 g.kg^{-1}) and Wazwazo (29 g.kg^{-1}) contain higher contents of potassium (Annex 5.2).

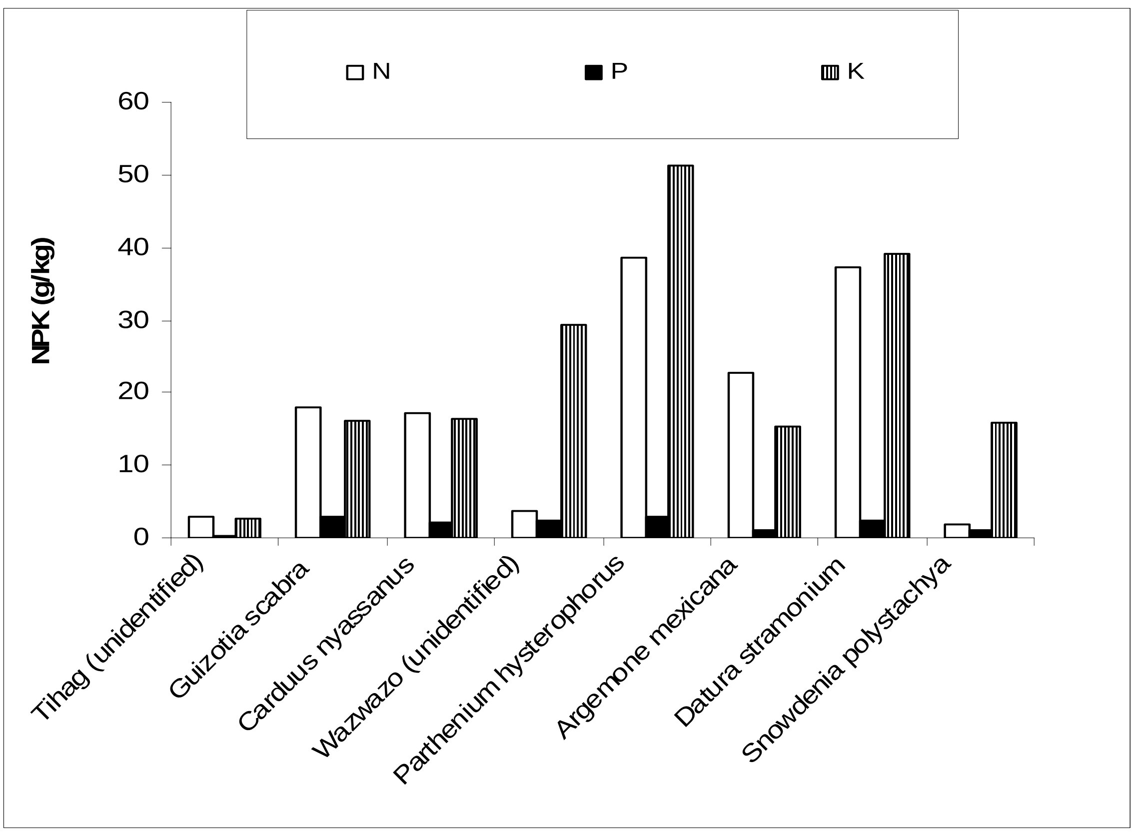

Figure 4.4 - NPK concentration of selected weeds used for compost making (g.kg^{-1})

Generally, the invasive alien weed called *Parthenium hysterophorus* and the homestead ordinary weed called Mestenagir (*Datura stramonium*) hold good amounts of all NPK than other weeds (Figure 4.4). Mestenagir (*Datura stramonium*) grows around rural homesteads. They are also well used for compost in good amounts than other weeds mentioned because they are not used for any other purpose even for animal feed.

4.2.2.3 NPK of green biomass

The green compost materials available are mainly indigenous plants such as Hohot (*Rumex nervosus*) *and* Kliaw (*Dodonaea anguistifolia*) left in the degraded landscape. Awhi (*Cordia africana*) and Tambokh (*Croton macrostachys*) are found around homesteads and farm boundaries. The existing exotic species are *Acacia saligna* and *Sasbania sasban*. They are planted through the Soil and Water Conservation activities.

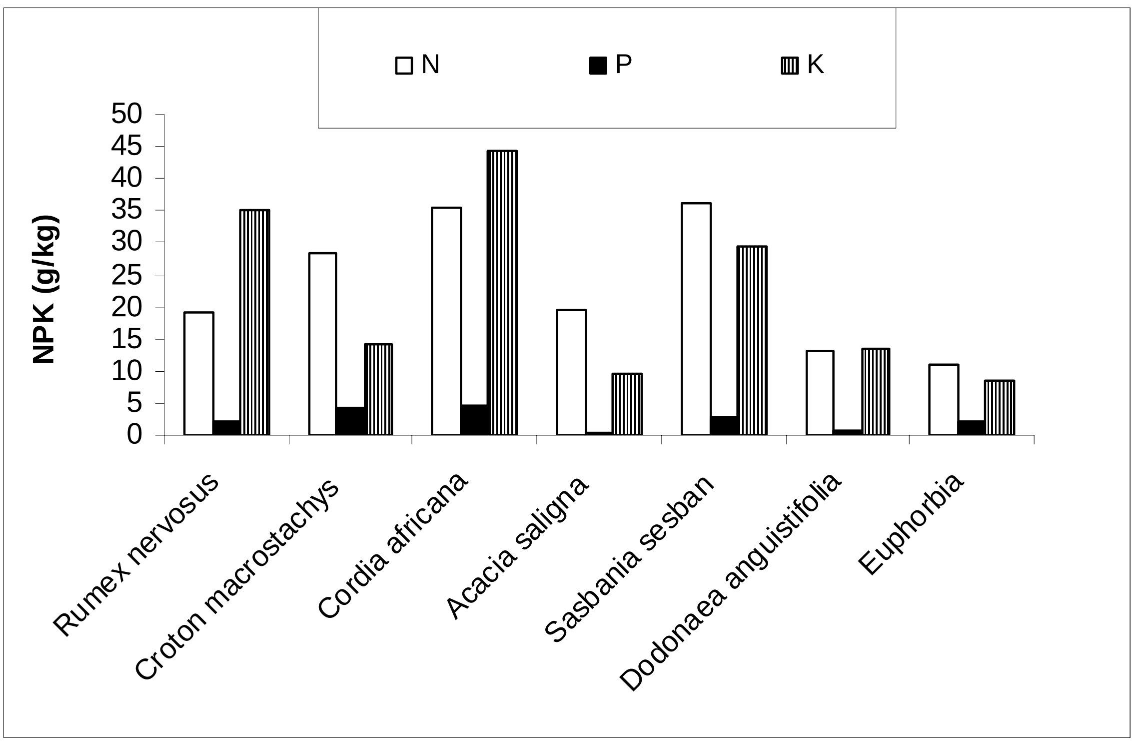

Figure 4.5 - The NPK (%) concentration of selected leaves and tree branches used for compost making (g.kg^{-1}).

Generally, the nutrient contents of the green composting plants are significantly higher in nitrogen (23.3 g.kg^{-1}) and potassium (22.1 g.kg^{-1}) than any other composting biomass. But the higher standard deviation, which are 14.1 (K) and 10.2 (N), show they vary significantly from each other (Table 4.9). The most important biomass with high nitrogen content is *Sasbania sesban* followed by Awhi (*Cordia africana*) and Tambokh (*Croton* macrostachyus) with 36, 35 and 28 g/kg respectively. With 44.2, 35.2 and 29.3

g.kg^{-1} the following green plants Awhi (*Cordia africana*), Hohot (*Rumex nervosus*) and *Sasbenia sesban* respectively are good in potassium (Annex 5.3).

4.2.2.4 NPK of animal manure

During compost preparation farmers give much attention for the availability of animal manure. They are good sources of nitrogen and phosphorous i.e., 18 and 5 g.kg^{-1} respectively. Their standard deviation 8.3, 1.7 and 3.3 for the NPK respectively shows a high variation from each other (Table 4.9).

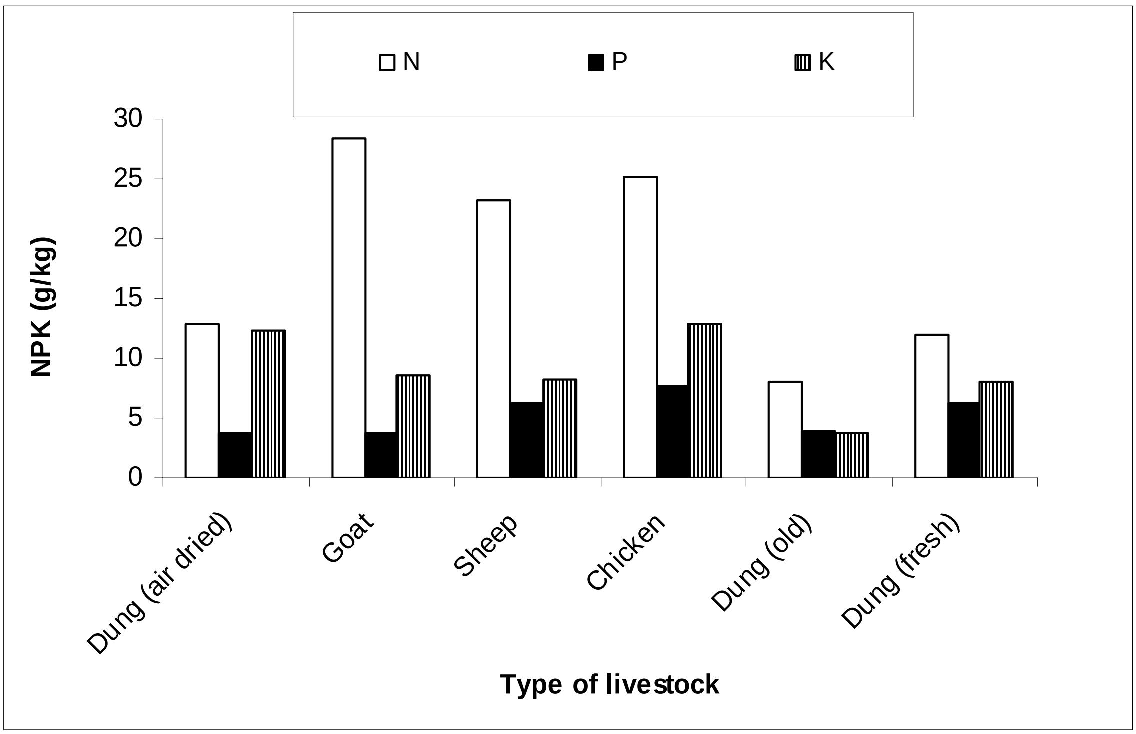

Figure 4.6 - The NPK (%) holding capacity of selected animal wastes manure (g.kg^{-1})

All types of manure are good in phosphorous while the highest is obtained from manures of chicken, sheep and fresh animal dung with 7.7, 6.3 and 6.2 g.kg^{-1} content respectively. Manures of goat, chicken and sheep are also good sources of nitrogen i.e., 28.4, 25.1 and 23.2 g.kg^{-1} respectively. Higher K content is obtained from chicken droppings (12.9 g.kg^{-1}) and air dried cattle dung (12.3 g.kg^{-1}) (Annex 5.4).

Table 4.9 - NPK content of different composting materials.

Compost material	Nutrient content (g.kg^{-1})		
	N	P	K
Farm residues (FR)	4.3±1.3^{b}	1.1±0.9^{b}	15.8±8.4^{a}
Weeds (W)	17.8±14.7^{ab}	1.9±1.0^{b}	23.3±15.6^{a}
Green matter (GM)	23.3±10.2^{a}	2.4±1.6^{b}	22.1±14.1^{a}
Animal manure (AM)	18.3±8.3^{ab}	5.3±1.7^{a}	9.0±3.3^{a}

Values presented are averages of FR (n=5); W (n=8); GM (n=7); AM (n=6) ±SD. Mean values along column with different letters indicates significant difference at P<0.05 level of confidence.

Generally, the highest sources of nitrogen is obtained from green material followed by animal manure and weeds. It is significantly higher from farm residues but not different from weed biomass and animal manure. Farm residues are lowest in N content (Table 4.9). The overall average phosphorous content of the animal manure (5.3 g.kg^{-1}) is significantly higher than other types of composting biomasses. While the rest are not significantly different from each other. Potassium shows that there is no significance difference among all the compost ingredients. However, weeds and green matter holds highest content (Table 4.9).

4.2.3 Compost quality analysis

The average pH values of the different types of composts are between 7 and 8. The 7.8 pH value of *Parthenium hysterophorus* compost is significantly higher than the farm residue compost but not different from the urban waste composts (Table 4.10). Except one, with a pH of 6.8, from the farm residue compost all types of compost are above 7.2. Mainly seven of the 10 compost are 7.5 and above, which are designated at high pH level (Annex 7.1).

There is no significance difference in the Electrical Conductivity (EC) values of the different types of compost (Table 4.10). However, with an average of 3.4 mS.cm^{-1} the *Parthenium hysterophorus* compost is slightly saline than the others (Landon, 1991). Two of the three composts from *Parthenium* have EC value of 3.9 and 4.7 mS.cm^{-1} while the urban waste composts are with EC of 0.7 mS.cm^{-1} (Annex 7.1). But they are not problematic for field crops (Landon, 1991).

The organic carbon contents in all the composts vary from 4.2 to 8.72 percent (Annex 7.1). There is no significant difference in the organic matter (carbon) content of the different composts but *Parthenium hysterophorus* compost has highest value (Table 4.10). All types of compost are in the medium level of organic matter (Landon, 1991). The highest records of organic carbon are observed with 8.55 and 8.72 percent in the farm residue and *Parthenium* composts respectively (Annex 7.1).

Table 4.10 - The pH, EC, OM and OC level of the different composts.

Compost type	pH (H_2O)	EC ($mS.cm^{-1}$)	OM (%)	OC (%)
Farm Residue	7.3 ± 0.3^{b}	1.6 ± 1.2^{a}	9.7 ± 3.0^{a}	5.7 ± 1.7^{a}
Parthenium hysterophorus	7.8 ± 0.1^{a}	3.4 ± 1.5^{a}	12.4 ± 3.4^{a}	7.2 ± 2.0^{a}
Urban Waste	7.6 ± 0.0^{ab}	0.8 ± 0.0^{a}	8.3 ± 1.0^{a}	4.8 ± 0.6^{a}

Mean values along columns with different letters indicates significant difference at $P<0.05$ level of confidence

The N content of the composts vary from each other and within their groups especially in the farm residue compost. But the nitrogen contents of the different composts do not have significant differences from each other. However, the nitrogen content of the farm residue and urban waste composts are higher than the *Parthenium* compost (Table 4.11). The N content of *Parthenium* compost ranges 0.42-0.44 percent; the urban waste compost has 0.67-0.7 perecnt while the farm residue compost is in the range of 0.38-1.05 percent (Annex 7.1).

With an average C:N ratio of 19 C:N *Parthenium* compost is significantly higher than the other composts (Table 4.11). Almost all the other compost than *Parthenium* have a C:N ratio below 8, only one from the 10 has a C:N ratio of 15 (Annex 7.1).

Table 4.11- The chemical characteristics of the different composts

Compost type	TN (%)	C:N	P ($mg.kg^{-1}$)	K ($mg.kg^{-1}$)	ESP (%)	BS (%)
Farm Residue	0.75 ± 0.3^{a}	9 ± 3.3^{b}	376 ± 89^{a}	2825 ± 1468^{b}	1.93 ± 1.0^{a}	118 ± 12^{a}
Parthenium hysterophorus	0.37 ± 0.1^{a}	19 ± 1.5^{a}	368 ± 25^{a}	8460 ± 1769^{a}	0.68 ± 0.1^{a}	122 ± 27^{a}
Urban Waste	0.69 ± 0.0^{a}	7 ± 1.4^{b}	309 ± 69^{a}	3686 ± 238^{b}	1.82 ± 0.0^{a}	120 ± 16^{a}

Mean values along columns with different letters indicate significant difference at $P<0.05$ level of confidence.

The average phosphorous content shows that all types of composts have higher amounts of phosphorous content. The phosphorous content of both (farm residue and

Parthenium) composts are higher i.e. 376 and 368 mg.kg^{-1} respectively (Table 4.11). Even though the P contents of all composts vary from 260 to 525 mg.kg^{-1} (Annex 7.1) they are not significantly different from each other. The values of the standard deviation shows the P of the farm residue compost (89) and urban waste compost (69) have higher variation with in their group than the P of the *Parthenium* compost (only 25) (Table 4.11). The lowest P content is from the urban waste compost while the highest from the farm residue compost (Annex 7.1).

Generally potassium content is very high in all types of composts. The average shows with 8,460 mg.kg^{-1} the *Parthenium* compost is potassium rich than all compost types. It is significantly different from the other composts (Table 4.11). But the K contents in all composts vary from 1,310 mg.kg^{-1} in the farm residue compost to 10,220 mg.kg^{-1} in the *Parthenium* compost (Annex 7.1). The lowest potassium level in the farm residue composts may be characterized by the low K content in the materials used for compost making farm residues and animal manure (Annex 5.1 and 5.4). The highest K content compost is prepared from weeds and green plants (Annex 5.2 and 5.3). The urban waste compost has K content between 3,520 and 3,850, the *Parthenium* compost 6,680-10,220 and the farm residue compost from 1,310 to 5,160 mg.kg^{-1} (Annex 7.1).

The average exchangeable sodium percentage (ESP) of all compost is between 0.7 and 2 percent. The lowest value is from *Parthenium* compost. The base saturation (BS) levels of all types of compost indicate that they are between 118 and 122 percent. However, all results show they are not significantly different from each other (Table 4.11). This value may indicate the presence of soluble salt or $CaCO_3$ in the compost.

Table 4.12 - The exchangeable base, CEC and BS level of different types of compost.

Compost type	**Exchangeable Base Cations (mmol/kg compost)**					**CEC**
	Na	**K**	**Ca**	**Mg**	**Sum of cations**	
FR	9 ± 4.7^{a}	78 ± 34^{b}	336 ± 70^{a}	148 ± 41^{a}	573 ± 67^{b}	489 ± 60^{a}
P	4 ± 0.5^{a}	260 ± 71^{a}	284 ± 13^{a}	189 ± 14^{a}	737 ± 70^{a}	616 ± 94^{a}
UW	8 ± 0.0^{a}	85 ± 9^{b}	347 ± 43^{a}	97 ± 31^{a}	537 ± 65^{b}	447 ± 3^{a}

Mean values along a colomun with different letters indicates significant difference at P<0.05 level of confidence.

The average values of the CEC of the different composts show they are at a good fertility potential. They do not have any significance difference (Table 4.12). However, the CEC of the *Parthenium* compost holds the highest value, which has a value of 721 $mmol.kg^{-1}$ (Annex 7.2). From the exchangeable base Cations, Ca has the highest value followed by Mg in all types of composts. *Parthenium* compost is significantly higher than the other composts in the exchangeable K and sum of cations. It is unusual to see the exchangeable K of the *Parthenium* compost is almost similar to its exchangeable Ca i.e. 260 and 284 $mmol.kg^{-1}$ respectively. There is no significant difference in the exchangeable cations of Na, Ca and Mg in all the composts. However, *Parthenium* compost is lower in exchangeable cations of Na and Ca and higher in the K and Mg (Table 4.12).

4.2.4 Biomass availability

Farmers in the study area use different types and amounts of biomass for making compost. Farmers do not have any especial preference for compost materials. But the availability of biomass varies from place to place and from family to family. The farmers of the study area identified more than 60 compost ingredients for compost making, of which 25-30 are short-listed based on the amount used in the compost making process (Table 4.13).

In the rural areas during compost preparation farm residues mainly straw, grass, stalk of field crops and animal manure are very important composting materials. Because they are available easily (Table 4.13) as left-over from animal feed. Farmers synonymously agreed during their group discussion that cattle leave 30-40 percent of their feed. The variation depends on the type of feed. For example, they eat green feed over 70 percent where as the unpalatable straw like faba bean eat less than 30 percent of the feed.

Table 4.13 - Biomass type, availability and frequency of farmers using plant biomass for compost making

R.N.	Composting materials		Used as	Amount used**	Availability
	Local name	**Sci./English name**			
Green materials	Hohot	*Rumex nervosus*	Green	2	Medium
	Tambokh	*Croton macrostachyus*	Green	2	Difficult
	Awhi	*Cordia Africana*	Green	2	Medium
	Hamli	Vegetable waste	Green	1	Medium
Farm residues	Teff	Teff	Dry	5	Very easy
	Sirnay/Sighem	Wheat/ Barley	Dry	5	Very easy
	Ifun/ Mishela	Maize/sorghum	Dry	4	Very easy
	Balonga/ Ater	*Vicia faba/ Pisum sativum*	Dry	4	Very easy
Dominant weeds	Parthenium	Parthenium *hysterophorus* *	Green	2	Very easy
	Medafe	*Argemone mexicana*	Green	1	Easy
	Mestenagir	*Dotura stramonium*	Green	1	Very easy
	- Tingta - Wazwazo	-*Guizotia scabra* - unidentified	Dry	2	Medium
Animal manure	Eyba	Fresh dung	-	3	Easy
	Akhor	Air dried manure	Dry	3	Easy
	Har'e Tel	Goat manure	Dry	1	Difficult
	Har'e Begi'e	Sheep manure	Dry	1	Difficult
	Har'e Derho	Chicken manure	Dry	1	Medium
	Zikhereme Ine	Old dung	Dry	3	Easy
	Shint kebti	Animal urine	Liquid	1	Easy
Grass	Tihag	*Bermuda grass*	Dry	2	Difficult
	Mugya	*Snowdenia ploystachya*	Dry	3	Easy
	Sa'eri Bet		Dry	2	Difficult
Others	Hamokhshti	Ash	Dry	1	Very easy

Key:- *In some places like Alamata area (Southern Tigray) parthenium weed is used as dominant composting material because it dominated much of the grazing and crop lands. **The amount of available biomass in each category to fill one (1*1.5*1.5 cubic meter) compost pit: **1** - Insignificant amount (<10 kg); **2** - Some amount (10-100 kg); **3** - Medium amount (100-500 kg); **4** – Higher amount (500-1,000 kg); and **5** – Highest amount (>1,000 kg).

Green composting materials refer to grass, fresh weed, leaves or tree branches. They are available mainly from dominant plants in their surroundings (Table 4.13). Animal manure is easy available for the farmers who own cattle. If not they have to negotiate with their neighbors, friends and/ or relatives to get animal manure. The household litters (including food items, vegetable wastes, chicken dropings and ash) and the weeds used for compost making are available all together amounting to about 10 percent by volume. Mostly weed is available during the weeding season of the year (July through September).

Table 4.14 – Compost biomass category and amount used in volume (dry mass) under different conditions per pit.

R. N.	Biomass category	Biomass available at conditions (kg)			Method of collection by families:	
		Low	Medium	High	With cattle	With no cattle
1	Farm residue	300-500	501-700	701-1000	Left-over of animal feed	Search for it
2	Animal manure	100-200	201-300	301-500	Collect from their pen	Collect from field
3	Green material	100-150	151-200	201-300	Collected during filling compost pit	
4	Household litter	<50	50-100	101-200	Collected in a special place throughout the year	
5	Weeds	<50	50-100	101-200	Mostly collected with farm residue	Collected during weeding
6	Water				To be fetched on time	
	Total	600-950	951-1400	1401-2250		
	Produce compost	**<3.2**	**3.2-6.4**	**>6.4**		

During compost making the farm residue accounts for about 50 percent of the total composting materials. Animal manure and green materials amount to about 40 percent of the total biomass needed for compost preparation. It may be available higher amount for the families who own cattle than those who do not. It is also dependent on the number of domestic animals a family own. This is connected with many farming families that they are initiated in using the animal manure because they have to clean their cattle pen. They mostly deposit it in fields near to their homesteads. But generally more livestock holding encourages familes to use organic manure (Manyong et al., 2001). This is a good chance to prepare compost.

Weeds, water and household litter together accounts about 10 percent of the total biomass. Household litter is collected through cleaning house compounds but it excludes ash because it is too much every where.

The total amounts of biomass in a 1.0mx1.5mx1.5m pit ranges from 600 to 950 kg at a lower biomass availability. This can make compost below 3.2 $t.yr^{-1}$. While under favourable conditions the available biomass ranges from 1,401 to 2,250 kg, which can produce more than 6.4 t compost a year (Table 4.14). Many farmers prepare one or two (1.0mx1.5mx1.5m) sized pits while others use bigger pits.

Table 4.15 - Family size and cattle holding per family by number (n=205) and percent.

Family size	No	1-2	3-4	≥5	Total
≤3	12	8	12	2	34 (16.6)
4-7	2	38	70	20	130 (63.4)
≥8	2	4	20	15	41 (20.0)
Total (%)	16 (7.8)	50 (24.4)	102 (49.8)	37 (18.0)	205 (100.0)

Some times it is observed that making compost is also a source of conflict between husbands and wives. It is on deciding on the use of animal manure either for compost or for cooking food. The conflict is mainly during the dry season because many people do not use the dung for fuel in the rainy season. During the rainy season it is left for compost making. However, some families are solving their conflicts by using it for all purposes by turn or by season. Another option is many families plant fast growing trees in their homesteads for firewoods and/or buy cheaper fire wood (result of the group discussion).

Labour is not a critical problem for many farmers. The optimum labour recommendation for compost making is four and above. More than 83 percent of the farming families consulted have sufficient labour for compost making. Moreover, 38 percent of the farming families consulted own at least one donkey or camel to support their labor demand (Annex 6.2).

4.2.5 Compost production capacity

The type and amount of biomass available varies from season to season (Figure 4.7). This is because all types of composting materials are not available through out the year. The results of the study clearly showed that most of the green composting materials are available between July and October. While the highest is from August to September. Dry materials are available between October and March, which can be stored. At this season water and green materials are short in the dry season except in irrigation areas (Figure 4.7). They are not easy to store for a longer period. Farmers' recommeded season for compost making in Tahtai Maichew district is at the end of the rainy season i.e., August to September. However, this is possible to prepare through out the year based on biomass and water management.

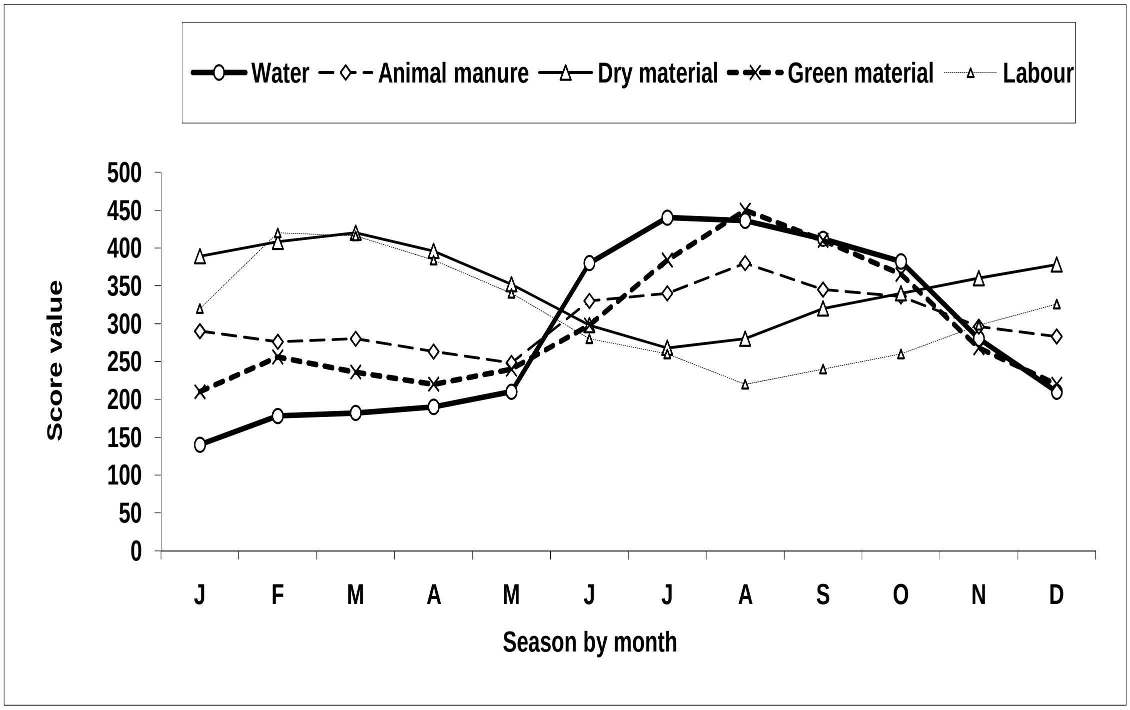

Figure 4.7 – Compost biomass availability by type of composting material and season.

The optimum animal holding to produce 6.4 $t.yr^{-1}$ compost is 3 cow and/or oxen (Table 4.15). Based on this 68 percent of the families own the recommended number of cattle. There are only 7.8 percent farming families without domestic animals. Therefore, the 24 percent farmers can get enough animal manure for 3.2 t and the other 68 percent for 6.4 t compost preparation. The additional animal holding as source of manure than cattle are about 70, 38 and 81.5 percent of the farming families own sheep/goat, equines and chicken respectively (Annex 6.2).

In addition to the animal holding improving biomass management makes great difference in the biomass availability. Whenever farmers practice good biomass management (by farmers' context it is follow up in collecting and storing biomass) farmers' capacity to produce more compost is improved. With the existing domestic animals supported by planting multipurpose trees and improved biomass management 50 percent of the farmers can produce more than 6.4 $t.yr^{-1}$ compost while other 31 percent of the farmers can prepare compost between 3.2-6.4 $t.yr^{-1}$. The existing animal holding without planting multipurpose trees but with improved biomass management the production capacity of farmers is still high i.e., greater than 6.4 $t.yr^{-1}$, 3.2-6.4 $t.yr^{-1}$ and 2.0-3.2 $t.yr^{-1}$ compost is produced by 40, 28 and 17 percent of the farmers respectively. On the other hand the existing animal holding without biomass management about 13 percent of the farmers can produce 6.4 $t.yr^{-1}$, the 36 percent farmers can produce compost between 3.2-6.4 $t.yr^{-1}$ and other 46 percent farmers can produce only 2.0-3.2 $t.yr^{-1}$ compost. Therefore, for farmers biomass management has better impact in their compost production than animal holding (Annex 6.1; Figure 4.8).

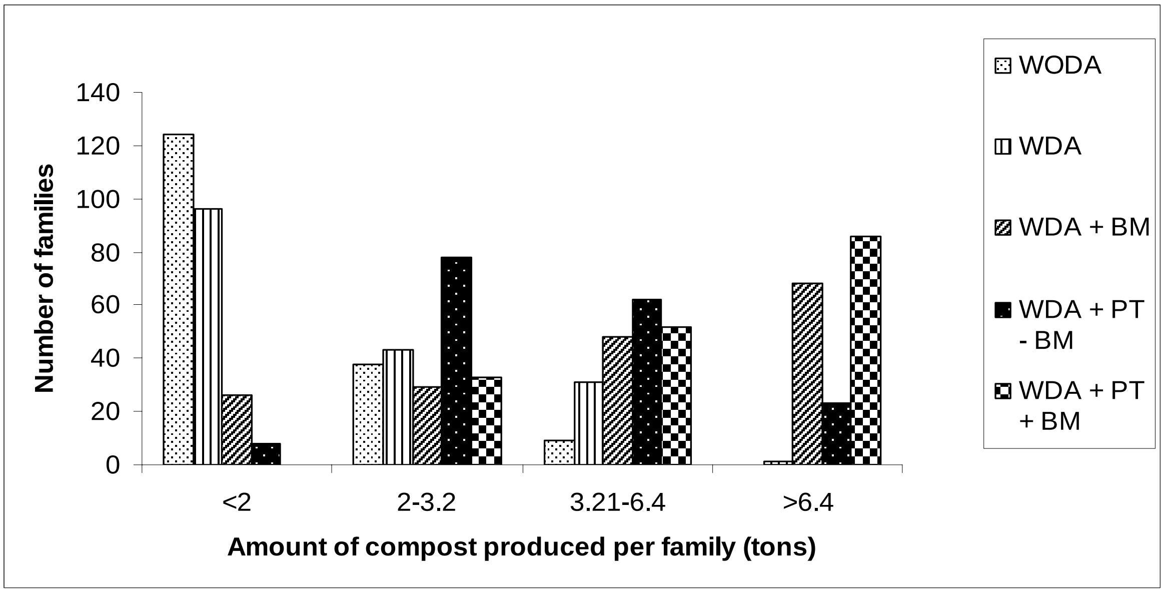

Figure 4.8 - The possibility of compost preparation under different conditions. Where WODA (without domestic animals); WDA (with domestic animals); WDA+BM (with domestic animals and biomass management); WDA+PT-BM (with domestic animals and planting multipurpose trees but without biomass management); WDA+PT+BM (with domestic animals, planting multipurpose trees and biomass management) .

On the other hand figure 4.8 shows no one can produce more than 6.4 ton compost without owning cattle and supported by biomass management. Therefore, this research indicates the availability of composting material depends on cattle ownership and proper biomass management.

4.3 The effect of compost

4.3.1 The effect on the physico-chemical characteristics of the soils

4.3.1.1 Physical evaluation of the soil

The bulk density of the soils of the experimental plots range from 1.36 to 1.46 $g.cm^{-3}$ it continued through out the experimental period. Statistically there is no significant change over time and treatments (Annex 8; Figure 4.9). However, generally there is a reduction trend in the plots with compost applications as compared with plots where mineral fertilizer (MF) was applied and the control (C) plots. Instead an increasing trend was observed in the control and mineral fertilizer plots.

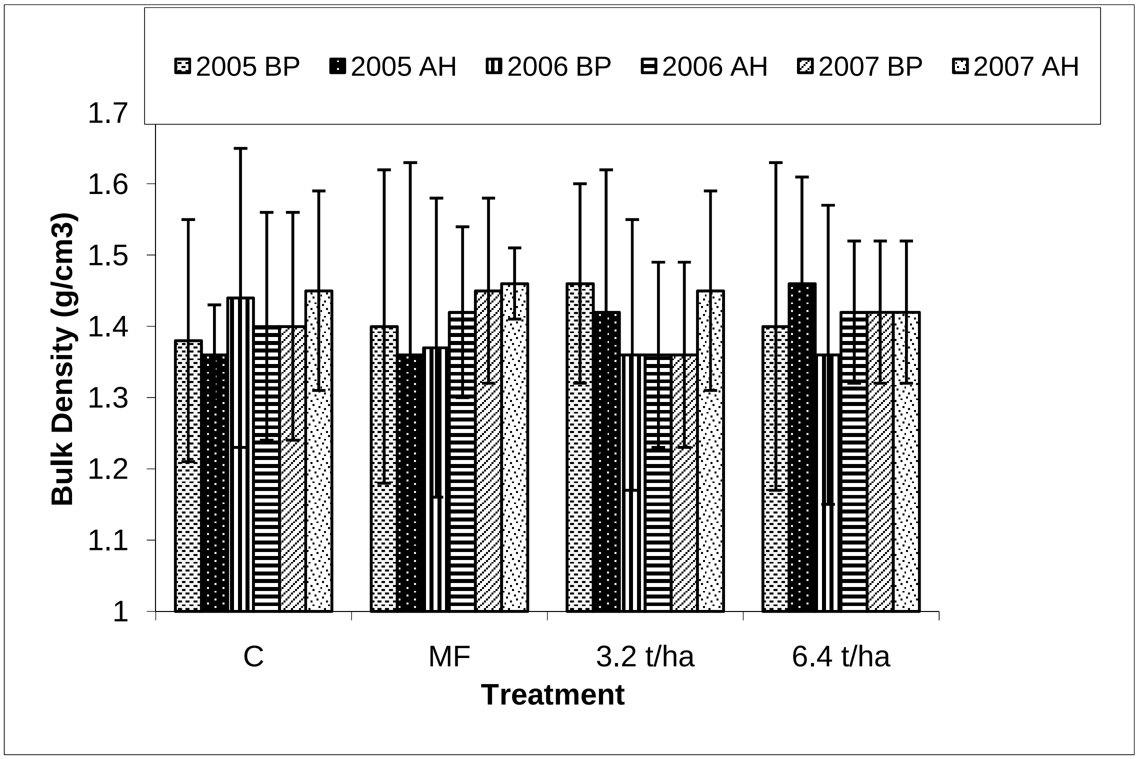

Figure 4.9 –The effect of the different treatments on soil bulk density (top soil). (C - control; MF - mineral fertilizer).

The trend of the moisture content in all the experimental plots is generally increased as compared to the first year. The control and the mineral fertilizer plots showed a significant difference in the second year than the first year but not in the third year. While the 3.2 and 6.4 $t.ha^{-1}.yr^{-1}$ compost applications show no significant difference in all the three years. They were almost constant in their moisture content. However, the moisture content of all the experimental plots was low at the beginning and increased very much in the second year (Table 4.16). The difference in the crop type and harvesting season show marked differences in the moisture content of the soil. This is because of the heavy rain in 2006 (Annex 2), which is immediately before the harvest and usually barley matures earlier than other crops (Section 3.2.3; Table 3.6).

Table 4.16 - Soil moisture content (volume %) between 2005 and 2007 (AH - after harvest; C - control; MF - mineral fertilizer)

Mean	**C**	**MF**	**3.2 t.ha^{-1}**	**6.4 t.ha^{-1}**
2005 AH	3.44 ± 1.29^{b}	3.82 ± 1.97^{b}	4.38 ± 3.56^{a}	3.48 ± 1.47^{a}
2006 AH	13.07 ± 5.65^{a}	12.15 ± 6.17^{a}	9.91 ± 6.00^{a}	10.90 ± 5.78^{a}
2007 AH	9.44 ± 4.10^{ab}	9.51 ± 4.92^{ab}	8.63 ± 4.73^{a}	10.14 ± 8.82^{a}

Mean values along a colomun with different letters indicates significant difference at P<0.05 level of confidence.

4.3.1.2 The chemical evaluation of the soil

There is no significant difference on the pH level of all the different treatments over the three years. However, there is a lower pH value recorded in all the soils mainly receiving 6.4 t.ha^{-1}.yr^{-1} of compost. Higher variation of pH was observed in the control and mineral fertilizer applied plots (Annex 9.1; Figure 4.10).

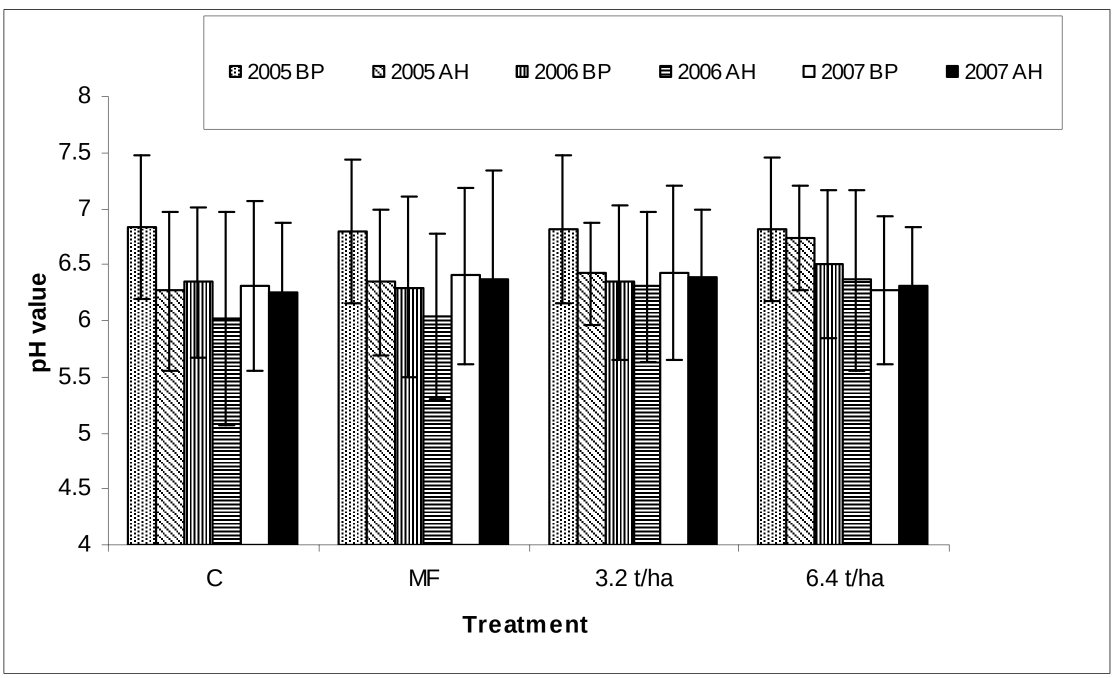

Figure 4.10 – Changes in pH values due to the treatments over three years (2005-2007) (AH - after harvest; BP - before planting; C - control; MF - mineral fertilizer).

There is no significant difference in the organic matter content of all the treatments over the three years. However, in all treatments and the control plot there is an increasing trend after the first application and a continuous decreasing trend afterwards. All plots reduced their organic matter content than the content at the beginning. The data shows there is a higher level of organic matter for the 6.4 $t.ha^{-1}.yr^{-1}$ compost throughout the experimentation period than the other treatments (Table 4.17). But generally the change in the soil organic matter level due to both applications is very low. Similar to the organic matter there is no significance difference in the organic carbon content of all the experimental plots over the three years (Annex 9.2).

Table 4.17 - The significance level of organic matter (%) by experimental period (2005-2007) (BP - before planting; AH - after harvest; C - control; MF - mineral fertilizer)

Year	C	MF	3.2 $t.ha^{-1}$	6.4 $t.ha^{-1}$
2005 BP	1.40±0.32	1.36±0.33	1.53±0.28	1.42±0.30
2005 AH	1.59±0.43	1.69±0.56	1.88±0.64	2.00±0.68
2006 BP	1.65±0.43	1.55±0.56	1.70±0.38	1.75±0.46
2006 AH	1.54±0.46	1.64±0.54	1.69±0.62	1.77±0.54
2007 BP	1.24±0.30	1.15±0.42	1.31±0.31	1.26±0.46
2007 AH	1.21±0.25	1.21±0.30	1.37±0.25	1.39±0.38
LSD (5%)	NS	NS	NS	NS

Prior to the compost application the nitrogen contents of both experimental plots were very low. But at the end of the experimentation period the nitrogen content of all the treatments were significantly higher than the earlier years. At the end of the experimentation period relatively the values of nitrogen were higher on the 6.4 $t.ha^{-1}.yr^{-1}$ compost and mineral fertilizer applications while the control plot had lowest (Table 4.18). There was no significant difference between 2005 and 2006 in both treatments. The higher the nitrogen content of the before planting of the third year may be due to the mulching of the straw of barley after the second harvest. This is because the straw of barley has high nitrogen content and the result of the end of the third year may be due to the faba bean, which is a a legume (Table 3.6).

Table 4.18 - The trend of nitrogen content (%) during the experimental periods (2005-2007). (BP - before planting; AH - after harvest; C - control; MF - mineral fertilizer)

Year	C	MF	3.2 t.ha^{-1}	6.4 t.ha^{-1}
2005 BP	0.057±0.010^{c}	0.05±0.006^{c}	0.052±0.004^{c}	0.057±0.008^{c}
2005 AH	0.067±0.008^{c}	0.062±0.012^{c}	0.070±0.015^{bc}	0.065±0.015^{c}
2006 BP	0.072±0.015^{bc}	0.067±0.014^{c}	0.058±0.015^{c}	0.068±0.008^{c}
2006 AH	0.055±0.025^{c}	0.058±0.011^{c}	0.063±0.005^{bc}	0.064±0.005^{c}
2007 BP	0.098±0.011^{ab}	0.106±0.019^{ab}	0.09±0.016^{ab}	0.11±0.019^{ab}
2007 AH	0.109±0.026^{a}	0.125±0.027^{a}	0.108±0.029^{a}	0.128±0.028^{a}

Means with the same letter are not significantly different at P<0.05 confidence interval.

Table 4.19 - Phosphorous (P) trend (mg.kg^{-1} soil) over the experimentation period (2005-2007)

Year	C	MF	3.2 t.ha^{-1}	6.4 t.ha^{-1}
2005 BP	19.2±13^{a}	15.8±10^{b}	16.2±14^{a}	17.7±13^{bc}
2005 AH	41.5±20^{a}	53.7±19^{a}	40.8±22^{a}	41.0±19^{ac}
2006 BP	35.2±17^{a}	45.2±9^{ac}	34.1±17^{a}	35.0±6^{ac}
2006 AH	36.9±28^{a}	59.4±20^{a}	50.5±20^{a}	57.5±18^{a}
2007 BP	25.1±13^{a}	28.0±13^{bc}	33.9±18^{a}	43.5±29^{ab}
2007 AH	24.0±12^{a}	25.9±11^{bc}	36.0±22^{a}	38.7±22^{ac}

Means with the same letter are not significantly different at P<0.05 confidence interval.
Key: BP - before planting; AH - after harvest; C - control; MF - mineral fertilizer

Initially the plots were different in their phosphorous content because they are found in three different locations. In all the experimental plots phosphorous increased in the second year. Even though P at the mineral fertilizer applied plots were lower at the beginning than the other plots it is boosted after mineral fertilizer was applied. Unlike the other plots after the harvest of the first and second year P was significantly higher. They are significantly different from the last year and first year before planting. The 6.4 t.ha^{-1}.yr^{-1} compost applied plots were significantly higher at the end of the second year (Table 4.19). But all started to decrease slowly till the end of the experimentation period. The decline rates in the compost applied plots are slow especially with the 6.4 t.ha^{-1}.yr^{-1} compost application. While there is no significance difference over the experimentation period in the control and the 3.2 $t.ha^{-1}.yr^{-1}$ compost application (Table 4.19).

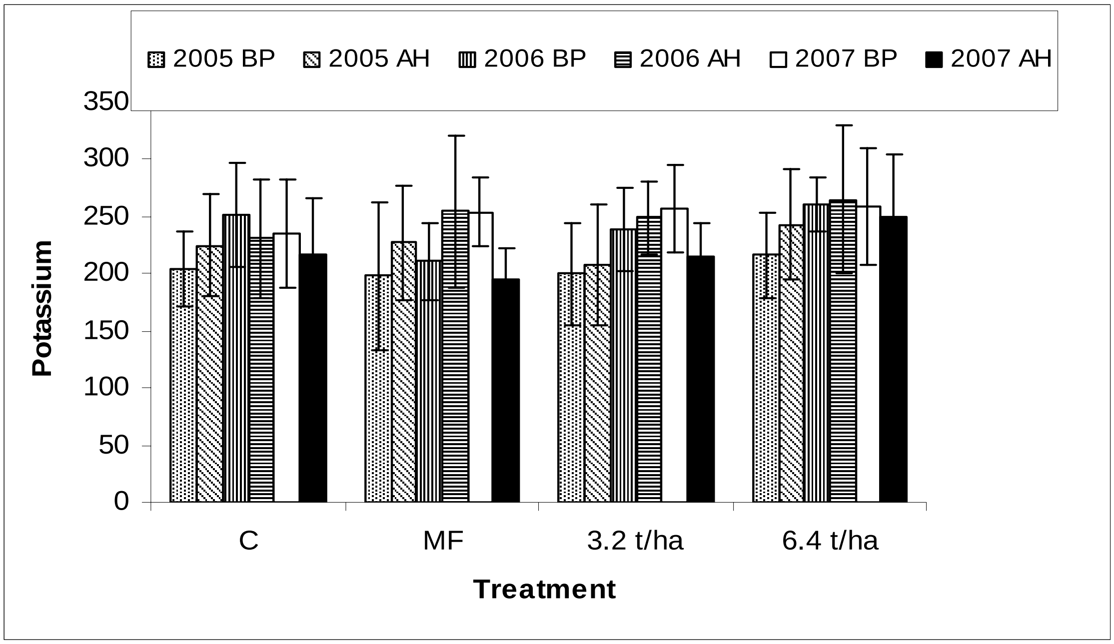

Figure 4.11 - Trend of potassium during the experimentation period (2005-2007) (AH - after harvest; BP - before planting; C - control; MF - mineral fertilizer).

In all treatments the potassium content of all the experiments do not show any significant difference over the experimentation period. However, there is an increasing trend especially in both compost applications. The control plots show a constant trend. Higher variability is observed in the mineral fertilizer applied and control plots than compost applications (Annex 9.4; Figure 4.11). This may be because of the no application of K as fertilizer.

Table 4.20 - The CEC (mmol/100 gm of soil) trend in three years (2005-2007)

Year	**C**	**MF**	**3.2 $t.ha^{-1}$**	**6.4 $t.ha^{-1}$**
2005 BP	27±10.0	28±7.6	29±8.6	27±7.6
2005 AH	37±9.1	37±10.9	36±10.6	36±9.5
2006 BP	39±14.1	35±5.2	37±9.7	37±11.5
2006 AH	36±10.0	36±8.9	36±11.4	35±9.4
2007 BP	36±9.1	36±7.4	36±7.8	38±7.8
2007 AH	34±9.1	36±11.0	37±10.9	35±9.7
LSD (5%)	NS	NS	NS	NS

The above table (4.20) showed that the trend of CEC is on increasing in all treatments. But there is no significant difference over the experimentation period in all the treatments.

4.3.2 Effect on yield

4.3.2.1 Grain yield

The average grain yields of teff and barley from plots applied with mineral fertilizer and 6.4 $t.ha^{-1}.yr^{-1}$ compost show they are significantly higher than the 3.2 $t.ha^{-1}.yr^{-1}$ compost application and the control plots. But there is no significant difference between the 6.4 $t.ha^{-1}$ compost and the mineral fertilizer applied plots. However, the yields from mineral fertilizer treatment are slightly higher (only 5 kg in teff and 75 kg in barley) than the 6.4 $t.ha^{-1}.yr^{-1}$ compost applied plots (Table 4.21). The grain yield between 3.2 $t.ha^{-1}.yr^{-1}$ compost and control plot are not significantly different. But grain yield of the 3.2 $t.ha^{-1}$ compost application is slightly better than the control plots.

Table 4.21 - Grain yield ($kg.ha^{-1}$) by crop and treatment in Tahtai Maichew district

Treatment/crop type	Teff	Barley	Faba bean
Control	872^{b}	2173^{b}	3334^{b}
Mineral Fertilizer	1120^{a}	3025^{a}	3832^{ab}
3.2 $t.ha^{-1}.yr^{-1}$ compost	935^{b}	2325^{b}	3886^{ab}
6.4 $t.ha^{-1}.yr^{-1}$ compost	1113^{a}	2950^{a}	4230^{a}
LSD (5%)	111	236	645
CV (%)	8.96	7.34	13.72

Means with the same letter are not significantly different at $P<0.05$ confidence interval.

The grain yield of faba bean (4,230 kg) from plots treated with 6.4 $t.ha^{-1}.yr^{-1}$ compost application is much higher than the other applications and the control plot. Therefore, it is significantly different from the control plot but not different from the mineral fertilizer and 3.2 $t.ha^{-1}.yr^{-1}$ compost applied plots (Table 4.21). The grain yield from mineral fertilizer applied plots are lower by 54 and 398 kg from the yield of the 3.2 $t.ha^{-1}.yr^{-1}$ and 6.4 $t.ha^{-1}.yr^{-1}$ compost applications respectively.

4.3.2.2 Biomass yield

The straw yields of faba bean and barley of all types of inputs are not significantly different from each other but significantly different from the control plots. While the straw yield of teff from mineral fertilizer and 6.4 $t.ha^{-1}.yr^{-1}$ compost applications are not significantly different from each other. But they are significantly different from the 3.2 $t.ha^{-1}.yr^{-1}$ compost application and the control plots. The straw yield of teff from the control plot is significantly lower than all the others. It shows any amount and type of input is needed to increase its straw yield.

The average straw yield of faba bean from mineral fertilizer and 3.2 $t.ha^{-1}.yr^{-1}$ compost applications are not significantly different from both the control plots and 6.4 $t.ha^{-1}.yr^{-1}$ compost applications. Therefore, these results indicate the straw yields from any type of treatment are significantly higher than the control plots (Table 4.22).

Table 4.22 - Straw yield ($kg.ha^{-1}$) by crop and treatment in Tahtai Maichew district

Treatment	**Teff**	**Barley**	**Faba bean**
Control	2812^{c}	7092^{b}	17065^{b}
Mineral Fertilizer	3485^{a}	9275^{a}	19728^{ab}
3.2 $t.ha^{-1}.yr^{-1}$ compost	3195^{b}	8575^{a}	19822^{ab}
6.4 $t.ha^{-1}.yr^{-1}$ compost	3428^{a}	9225^{a}	21039^{a}
LSD (5%)	197	916	2878
CV (%)	4.96	8.71	12.04

Means with the same letter are not significantly different at $P<0.05$ confidence interval for Teff, Barley and Faba bean.

4.3.2.3 Harvest index and kernel weight

The harvest index (HI) of teff and barley treated with 6.4 $t.ha^{-1}.yr^{-1}$ compost and mineral fertilizer applications are significantly different from the 3.2 $t.ha^{-1}.yr^{-1}$ compost application. But they are not significantly different from each other and the control plots. The harvest index of the faba bean shows there is no significant difference among all the treatments and the control plot. This indicates, there is no input influence in the HI of the grain of the faba bean (Table 4.23).

Table 4.23 - Harvest index (HI) for teff, barley and faba bean, and kernel weight for barley and faba bean crops as affected by treatments.

Treatment	Harvest Index			1,000 grain weight	
	Teff	Barley	Faba bean	Barley	Faba bean
Control	0.31^{ab}	0.31^{a}	0.20	42^{c}	318
Mineral Fertilizer	0.33^{a}	0.33^{a}	0.20	46^{a}	327
3.2 $t.ha^{-1}.yr^{-1}$ compost	0.29^{b}	0.28^{b}	0.20	43^{bc}	322
6.4 $t.ha^{-1}.yr^{-1}$ compost	0.33^{a}	0.33^{a}	0.20	45^{ab}	324
LSD (5%)	0.03	0.03	NS	2.68	NS
CV (%)	7.78	8.30	3.81	4.95	4.98

Means with the same letter are not significantly different at P<0.05 confidence interval for Teff, Barley and Faba bean

The 1000 grain weight of barley treated with mineral fertilizer is significantly higher than the grain weight of the 3.2 $t.ha^{-1}.yr^{-1}$ compost and control plots. But not different from the 6.4 $t.ha^{-1}.yr^{-1}$ compost application. The 1000 grain weight of the 3.2 $t.ha^{-1}.yr^{-1}$ compost applied plots are not significantly different from the 6.4 $t.ha^{-1}.yr^{-1}$ compost applied plots and the control plots.

There is no significant difference in all the treatments and control plots of faba bean. But mineral fertilizer applied plots is showing highest 1000 grain weight while the control plot is the lowest. This indicates input does not have significant influence in the grain weight of faba bean (Table 4.23). However, the 1000 grain weight of barley and faba bean from the control plots are inferior than other treatments (Table 4.23).

4.3.2.4 Nutrient content of grain and straw

There is no significant difference among treatments and the control plots in their NPK level of the grain and straw of faba bean and barley. However, generally treatments with mineral fertilizer and 6.4 $t.ha^{-1}.yr^{-1}$ compost applications showed slightly higher nitrogen level than the 3.2 $t.ha^{-1}.yr^{-1}$ compost application and the control plots (Table 4.24).

Table 4.24 - The NPK content of faba bean and barley grains as affected by treatments.

Treatment	Faba bean			Barley		
	N (%)	**P (%)**	**K (%)**	**N (%)**	**P (%)**	**K (%)**
C	4.06±0.34	0.18±0.07	1.14±0.07	1.45±0.05	0.03±0.01	0.62±0.01
MF	4.08±0.21	0.17±0.06	1.16±0.07	1.61±0.02	0.03±0.00	0.60±0.07
3.2 $t.ha^{-1}.yr^{-1}$ compost	4.03±0.32	0.16±0.05	1.16±0.05	1.44±0.08	0.05±0.00	0.62±0.04
6.4 $t.ha^{-1}.yr^{-1}$ compost	4.09±0.18	0.17±0.05	1.16±0.08	1.68±0.12	0.03±0.01	0.62±0.04
LSD (5%)	NS	NS	NS	NS	NS	NS

The nitrogen (4.03-4.09 percent) and phosphorous (0.16-0.18 percent) content of the grain of faba bean are much higher than their respective straw (Table 4.24 and 4.25). The nitrogen level of the straw of faba bean ranges in 1.19-1.37 percent and uniformly 0.10 percent phosphorous (Tables 4.25). The K content of the straw of faba bean is higher than its content in the grain i.e, 1.33 -1.43 percent versus 1.14-1.16 percent respectively.

Table 4.25 - The NPK content in faba bean straw as affected by treatments

Treatment	Straw		
	N (%)	**P (%)**	**K (%)**
C	1.19±0.28	0.10±0.02	1.33±0.29
MF	1.31±0.42	0.10±0.05	1.38±0.31
3.2 $t.ha^{-1}.yr^{-1}$ compost	1.31±0.61	0.10±0.04	1.40±0.17
6.4 $t.ha^{-1}.yr^{-1}$ compost	1.37±0.18	0.10±0.05	1.43±0.31
LSD (5%)	NS	NS	NS

In both the grain and straw higher nitrogen and potassium content ae observed with the 6.4 $t.ha^{-1}.yr^{-1}$ compost application than mineral fertilizer applied plots (Tables 4.24 and 4.25). This directly shows there is higher removal of nutrients through grain and straw of crops especially barley and faba bean reflected by the higher yields.

4.3.2.5 Trend of production

Figure 4.12 shows the cumulative productivity index of both the grain and straw of teff, barley and faba bean grown in the experimentation under the different treatments. The productivity trend of the grain and straw yields of the three crops show that the application of compost 6.4 $t.ha^{-1}.yr^{-1}$ is highest in all the three consecutive years (2005-2007). The productivity of mineral fertilizer was leading until the second production year. However, eventually the 6.4 $t.ha^{-1}.yr^{-1}$ compost application out-yielded the mineral fertilizer by 11 percent (Annex 10.2). The result of the productivity index shows the mineral fertilizer application is almost similar to the 3.2 $t.ha^{-1}.yr^{-1}$compost application.

The control plots are the least productive in all years. They are lower by 20 percent (by 2005), 24 percent (until 2006) and 13 percent (until 2007) than the yields of the mineral fertilizer in the three consecutive years (Figure 4.12; Annex 10.1-10.3).

The direct reflection of this index is if there is no input application production is always on declining. On the other hand the continuity of the productivity of mineral fertilizer is not competitive with the 6.4 $t.ha^{-1}.yr^{-1}$ compost application.

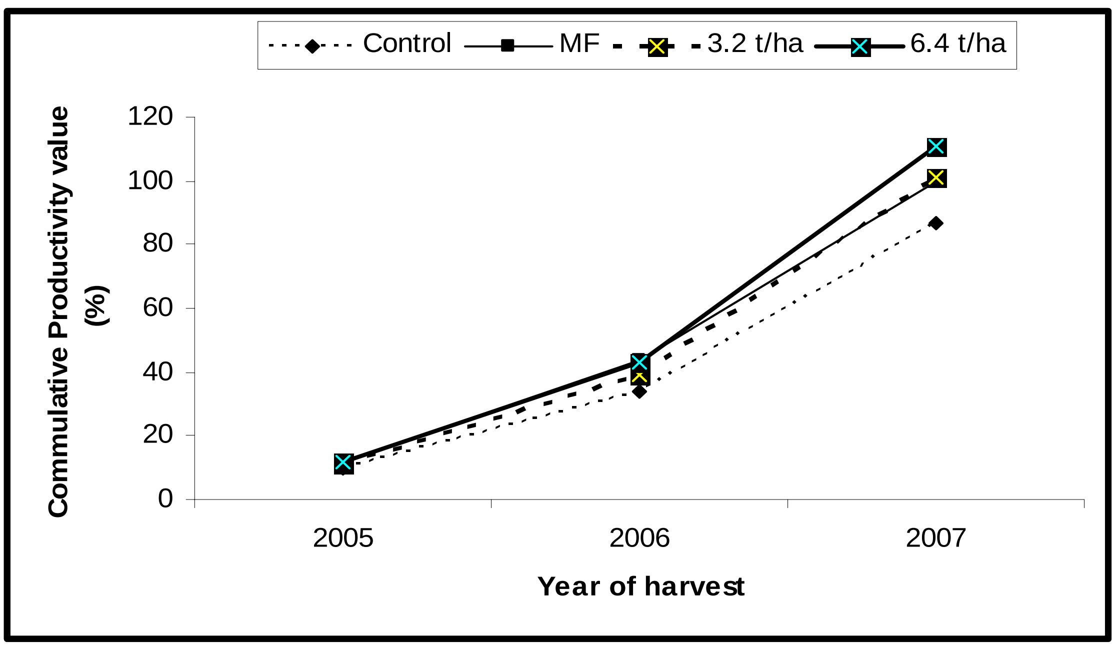

Figure 4.12 - Cumulative productivity index of grain and straw production for teff, barley and faba bean crops (percent)

4.3.3 Agronomic performance of crops as affected by treatments

The result of the observation for the agronomic performance of the crops as affected by the different treatments show that in all crops the germination of the crops treated with mineral fertilizer emerged earlier than the other treatments. With 50 percent maturity all the three crops with mineral fertilizer application matured first. Compost applied and control plots delayed in maturity for 5-7 days than the mineral fertilizer applied plots.

However, this delay is due to the continuous emergence of new ears (grains) in the different crops especially faba bean (field observation).

Based on the plant tiller, seeds per stick and general yield of all crops especially teff and barley farmers' preference, applications of mineral fertilizer and 6.4 $t.ha^{-1}.yr^{-1}$ compost plots are selected as the best. Many farmers appreciated the effect of the 6.4 $t.ha^{-1}.yr^{-1}$ compost application than the mineral fertilizer (Table 4.26). This is mainly due to there is no money required to produce.

Table 4.26 - Agronomic performance based on farmers' observation for the treatments (inputs)

Characteristics	**Teff**				**Barley**				**Faba bean**			
	C	**MF**	**3.2**	**6.4**	**C**	**MF**	**3.2**	**6.4**	**C**	**MF**	**3.2**	**6.4**
Germination (50% cover)	4	5	4	4	4	5	4	4	4	5	4	4
Moisture	4	3	4	5	4	3	4	5	4	4	5	5
Maturity period (50% cover)	4	5	4	4	4	5	4	4	4	5	4	4
More tiller	3	5	4	5	3	5	4	5	4	5	4	5
Seeds per stick	3	5	4	5	3	5	4	5	4	5	5	5
Accessibility	5	4	5	4	5	4	5	4	5	4	5	4
Yield (crop and biomass)	3	5	4	5	3	5	4	5	4	5	5	5
General adaptation by farmers	3	4	5	4	3	4	5	4	5	4	5	4
Total score	**29**	**36**	**34**	**36**	**29**	**36**	**34**	**36**	**34**	**37**	**37**	**36**

Key:- Score 1-5 (lowest - highest)

In the study area always rain delayed at the beginning and stops early in September and sometimes in late August. Therefore, farmers are shifting from long-season growing crops (millet, sorghum, maize and other varieties of teff) into short-season growing crops (barley, wheat, teff and legumes) to cope with this rainfall change. Heavy rainfall comes only in two months (July and August). Some times crops fail to mature. It was easy recognizable that in all crops in plots with mineral fertilizer matured faster while plots applied with 6.4 $t.ha^{-1}.yr^{-1}$ compost applications was good in their moisture holding during maturity period. Farmers said when rain stops early crops sown with compost wilt later than the crops with mineral fertilizer.

In all crops plant height at flowering stage were taller with mineral fertilizer than any other treatments. But at the maturity stage the mineral fertilizer and the 6.4 $t.ha^{-1}.yr^{-1}$ compost applied plots become approximately the same height. While the crops in the control plots were short (Table 4.27).

Table 4.27 - Agronomic characteristic situation based on farmers' observation.

Characteristics		**Teff**				**Barley**				**Faba bean**			
		C	**MF**	**3.2**	**6.4**	**C**	**MF**	**3.2**	**6.4**	**C**	**MF**	**3.2**	**6.4**
Plant height*	Flowering stage	3	1	2	2	3	1	2	2	3	1	2	2
	Maturity stage	3	1	2	1	4	3	2	1	4	3	2	1
Weed***		L	L	M	H	L	L	M	H	M	L	L	L
Color **		Y	G	G	DG	Y	G	G	DG	G	G	G	DG
Vigorousity***		H	L	M	L	H	L	M	L	H	L	M	L
Disease and insect***		L	H	L	L	L	H	L	L	L	H	L	L
Bird raid***		M	L	M	H	M	L	M	H	M	L	M	H

Key:- The numbers 1, 2 and 3 in the * sign show highest (first), second and third respectively. The letters in the ** sign show G – green, DG – deep green and Y – yellow. The letters in *** signs show as H – high, M – medium and L – low; MF - mineral fertilizer; 3.2 and 6.4 - compost application $t.ha^{-1}.yr^{-1}$

Colors of all crops were observed from germination to maturity in all treatments. Crops with 6.4 $t.ha^{-1}.yr^{-1}$ compost application were deep green than other treatments. All the control plots in teff and barley were yellowish in color. The vigorousity of barley and faba bean with control plots were resistant to wind than the other plots. While the plots with mineral fertilizer and 6.4 $t.ha^{-1}.yr^{-1}$ compost applications were affected by windy rain. This was due to their taller height than the other treatments (Table 4.27).

The density and size of weeds observed in the different treatments were not different from each other. There were similar types and relatively amounts of local weeds in all treatments. These may be transported by cattle or wind. However, there was relatively more weed in compost than the plots with mineral fertilizer and control plots. This may be sourced from weed seeds obtained from undecomposed composting materials.

More diseases and insect problem such as smut were observed in plots treated with mineral fertilizer. More bird raid was observed in composted plots than other input applications (Table 4.22).

4.3.4 The economic effect of compost and mineral fertilizer

4.3.4.1 Financial implications of the farm inputs

The five year (2003-2007) average cost of 150 kg mineral fertilizer (100 kg DAP and 50 kg Urea) was 594 ETB (equivalent with 59.4USD). This is at cash purchase price of mineral fertilizer. On the other hand the production cost of 3.2 t compost was 310 ETB while it was 620 ETB for 6.4 t compost. The production cost of preparing 6.4 t compost is higher by only 26 ETB (2.6 USD) than the cost of mineral fertilizer while the production cost of the 3.2 t compost is 52 % of the cost of the recommended mineral fertilizer (Table 4.28).

According to farmers' explanation the price of mineral fertilizer and the production cost of compost are divided into real price and indirect cost. The indirect cost is mostly human and animal labour (Annex 10.3-10.5).

Table 4.28 - Farmers' cost analysis Ethiopian Birr (ETB) for different inputs for a hectare of land

R.N.	Item	C	MF	3.2 $t.ha^{-1}.yr^{-1}$ compost	6.4 $t.ha^{-1}.yr^{-1}$ compost
1	Real price	-	496.73	-	-
2	Labor cost (indirect cost)	-	97.50	310.00	620.00
	Total cost	**-**	**594.00**	**310.00**	**620.00**

Source: survey data in the study area (2007). C - control; MF - mineral fertilizer.

The net income of teff and barley treated with mineral fertilizer are significantly higher than the control and 3.2 $t.ha^{-1}.yr^{-1}$ compost applications. The net income of the plots from the mineral fertilizer is 8,623 ETB (teff) and 18,297 ETB (barley). But it is not significantly different from the 6.4 $t.ha^{-1}.yr^{-1}$ compost application. It is higher by 120 and 300 ETB in teff and barley respectively than the 6.4 $t.ha^{-1}.yr^{-1}$ compost. On the other hand there was no significant difference in the net income of the 3.2 $t.ha^{-1}.yr^{-1}$ compost applied plots and the control plot of teff and barley (Table 4.29).

Table 4.29 - The net income of the three crops (teff, barley and faba bean) in Ethiopian Birr ($ETB.ha^{-1}$) under different treatments

Treatments	Teff	Barley	Faba bean
Control	$7{,}272 \pm 687^{bc}$	$13{,}866 \pm 2276^{bc}$	$22{,}566 \pm 2008^{a}$
Mineral fertilizer	$8{,}623 \pm 662^{a}$	$18{,}297 \pm 1218^{a}$	$25{,}366 \pm 3492^{a}$
3.2 $t.ha^{-1}.yr^{-1}$ compost	$7{,}664 \pm 639^{b}$	$15{,}202 \pm 1670^{b}$	$25{,}984 \pm 4890^{a}$
6.4 $t.ha^{-1}.yr^{-1}$ compost	$8{,}502 \pm 100^{ab}$	$17{,}926 \pm 1467^{ab}$	$27{,}896 \pm 4736^{a}$

Means with the same letter are not significantly different at $P<0.05$ confidence interval for Teff, Barley and Faba bean

There is no significant difference in the net income of faba bean under the different treatments and the control plot. However, with 27,896 ETB the 6.4 $t.ha^{-1}.yr^{-1}$ compost application is the highest. The net income of the 3.2 $t.ha^{-1}.yr^{-1}$ compost application is also higher than the mineral fertilizer application by 618 ETB (Table 4.29). In all crops control plots hold the lowest net income.

4.3.4.2 Marginal rate of return of the crops

The marginal rate of return of the yields of teff and barley (grain and straw) was found to be higher under mineral fertilizer. Where an additional one ETB invested can gain another 2.3 ETB (teff) and 7.5 ETB (barley). It is followed by the 6.4 $t.ha^{-1}.yr^{-1}$ compost application, which is less by only 0.30 ETB in teff and 0.90 ETB in barley from the mineral fertilizer application.

While the marginal rate of return of faba bean under 3.2 $t.ha^{-1}.yr^{-1}$ compost application was highest, this is a gain of 11.00 ETB by investing one extra ETB. It was followed by 6.4 $t.ha^{-1}.yr^{-1}$ compost application i.e., 8.00 ETB. The profitability of the use of the mineral fertilizer is less by about 57 percent from the 3.2 $t.ha^{-1}.yr^{-1}$ compost application (Table 4.30).

Table 4.30 - The Marginal Rate of Return (MRR) as affected by crop and treatment

Treatment	**Teff**	**Barley**	**Faba bean**
Control	0	0	0
Mineral fertilizer	2.3	7.5	4.7
3.2 $t.ha^{-1}.yr^{-1}$ compost	1.3	4.3	11.0
6.4 $t.ha^{-1}.yr^{-1}$ compost	2.0	6.6	8.0

This is reflected that mineral fertilizer gave the best return for teff and barley while faba bean is far better in 3.2 $t.ha^{-1}.yr^{-1}$ compost application. Therefore, the result of the study shows that farmers are right that input applications are crop specific. Then blanket recommendations of any types of inputs do not work. It implies that farmers need to apply mineral fertilizer for the best achievement in marginal gains. It is followed by the 6.4 $t.ha^{-1}.yr^{-1}$ compost application on teff and barley crops. However, it is preferable to apply 3.2 $t.ha^{-1}.yr^{-1}$ compost for a higher return in the faba bean (Table 4.30).

4.4 Farm level partial nutrient balance

The partial nutrient balance of the study considered only the most important inputs and outputs. These are: the inputs include mineral fertilizer (**IN1**), organic inputs (**IN2**) and biological N-fixation (**IN4**), while the output harvest products or grain (**Out1**) and residues removed (**Out2**). The others (atmosphoric deposition-(**IN3)**, Sedimentation-(**IN5)**, leaching losses-(**Out3)**, gaseous losses-(**Out4)**, and erosion-(**Out5**) were not considered due to their complexity in measurement and calculation.

4.4.1 Farm level nutrient import

In the input utilization the amount applied and the nutrient content of the compost are influential. The national recommended rate of mineral fertilizer in drier areas of Ethiopia (100 kg DAP and 50 kg Urea) supplies around 39 kg N $ha^{-1}.yr^{-1}$ to the soil. While the 6.4 $t.ha^{-1}.yr^{-1}$ compost application supplied 36.4 kg N $ha^{-1}.yr^{-1}$. The later is about 93% of the N supply of the mineral fertilizer. But other types of compost are higher in their N level (42-44 $kg.ha^{-1}.yr^{-1}$ from the farm residue and urban waste compost) by 6.4 $t.ha^{-1}.yr^{-1}$ compost application rate (Annex 11.1). However, the over-all average nitrogen supply from the 3.2 $t.ha^{-1}.yr^{-1}$ compost application is only 18.2 kg, which is below 47% of the N supply of the mineral fertilizer application (Figure 4.13; Annex 11.2 and 11.3).

Moreover, the N input supply varies from crop to crop because legume crops gain more N through biological N-fixation than other crops. For example, faba bean gains more N i.e., about 125 kg N $ha^{-1}.yr^{-1}$ through biological N-fixation. The N fixation of faba bean is extrapolated from the overall average of 10-350 kg N ha^{-1} in Australia and 54-133 kg N ha^{-1} in the Middle East study by Rochester et al., (1998) and 76-125 kg N ha^{-1} of the study by Carranca et al., (1999). The mount of N gained through biological N-fixation accounts 72-87% of the total inputs of applications while the control plots gained 100% of their N supply through biological N-fixation (Figure 4.13-4.14; Table 4.31; Annex 11.3).

In all crops the phosphorous added to the soil from the recommended rate of fertilizer is 18 kg P $ha^{-1}.yr^{-1}$. But the P from 3.2 $t.ha^{-1}.yr^{-1}$ and 6.4 $t.ha^{-1}.yr^{-1}$ compost application is only 1.1 and 2.3 $kg.ha^{-1}.yr^{-1}$ respectively. They are insignificant amount, which covers only 6-13 percent of the P supplied by the mineral fertilizer (Annex 11.2-11.3). All types of compost gives very small amount of P, which is less than 2.5 $kg.ha^{-1}.yr^{-1}$ (Figure 4.13-4.14; Table 4.31; Annex 11.1).

The amounts of potassium (K) supplied through compost applications are 16 and 32 $kg.ha^{-1}.yr^{-1}$ from the applications of 3.2 $t.ha^{-1}.yr^{-1}$ and 6.4 $t.ha^{-1}.yr^{-1}$ of compost respectively (Figure 4.13-4.14; Annex 11.2-11.3). There is no K added to the soils in the control and the mineral fertilizer plots. Because there is no recommended K application as mineral fertilizer in Ethiopia. However, different types of compost can supply different amounts of potassium i.e., 18, 54 and 24 kg K $ha^{-1}.yr^{-1}$ from farm residue compost, *Parthenium* compost and urban waste compost respectively at 6.4 $t.ha^{-1}.yr^{-1}$ compost application rate (Annex 11.1).

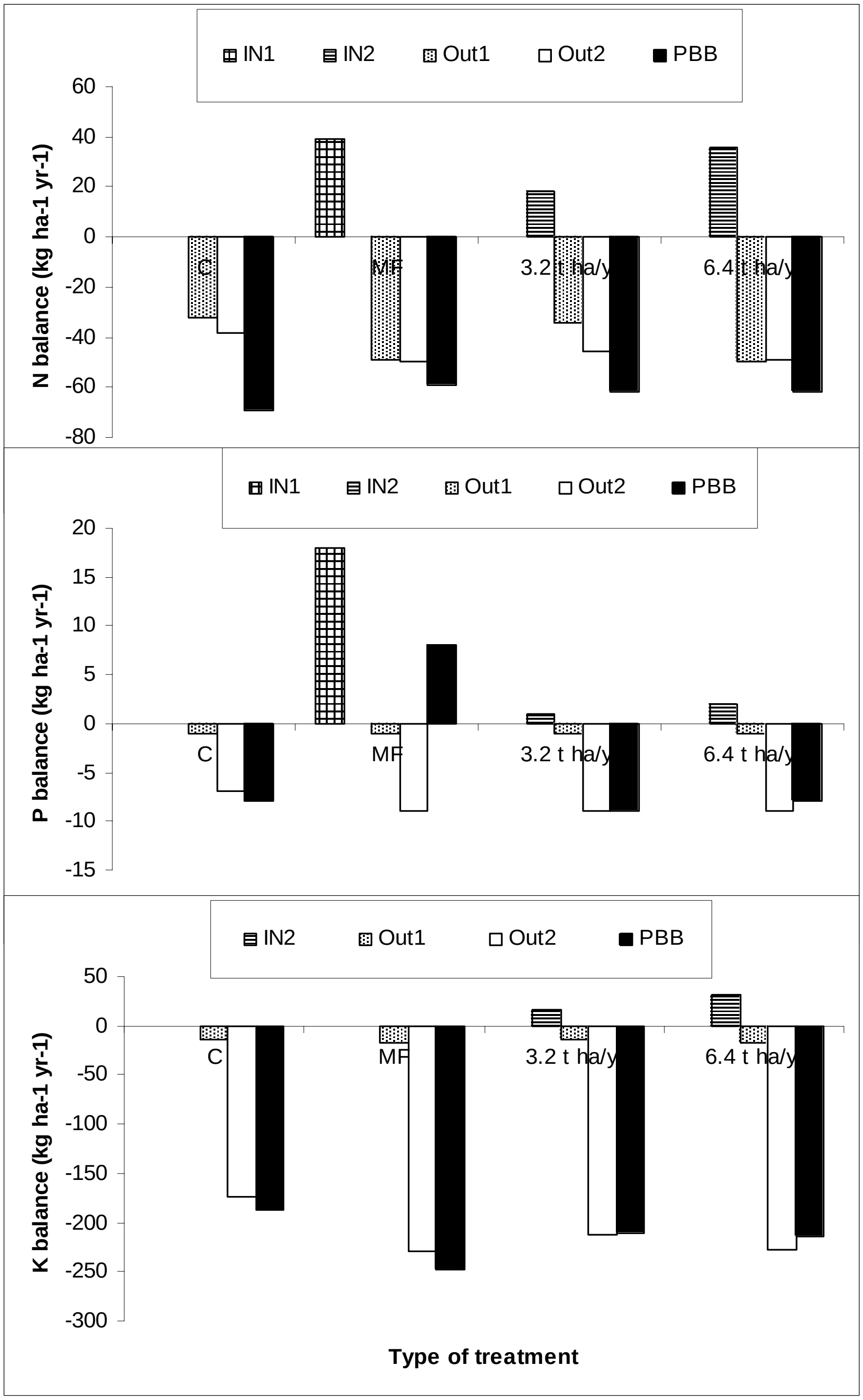

Figure 4.13 - The N, P and K input-output balance (kg.ha^{-1}.yr^{-1}) for barley. Where IN1 (mineral fertilizer), IN2 (organic inputs), Out1 (output harvest products or grain), Out2 (residues removed) and PBB (partial balance for barley). Inputs represent the amount supplied as mineral fertilizer or compost and biological N-fixation, and the output represents the nutrient removal by the crop (grain or biomass). Values represent averages of 6 replications.

4.4.2 Farm level export of nutrients

In all the crops (faba bean and barley) huge amounts of nutrient are exported by both grain and straw. This is because they are very important for human food and animal feed in the mixed-farming system. The highest N removal are 386 kg N $ha^{-1}.yr^{-1}$ from faba bean and 99 kg N $ha^{-1}.yr^{-1}$ from barley. All are from the 6.4 $t.ha^{-1}.yr^{-1}$ compost applied fields. The N removed in barley with mineral fertilizer and 6.4 $t.ha^{-1}.yr^{-1}$ compost applications are highest (Figure 4.14; Annex 11.2-11.3).

Phosphrous removal in barley ranges 8-10 $kg.ha^{-1}.yr^{-1}$. The lowest phosphorous removal is in the control plot while the rest are almost similar. The lowest P removal in the faba bean (21 $kg.ha^{-1}.yr^{-1}$) is also from the control plot while the highest removal (25.6 $kg.ha^{-1}.yr^{-1}$) is from 6.4 $t.ha^{-1}.yr^{-1}$ compost applied fields (Figure 4.13-4.14; Table 4.31; Annex 11.2-11.3).

Potassium removals are highest in both crops 188-247 $kg.ha^{-1}.yr^{-1}$ from barley and 236-286 $kg.ha^{-1}.yr^{-1}$ from faba bean (Table 4.31). In both crops the removals are lowest in the control plots. Where as the highest are in the plots with mineral fertilizer and 6.4 $t.ha^{-1}.yr^{-1}$ compost applications for barley and faba bean respectively (Table 4.24-4.25).

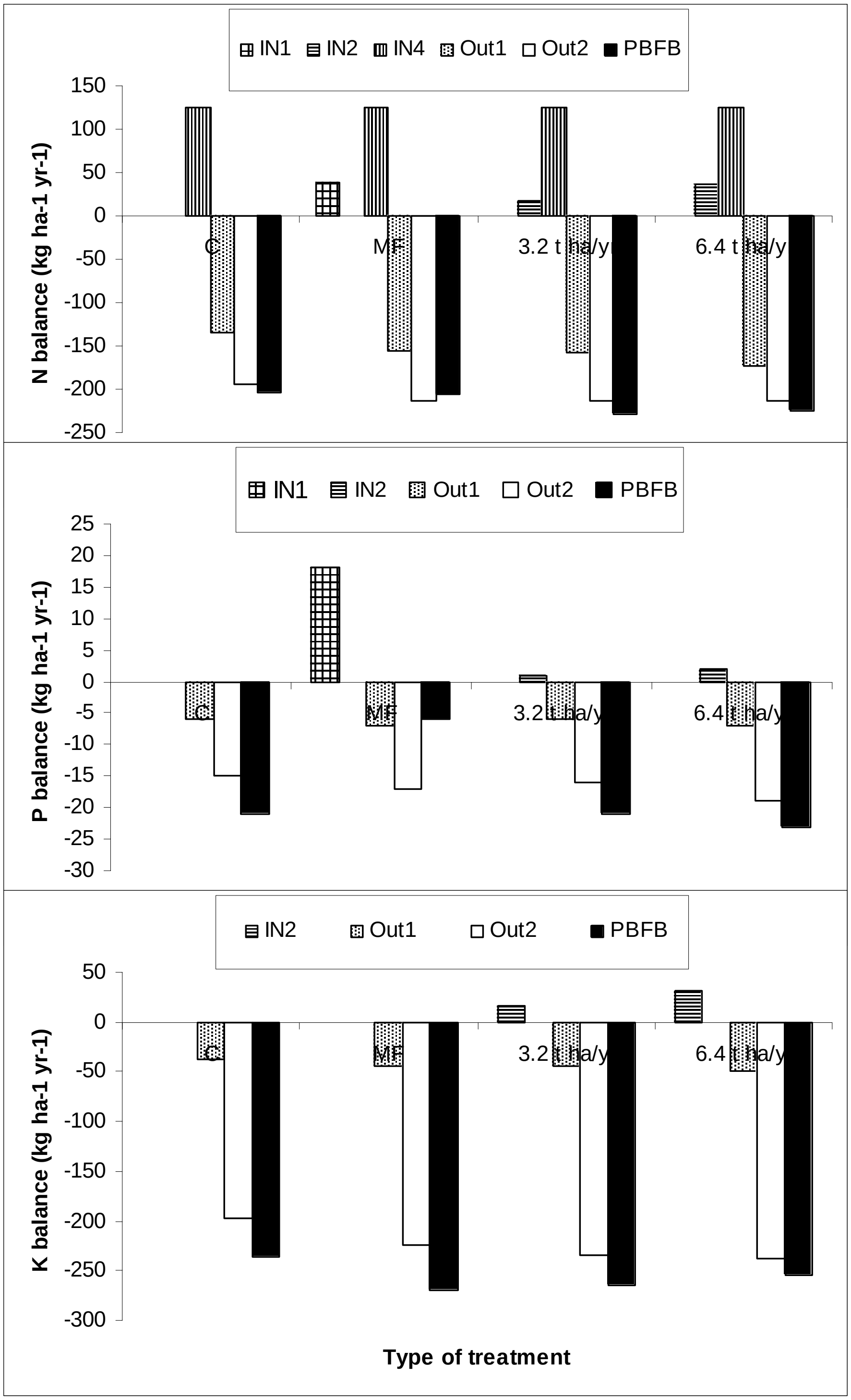

Figure 4.14 - The N, P and K input-output balance ($kg.ha^{-1}.yr^{-1}$) for faba bean. Where **IN1** (mineral fertilizer), **IN2** (organic inputs),**IN4** (biological N-fixation), **Out1** (output harvest products or grain), **Out2** (residues removed) and **PBFB** (partial balance for faba bean). Inputs represent the amount supplied as mineral fertilizer or compost and biological N-fixation, and the output represents the nutrient removal by the crop (grain or biomass). Values represent averages of 6 replications.

4.4.3 Partial input-output nutrient balance

The partial input-output nutrient balance showed N in the faba bean farms are depleted above 204 kg N $ha^{-1}.yr^{-1}$ while the barley ranges between 59 and 69 $kg.ha^{-1}.yr^{-1}$. In the barley the highest (negative) nutrient balance of N was from the control plots (-69 kg N $ha^{-1}.yr^{-1}$). It is because there was no input application for the compensation of the nutrients removed. While in the faba bean the highest is from both compost applications especially the 3.2 $t.ha^{-1}.yr^{-1}$ compost application plots i.e., -228 kg N $ha^{1}.yr^{-1}$. The lowest balance for N in barley crop is for the plots with mineral fertilizer. It is because the amount of N added as mineral fertilizer holds higher compensation. In faba bean the lowest is from both the control and mineral fertilizer applied plots. This is directly related to the low yield and mineral fertilizer application respectively (Table 4.31).

The partial input-output nutrient balance for P in the barley showed all treatments and the control are negative but the plots with mineral fertilizer application are positive (+7.8 $kg.ha^{-1}.yr^{-1}$). In the faba bean crop mineral fertilizer applied fields are still the lowest depletion (-5.6 $kg.ha^{-1}.yr^{-1}$) nearer to an equilibrium. This is directly the reflection of the application of mineral fertilizer. Highest depletions in barley and faba bean are in the 3.2 and 6.4 $t.ha^{-1}.yr^{-1}$ compost applications respectively (Table 4.31). This is the reflection of the smaller amount of phosphorous applied by the composts.

The partial nutrient balance indicates depletion of K is high in all crops and treatments. The lowest depletion is potassium i.e., 188 and 236 $kg.ha^{-1}.yr^{-1}$ in barley and faba bean respectively are in the control plot. While the highest depletion is observed in the mineral fertilizer plots i.e., -247 and -269 $kg.ha^{-1}.yr^{-1}$ for barley and faba bean respectively. This is directly the reflection of the type of input and dependent on the amount of yield. Because there was no much difference in the NPK content of the grains and straw (Table 4.24 - 4.25).

Table 4.31- Partial input-output balance of NPK in barley and faba bean (kg.ha^{-1}.yr^{-1})

	Treatment	Barley			Faba bean		
		Input	Output	Partial balance	Input	Output	Partial balance
	Check	0	69.2	-69.2	125	328.7	-203.7
	Mineral fertilizer	39	98.1	-59.1	164	368.5	-204.5
N	3.2 t.ha^{-1}.yr^{-1} compost	18.2	79.5	-61.5	143.2	371.0	-227.8
	6.4 t.ha^{-1}.yr^{-1} compost	36.5	98.9	-62.4	161.5	386.1	-224.6
	Check	0	7.7	-7.7	0	20.6	-20.6
	Mineral fertilizer	18	10.2	7.8	18	23.6	-5.6
P	3.2 t.ha^{-1}.yr^{-1} compost	1.1	9.7	-8.6	1.1	22.1	-21.0
	6.4 t.ha^{-1}.yr^{-1} compost	2.3	10.2	-7.9	2.3	25.6	-23.3
	Check	0	187.5	-187.5	0	235.9	-235.9
	Mineral fertilizer	0	247	-247.0	0	268.9	-268.9
K	3.2 t.ha^{-1}.yr^{-1} compost	16	227	-211.0	16	280.2	-264.2
	6.4 t.ha^{-1}.yr^{-1} compost	32	246.4	-214.4	32	286.3	-254.3

The nutrient removal by crop cultivation especially by faba bean is immense. The control plot has the lowest removal in both crops, which corresponds with its lower production. It is also highly related to the lowest amount of input application especially no K application through mineral fertilizer. On the other hand, whenever input is applied to the soil, production and nutrient removal increases. This removal shows that the soil nutrients are highly exploited by the crop production system. Much of the removal in all crops is from straw than grain. For example, the NPK removal from the barley straw accounts 50-58, 89-91 and 93-94 percent while from faba bean it is 55-59, 70-73 and 83-84 respectively to their total removal (Annex 11.2 and 11.3).

Table 4.32 - Years the estimated N, P and K stock at plough layer level can compensate as per treatment situation

Treatment	N		P		K	
	barley	faba bean	barley	faba bean	barley	faba bean
Control	17	6	6	2	2	2
Mineral fertilizer	20	6	unlimited	8	2	1
3.2 t.ha^{-1}.yr^{-1} compost	20	5	5	2	2	1
6.4 t.ha^{-1}.yr^{-1} compost	20	5	6	2	2	2

The existing NPK stock in the plough layer soils of the study area show that soil nutrients very low. The estimated plough layer stock show N, P and K can give yields for a very short period of time. The phosphorous in the stock can serve for unlimited time by the present rate of mineral fertilizer but it is only when cropped with barley. On the other hand it only serve for 2-8 years by planting faba bean. Nitrogen in the plough layer can compensate longer years for 17-20 years by planting barley only while it is for 5-6 years by faba bean. Potassium in the plough layer is almost neglegible for both crops, which does not serve more than 2 years at this removal level. The mineral fertilizer application serves more years in phosphorous while 6.4 $t.ha^{-1}.yr^{-1}$ better in potassium (Table 4.32). Therefore, it requires to be improved to sustain and increase crop production.

4.5 Soil fertility management

4.5.1 Farmers' preferences for soil fertility management technologies

All the crop rotation, animal manure, planting multi-purpose trees and compost are strongly implemented by over 85 percent of the respondent farmers. Using crop rotation as a means of soil fertility renewal is still very high through out the country. About 87 percent of the farmers are using crop rotation every year while the other 13 percent are partially using crop rotation. This is because some of their farms found near to their houses and they are very fertile because they are over manured. Physical and biological Soil and Water Conservation work in cultivated and non-cultivated fields is strongly used by over 83% and still over 14% start to reclaim the physical loss of soil from their farms (Table 4.33). Due to high land degradation it can be concluded that nobody is out of this practice. This is supported by growing multipurpose trees in order to use them mainly for animal feed and protecting soil and water removal. It accounts for over 90 percent of the respondents.

About 75% of the respondents are using mineral fertilizer; however, the amount used varies from family to family. The majority of the respondents said, they buy the mineral fertilizer because they are able to buy mainly from their earnings especially from irrigation. They also use it by mixing with compost and animal manure. There are farmers, who buy 50 or 100 kg mineral fertilizer in order to share with other farmers.

Farmers said the most known soil nutrient renewing techniques are applications of animal dung, compost or planting legumes through crop rotation. Always after legume any type of crop can be planted. Nowadays due to the land shortage fallowing is almost unthinkable to practice in Tigray. Planting some type of crops such as flux is considered as fallow or resting period. This is because the owner of the plot does not plough it properly and wanted to occupy the field rather than let cattle graze freely the biomass grown in the field. Intercropping is practiced mainly in vegetables in irrigation areas. In some field plots crops like mixing oil crops with teff, or tomato with teff, finger millet, sorghum, maize, faba bean etc. is practiced. Leaving crop residues are new and resisted by farmers because farmers take all crop residues back home as animal feed and again they let their animals to graze in the harvested field.

Table 4.33 - Farmers' responses (n=171) to different soil fertility management practices

R.N	Traditional Practices	Regular users	Partial users	Tend to leave	Non users
1	Fallow	1.7	0.6	5.3	92.4
2	SWC *(Kirit or Gedeba)*	83.5	14.1	1.2	1.2
3	Crop rotation	87.1	12.9	0	0
4	Animal manure	81.9	15.2	1.2	1.7
5	Planting multi-purpose trees	38.6	56.7	2.3	2.3
6	Compost	38.6	59.6	1.7	0
7	Mineral fertilizer	60.2	15.2	22.2	2.3
8	Mixed cropping (intercropping locally called *Ziniq* and/or *Wahrar*)	12.3	17.5	0	70.1
9	Leaving crop residues in the field	0	22.8	47.4	29.8

Source: field assessment and questionnaire.

Soil type, level of soil fertility and type of soil management vary from place to place and differ based on the difference in the management practices. The type of input used and the soil fertility management practices also vary based on the moisture availability. The score of the respondent farmers show most farmers use compost and animal manure (Table 4.34).

Table 4.34 - The degree of preference for input or practices by farmers for improving soil fertility and yield

R.N.	Farming in	Condition	Preference scores for improving soil fertility and yield				
			MF	**Com**	**AM**	**Fallow**	**SWC**
1	BA'EKHEL (light-yellow)	High RF	3	4	5	-	2
		Low RF	3	5	4	1	2
2	HUTSA - sandy	High RF	2	5	4	-	3
		Low RF	2	5	4	-	3
3	Deep WALKA (clay)	High RF	5	4	4	-	-
		Low RF	3	5	5	-	-
4	Shallow WALKA (clay)	High RF	3	5	5	-	2
		Low RF	-	5	4	-	3
5	Stony	Plain	2	4	4	-	5
		Steep slope	-	3	3	4	5
6	Irrigation	Sufficient water	5	4	4	-	-
		Less water	1	5	4	3	2
	Total score		**29**	**54**	**50**	**8**	**27**

Key: MF – mineral fertilizer; Com – compost; AM – animal manure; SWC – soil and water conservation. Where: 5 is the highest and 1 is the lowest value.

Farmers prefer using compost and animal manure in sandy (*Hutsa*) soils and moisture stressed areas. This is because farmers believe that sandy soil is succeptible to moisture stress, when dressed with mineral fertilizer. They apply mineral fertilizer in deep soils with good water suppply (high rainfall or irrigation). But this also depends on the family´s capacity to buy mineral fertilizer. SWC practices are highly used in stony or gravelly farms supported by local inputs (compost and animal manure (Table 4.34).

The experience of many farmers indicate a continuous use of mineral fertilizer in irrigation areas without sufficient water supply for more than four years resulted in crust formation. They believe it is a sign of unhealthy soil. While using compost or animal manure in all irrigation fields is one way of healing the soil especially the crust formation. Moreover, it is a guarantee for a better income. The high scores in the Table 4.34 indicates the degree of farmers' preference for compost and animal manure.

4.5.2 Trends in input utilization and marketing

The consumption rate of all types of inputs increased from time to time. The use of the different inputs in the Tahtai Maichew District increased between 2005 and 2007 such as compost from 7,685 into 28,071 tons; animal manure from 13,722 into 34,190 tons and mineral fertilizer from 166 into 320 tons. Regardless of the low amount of mineral fertilizer used there is an increase of 265, 149 and 92 percent in compost, animal manure and mineral fertilizer respectively (with a decrease in 2006). The application rate of inputs per hectare have been increased between 2005 and 2007 i.e., mineral fertilizer from about 73 to 85 kg, compost from 1.5 to 4.6 tons and animal manure from 2.0 to 4.6 tons (Table 4.35).

Table 4.35 - Amounts and types of input used by farmers in Tahtai Maichew district in 2005 - 2007

R. N.	Types of input	2005			2006			2007		
		t	ha	$t.ha^{-1}$	t	ha	$t.ha^{-1}$	t	ha	$t.ha^{-1}$
1	DAP and Urea	166	2 282	72.6*	295	5 865	50.2*	320	3 752	85.2*
2	Compost	7 685	5 125	1.5	6 002	4 268	1.41	28 071	6 106	4.60
3	Manure	13 722	6 861	2.0	13 080	6 540	2.0	34 190	7 433	4.60

* Indicates kg of DAP and Urea (mixed) per hectare consumption (not ton per hectare).
Source: Tahtai Maichew District Agriculture office (extension department).

The preparation and use of compost is increasing with time through out the region if not through out the country. It is evident that more than 190,000 farming families in the Tigray Region produced 237,684 ton of compost and applied to over 101,000 hectares of cultivated land (Annex 13). The rough regional application rate from this data is between 2 and 3 ton per hectare. About 12 percent (28,000 ton) of the total compost is used by the farmers in the Tahtai Maichew district, where the study area is located. This district and its neighboring districts (Laelai Maichew, Adwa and Naeder Adet) produced 53,000 ton of compost (Annex 13). This is due to the recent scaling up undergone by farmers supported by the government and NGOs to counteract against to the ever increasing fertilizer prices.

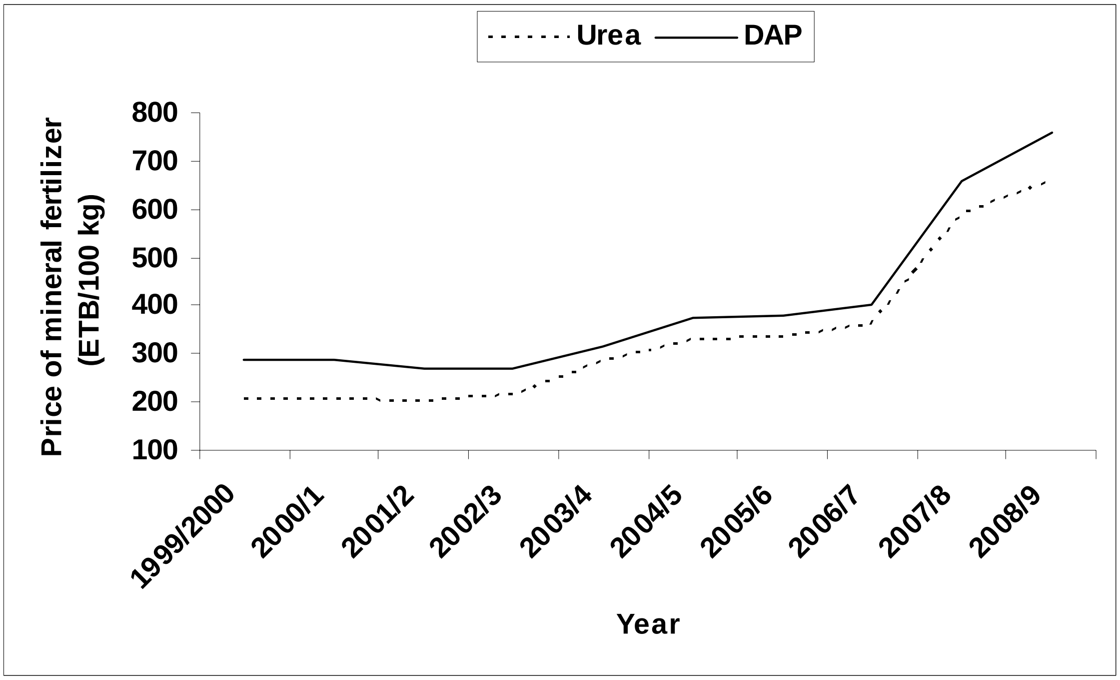

Figure 4.15 - Trend of mineral fertilizer prices between 1999/2000 and 2008/9 at Tahtai Maichew District (ETB/100kg). Source: Tahtai Maichew District Agriculture Office (Extension Department)

In the Tahtai Maichew district the price of DAP has increased from about 288 ETB to about 760 ETB and Urea increased from about 207 ETB to 660 ETB (1USD=10 ETB by 2007) (Figure 4.15). This is an increase of 264% (DAP) and 319% (Urea) between 1999/2000 and 2008/9 respectively. This increase has discouraged many smallholder farmers from buying and using mineral fertilizer.

Table 4.36 - Amount of mineral fertilizer supplied and consumed by farmers in Tahtai Maichew District (2005 -2007) in tons

Types of inputs	**2005**		**2006**		**2007**	
	Supplied	**Consumed**	**Supplied**	**Consumed**	**Supplied**	**Consumed**
DAP	222	61 (27.5%)	303	100 (33.1%)	148	121 (81.6%)
Urea	197	104 (53.1%)	239	194 (81.3%)	198	*199 (100.0%)
Total	**417**	**166 (39.5%)**	**542**	**295 (54.4%)**	**347**	**320 (92.2%)**

Source: Tahtai Maichew District Agriculture Office (extension department). *Brought from another district.

The overall supply of mineral fertilizer, in Tahtai Maichew district is very little. It is only between 347 and 542 $t.yr^{-1}$. The consumption is also very low, which accounts for 40 and 92 percent of the total supply. The consumption of Urea ranges from 53 to 100 percent of the supply as compared to the 27.5 to 81.6 percent of the DAP fertilizer (Table 4.36). This shows us that farmers buy more of the Urea than the DAP fertilizer. According to the response of the farmers during the group discussion and field assessment they found out that urea fertilizer gives more yield but this is generally less sustainable.

5. DISCUSSIONS

The main objective of this discussion is to assess the situation on the following points **1.** identifying the present status of the soils of the study area. **2.** compost production capacity of smallholder farmers. **3.** effect of the present application rate of compost on soil characteristics and yields. **4.** the nutrient balance under the application of compost and mineral fertilizer. **5.** Assessing, if the smallholder agriculture is sustainable under low input agriculture.

5.1 Soil fertility status

All the profiles indicate that the soils in the study area are deeper than one meter, which ranges between 110 and 207cm (Table 4.4). Many of the soil types referred except Lithosols (Leptosols), Rendzinas and limited Vertisols of Hagere Selam area are deeper than one meter (Aseffa, 2005; Mitiku, 1997; Virgo and Munro, 1977). The plough layers of all soils are dominated by loam and silt loam texture. The plough layer of most soils, except Vertisols, of the studies undertaken by Nyssen et al (2008), Aseffa (2005), Mitiku (1997) and Virgo and Munro (1977) show textures are sandy-loam, sandy-clay-loam or loam.

Therefore, these soils are dominated by soil sediments derived from the adjacent hills, because of the commonly seen severe soil erosion in Tigray (Esser et al., 2002). The locations of the profiles, which are in the foot slopes, are also evidences for the erosional deposition of the soils. Virgo and Munro (1977) reported that the result of the empirical methods and suspended sediment measurements indicate high rates of regional soil loss (17-33 $t.ha^{-1}.yr^{-1}$), accounted for by seasonally high rates of rainfall erosivity, steep terrain and poor land use. Applications of the universal soil loss equation to arable lands indicate potential annual soil losses are in the range of 400 $t.ha^{-1}$ on the Vertisols and 200 $t.ha^{-1}$ on the Cambisols.

The plough layer bulk density of all the profiles range between 1.05 and 1.34 $g.cm^{-3}$ (Table 4.4). It goes in line with the finding of Baruah and Barthakur (1997) that bulk density of loams and clay loam, generally vary from 1.1 to 1.5 $g.cm^{-3}$. This indicates that the soils are not compacted. These low values are against the general principle, that soils cultivated for a long period are reflected by higher values of bulk density (Tegene, 1996).

The plough layer of all the soils are characterized by weakly alkaline to moderately alkaline reactions (pH values) and low level of EC (Table 4.4). Regardless of the soil type all studies indicate a pH value of weakly alkaline to moderate alkaline reactions (Van de Wauw et al., 2008; Mitiku et al., 1997; Tegene, 1996; Virgo and Munro, 1977). The soil reaction of Vertisols vary from weakly acid to weakly alkaline; pH-values are in the range 6.0 to 8.0. Higher pH values (8.0-9.5) were measured on Vertisols with much exchangeable sodium (FAO, 2001). Even though the pH values (1:2.5 soil:water) do not have precise significance but some generalizations can be made. Therefore, generally they are not problematic for crop cultivation (Landon, 1991).

The organic matter contents of the soils range between 1.26 and 2.38 percent at the plough layer (Table 4.5). The highest OM (2.38%) level is observed in Profile-04, which is a Vertic Luvisol. A research work conducted around Axum by Schmid et al. (2008) without specifying the soil type reported that organic matter in the area is low. The organic carbon of the Vertisols of the Hagere Selam area of Central Tigray contain 1.1-1.6 percent (Van de Wauw et al., 2008) while the Gormedo area reported as 2.6 percent (Mitiku, 1997). The organic carbon contents of the Luvisols are at low level, but vary widely from the lowest 0.4 percent in Tabeldi to the highest 1.4 percent in both Romanat and Teghane (Aseffa, 2005; Mitiku, 1997). While the organic carbon of the Cambisols range from the lowest 0.3 percent in Quiha to 2.35 percent in Teghane (Aseffa, 2005; Virgo and Munro, 1977).

The nitrogen content in the soil profiles is at a very low level, which ranges from 0.04 to 0.07% (Table 4.5). The nitrogen content of the Vertisols of the Hagere Selam area of the Central Tigray is 0.09-0.16 percent (Van de Wauw et al., 2008); the Melbe area also reported the percentage of total nitrogen in the surface soils as 0.07-0.13 in the cultivated soils while 0.20-0.27% in the uncultivated soils (Tegene, 1996). Luvisols reported low (0.122%) while Cambisols higher (0.227%) both in Teghane, Tigray (Aseffa, 2005). C:N ratio of a soil is a good indicator of organic matter quality and the degree of humification (Schmid et al., 2008). Four of the six profiles (01, 02, 04, and 06) have C:N ratio of 18 and above (Table 4.5). This value slows mineralization of organic matter. The low nitrogen content might be attributed to the longer history of cultivation and other types of land degradation, especially erosion. There is also very little replenishment to the soil (Tegene, 1996).

The phosphorous (P) in general does not occur as abundant (Bergmann, 1992). P in the plough layer of the soils in the study area shows a wide range from 8.2 to 46.9 mg.kg^{-1} (Table 4.5). Phosphorous contents are adequate in the plough layer soils of the 3 profiles (01 or Fluvic Vertisol, 03 or Endoleptic Cambisol and 04 or Vertic Luvisol) for cereals, grasses, soybeans, and maize. The P in the other two profiles i.e., 05 and 06 (both Vertic Cambisols) are in the low level. Profile-02 (Vertic Luvisol) is deficient with 8.2 mg P kg^{-1} (Landon, 1984; Tegene, 1996) (Table 4.5). This is in agreement with the findings of Schmid et al. (2008).

The potassium (K) levels in the plough layer of the soils are above 100 mg.kg^{-1}. But according to the rating of Landon (1991) the K levels of these soils are at low level. It may be because potassium is absorbed by plants in larger amounts than any other nutrient except nitrogen (Bergmann, 1992). Therefore, the soils of Tigray in general and the study area in particular are not adequate in potassium. It is against the generalized conclusion of the studies in Ethiopia that potassium is adequately available in the soil.

The cation exchange capacity (CEC) is an indicator of the potential fertility levels of soils. CEC for all profiles vary from 275 to 544 mmol.kg^{-1} (Table 4.5). There are five sites at high (250-400 mmol.kg^{-1}) level and only one, which is Fluvic Vertisol, is at a very high level i.e., 540 mmol.kg^{-1}. The Vertisols of the Hagere Selam area of Central Tigray contain CEC 39.1-57.9 cmol(+) kg^{-1} soil (Van de Wauw et al., 2008). Most Vertisols have a high cation exchange capacity (CEC). The CEC of the soil material (in 1 M NH_4OAc at pH 7.0) is commonly between 30 and 80 cmol(+)/kg of dry soil; the CEC of the clay is of the order of 50 to 100 cmol(+)/kg clay (FAO, 2001). While the Chromic Vertisol in Quiha by Virgo and Munro (1977) with CEC (28) is much lower. Moreover, Landon (1991) recommended a supplement of small quantity of lime and K fertilizer to such soils.

The character of the top soil of the study area, loam and silt loam, shows more the character of deposition from erosion than development from parent rocks. This is because Tigray is one of the seriously eroded parts of the country. Even though the properties of the plough layer soil (OM, N, P and K) of the study vary from place to place, they are dominantly not adequate for crop production. Therefore, there is no guarantee for a sustainable production unless maintained with a better nutrient replenishment.

5.2 Compost production and quality enhancement

5.2.1 Compost production capacity of farmers

Nowadays composting is widely expanding to the farmers of Sub-Saharan Africa to improve soil fertility and crop production (Mugwe et al., 2007). It is also the case in Ethiopia, particularly in the last two decades. For example, by 1995 compost was used by 11 percent of the contacted farmers in Southern Ethiopia (Elias, 2002), while there are no data for this period available for Tigray. But by 2005 about 25 percent of the farmers in Tigray practiced composting (Araya and Edwards, 2006; SSNC, 2008). While the present study found out that in the present time about 88 percent of the farmers in the study area are using compost (Table 4.33).

The average amount of compost prepared and used in the study area is 3.2 $t.ha^{-1}.yr^{-1}$. It varies from 2.8-6.0 $t.ha^{-1}.yr^{-1}$. Compost applications vary from farmer to farmer and from country to country depending on amount produced and types of crop used and the soil (Table 4.7). The dry matter application rates of compost in other countries is also variable from the lowest 10 and 11.2 $t.ha^{-1}.yr^{-1}$ (Manna et al., 2001; Smiciklas et al, 2008) in the semiarid part of India to over 134 $t.ha^{-1}.yr^{-1}$ in the Illinois, US (Smiciklas et al, 2008). The equivalent amounts of N, P and K applied as compost vary very much 60-123 (N), 13-45 (P) and 17-78 (K) $kg.ha^{-1}$ (Manna et al., 2001). The highest N, P and K application through compost are 1,478 (N), 538 (P) and 941 (K) $kg.ha^{-1}$ (Table 2.2). The later applications are far beyond the usual nutrient applications through organic and inorganic fertilizers.

This shows that the amounts of compost applied by the farmers of the study area are very small compared to the other applications. Therefore, the yields of the different crops directly indicate the need to improve the amount of compost production level at least to 6.4 $t.ha^{-1}.yr^{-1}$ (Section 4.4). But this depends on the availability of biomass (Drechsel and Reck, 1998).

Based on the assessments conducted in Ethiopia, composting biomass availability is abundant if well managed. For example, Tulema et al. (2007) estimated the total annual available biomass (dry matter basis) for Ethiopia as 22.7×10^6 t dry-manure, 12.7×10^6 t crop-residue and various other unexploited organic matter by-products. The other country level estimate by Devi et al. (2007) is 1.6×10^{11} (compost/vermicomposting), 8.5×10^9 (poultry manure) and 1.8×10^{10} $t.yr^{-1}$ (FYM).

This high manure availability is mainly because Ethiopia in general has the highest livestock population in Africa (Zinash, 2001) and of course animal manure is mostly available to the farmers who own cattle (Kikafunda et al., 2001). Cattle ownership is common in Africa in general and Ethiopia in particular. This study also confirmed that over 92 percent of the respondants own cattle, which gives evidence for the availability of animal manure (Table 4.15). 68 percent of the respondant farmers can accumulate sufficient amounts of animal manure (Table 4.15) to prepare 6.4 $t.yr^{-1}$ compost. At least they qualify for the minimum requirement to get enough animal manure. This is because they own the recommended number of animals, which is 3 cattle per family.

However, the amounts of manure available from cattle are variable. There are limited estimates on manure production from each cow or ox per day or per year. For example, estimated manure production at Kano, northern Nigeria, by farm-holding ranged between 2.3-15.3 t over two years (Harris, 1998). Detailed estimations state that one zero-grazed cattle produces 1-1.5 $t.ha^{-1}.yr^{-1}$ manure (Nandwa and Bekunda, 1998; Stroebel, 1987). Another study by Laegreid et al. (1999) showed that one cow can give manure with amounts of 4, 10 and 5.5 $t.yr^{-1}$ as liquid, slurry and stable manure respectively.

The present production capacity of farmers without much care or management is only 3.2 $t.ha^{-1}.yr^{-1}$. But as it is shown in Chapter 4, this application rate is not sufficient to produce similar yields to the 150 $kg.ha^{-1}.yr^{-1}$ mineral fertilizer applications. Therefore, our focus should go to the 6.4 $t.ha^{-1}.yr^{-1}$ or more compost application. From the assessment made in this study, 50 percent of the farmers responded that they can be able to produce over 6.4 $t.yr^{-1}$ compost, while 31 percent of the farmers responded as they can only produce 3.2-6.4 $t.yr^{-1}$ (Section 4.2.2; Annex 6.1). These amounts could be achieved, if farmers improve their biomass and manure management and plant different types of trees around their farms and/or homesteads (Annex 6.2). It is possible for farmers to get sufficient amount of biomass to prepare 6.4 t and above compost annually. But this requires better management than before in collecting, storing and preparing compost. It is mentioned that not all types of composting materials are available throughout the year (Section 4.2.5). Therefore, the availability of biomass should be improved through continuous biomass collection and storage management. The existing potential shows that 68 percent of the surveyed farmers own the required number of cattle (three and above). The other good opportunity to enhance the availability of biomass is to strengthen the rural and urban relationships by re-importing the nutrients as urban waste, which were exported as food system. These are important indicators for the need of effective organic waste management for the urban and closing the natural ecological cycles (Erhart et al., 2007).

5.2.2 Compost quality enhancement

The study showed that the average OM, OC and N of the composts produced by farmers is low while the C:N ratio is rather high (Annex 7.1-7.2). The organic carbon content in the composts vary from 48 to 72 $g.kg^{-1}$ all are very low as compared with other applications. For example, according to Young (1989) and Asmelash (2001) compost often contains about 120-200 $g.kg^{-1}$ organic carbon. However, the organic carbon content of the compost reported by Wahba (2007) from Egypt is very high, which is 300 $g.kg^{-1}$.

Nitrogen is the most demanded nutrient in any cropping system (Tegene, 1996). The N contents of the different composts vary from 2.4-10.5 $g.kg^{-1}$. Only six of the ten composts contain N >5 $g.kg^{-1}$ and only one >10 $g.kg^{-1}$ (Annex 7.1). The N content of compost from Holeta area in Central Western Ethiopia is reported to range between 6.7 and 11.2 $g.kg^{-1}$ (Getnet, 2008), which are similar to the findings of this study. Other studies such as Harti and Erhart (2005) reported that 11.5 g N kg^{-1} while the study by Wahba (2007) reported 15.3 g N kg^{-1}. All reports are in the range of Travis et al. (2003), who stated that the N of finished compost should range between 5-25 $g.kg^{-1}$. However, the nitrogen content of the four out of the ten composts produced by farmers of this study lie below this range.

The C:N ratio of all the compost ranges from 6 to 21 (Annex 7.1). *Parthenium* compost has an average 19 C:N ratio. It is significantly higher than the other compost types. The average C:N ratios of the other composts are below 10. Darlington (2003) and Getinet et al. (2008) reported 25:1 C:N ratio in matured compost. Manna et al. (2001) in a similar report obtained C:N ratios in the range of 8-22 in the semi-arid tropics of India (See other C:N ratios listed in Table 5.1). But compost with higher C:N ratio is not recommended for application because C:N ratio >15 is an indication of limited N availability due to immobilization in the soil (Gutser et al., 2005; Forster et al., 1993). While a very low C:N ratios, below 6-7, indicate that materials are strongly humified and easily available and therefore well suitable for field application (Gutser et al., 2005; Darlington, 2001; Manna et al, 2001; Landon, 1991). Therefore, the *Parthenium* compost would be good for agriculture if its C:N ratio is reduced.

Improving the qualities of OC, N and C:N ratio of the composts are very important to achieve good results from the agriculture. Animal wastes are rich in N than plants (Asmelash, 2001; Cyber-north, 2004). Generally, dry materials e.g. woody materials or dead leaves have higher C:N ratios while green materials usually have lower C:N ratios (Young, 1989; Cyber-north, 2004). This is because the dry, coarse materials such as straw, wood chips, etc. are high in C and low in N while the green materials such as grass clippings, fresh plant material, kitchen scarps and manure are high in nitrogen and low in carbon (Table 5.1). The more varied the mixing of the organic materials including into the pile is, the better the chance of maintaining the proper C:N ratio and efficient decomposition. The optimum proportion of the mix of the different composting materials Carbon:Nitrogen (C:N) is 30:1 (Getinet et al., 2008; Young, 1989; Richard, 1996). According to Richard (1996) when composting has high carbon materials (100:1) additional nitrogen (Urea - fertilizer) may be required to reduce the C:N ratio to the optimal range.

The lower quality of the compost prepared by farmers could be due to the types of composting materials used and/or their management. Similar results reported that the quality of compost can vary from the method or duration of composting, animal diet and storing manure (Briggs and Twomlow, 2002; Harris, 2002; Lekasi et al., 2001; Miner et al., 2001; Lekasi et al., 1998; Nandwa and Bekunda, 1998; Snapp et al., 1998; Hadas et al., 1996). Manure management can improve the quantity and quality of manure, reduce family conflict and the required labour for compost making (Harris, 2002; Lekasi et al., 2001). For example, Harris (2002) reviewed that "the best quality dung and manure comes from farmers, where considerable care has been taken in collecting and storing dung." There is a similar experience from Lekasi et al. (1998) and Probert et al.

(1995). Animal manure collected from a feeding space on concrete floor increased the N, P and OC contents better than on soil floor. According to Kwakye (1980), a three months' storage of manure resulted in 59 percent nitrogen loss. Regular turning of compost reduced N content into 1.2 percent while not turned is 1.4 percent (Lekasi et al., 2001). According to Lekasi et al. (2001) compost prepared within shading is higher in organic carbon than without shade.

Table 5.1- Some examples of C:N ratio of composting materials

Item	C:N ratio	Source
Animal waste		
Urine	0.8:1	Cyber-north, 2004; Cooperband, 2002; Asmelash, 2001
Cow manure	20:1	Cyber-north, 2004; Cooperband, 2002; Asmelash, 2001
Horse manure	25:1	Cyber-north, 2004; Cooperband, 2002; Asmelash, 2001
Horse manure with litter	60:1	Cyber-north, 2004; Cooperband, 2002
Rotted manure	20:1	Cyber-north, 2004; Cooperband, 2002
Poultry manure (fresh)	10-12:1	Cyber-north, 2004; Cooperband, 2002; Asmelash, 2001
Poultry manure with litter	18:1	Cyber-north, 2004; Cooperband, 2002; Asmelash, 2001
Green material		
Vegetable trimmings	12-20:1	Cyber-north, 2004; Cooperband, 2002; Asmelash, 2001
Alfalfa hay	10:1	Cyber-north, 2004; Cooperband, 2002
Oak leaves (green)	26:1	Cyber-north, 2004; Cooperband, 2002
Grass clippings	12-25:1	Cyber-north, 2004; Cooperband, 2002; Asmelash, 2001
Dry material		
Corn stalks	60:1	Cyber-north, 2004; Cooperband, 2002; Asmelash, 2001
Straw	80:1	Cyber-north, 2004; Cooperband, 2002; Asmelash, 2001
Food items		
Food scarps	18:1	Cyber-north, 2004; Cooperband, 2002
Unsorted		
Humus	7:1	Cyber-north, 2004; Cooperband, 2002
Coffee grounds/compost	20:1	Cyber-north, 2004; Cooperband, 2002; Ravishankar et al., 2001
Peat moss	58:1	Cyber-north, 2004; Cooperband, 2002

However, mostly Ethiopian farmers prepare their compost without proper shade and they turn the compost at least once. Powell et al. (1994) also reported large amounts of urine N loss through volatilization of ammonia unless managed well. Use of bedding straw reduced losses of ammonia by up to 80 percent, is also another experience from Nzuma and Muwira (2000). The storage of animal manure and animal feeding space by most Ethiopian farmers are in an open field. Human faeces is also another source of manure. But most farmers do not feel free to transport human faeces and urine into compost pits. They believe they will be sick of it. Instead usually families drop it onto their near by fields.

The quality of compost can be improved by using nutrient rich materials. Therefore most farmers use animal manure for compost preparation. They contain >20 $g.kg^{-1}$ N (Snapp et al., 1998). Poultry manure is rich in N and P. Its content ranges 20.2-48, 16-18 and 14.2 $g.kg^{-1}$ of N, P and K respectively (Nandwa and Bekunda, 1998; Ahn, 1970). The research revealed that poultry manure is 25.1, 7.7 and 12.9 $g.kg^{-1}$ N, P and K respectively (Annex 5.4), which lie within the above range.

On the other hand straw and farm yard manure have lower N, P and K content with 5.4-7.2, 0.36-2.6 and 3.4-24.8 $g.kg^{-1}$ respectively (Channappagoudar et al., 2007; Lekasi et al., 2001; Tegene, 1998b; Table 5.2). The result of this research is also similar to this data (Annex 5.1).

In Ethiopia additional biomass sources other than animal manure are plant biomass such as weeds and tree trimmings. Returning weeds into compost helps in returning nutrients to the soil, reduces weed infestation and their seeds (Katovich et al., 2005; Bationo and Mukwunye, 1991). The nutrient rich weeds available in the study area are *Parthenium*, Mestenagir (*Datura stramonium*) and Medafe (*Argemone mexicana*). Both contains higher content of nitrogen in the range of 22.8-38.5 $g.kg^{-1}$, while the first two contain 39.2-51.2 $g.kg^{-1}$ potassium as well. The study conducted in India by Channappagoudar et al. (2007) reported that the N content of *Parthenium* compost is within this range (Table 5.2). In Ethiopia these weeds are not only good in their nutrient holding but also in volume because they are not used as animal feed. But the problem in the C:N ratio has to be reduced to the required level.

The other most important green plants (from tree trimmings) identified with good nutrient content are Tamboukh (*Croton* macrostachyus), Awhi (*Cordia africana*) and *Sasbenia sasba* contain N between 28.4-36.3 $g.kg^{-1}$ (Annex 5.1-5.4). However, other studies show that the N contents of plants vary from 2.0 to 60 $g.kg^{-1}$ of their dry matter

(Baruah and Barthakur, 1997). For example, *Croton macrostachyus* and *Erythrina abyssinica* contain 39.7 and 33.4 g.kg^{-1} nitrogen respectively (Elias, 2002).

Table 5.2- Nutrient content (g.kg^{-1}) of some types of biomass used as composting materials (dry matter) as reported by various authors.

Item	**Nutrient content (g.kg^{-1})**				**Source**
	N	**P**	**K**	**OM**	
Vegetables especially lettuce	45-65	3.0-8.0	60-100		Campbell (ed) 2000 - US
Small grains (barley, oats, rye and wheat)	40-50				Campbell (ed) 2000 - US
Cauliflower	3.0-7.0				Campbell (ed) 2000 - US
Corn at seedling stage	40-50	4.0-6.0			Campbell (ed) 2000 - US
Banana crop residue	14.0-26.5	6.5-7.0	12.0-14.0	45-65*	Ravishankar et al., 2001
Acacia albida				50-100*	Young, 1989
Poultry manure	4.0	18.0			Nandwa and Bekunda, 1998
Sheep manure	20.0	4.0	21.0	60*	Tegene, 1998b, Ethiopia
Goat manure	28.0	6.0	24.0	60*	Tegene, 1998b, Ethiopia
Horse manure	7.0	1.0	4.0	60*	Tegene, 1998b, Ethiopia
Dairy manure	7.0	1.0	5.0	30*	Tegene, 1998b, Ethiopia
Animal manure	13.9-16.8	2.3-3.2			Elias, 2002 Ethiopia
Bisana (*Croton macrostachyus*)	39.7	2.7			Elias, 2002 Ethiopia
Bortwa (*Erythrina abyssinica*)	33.4	1.8			Elias, 2002 Ethiopia
Mokota (*Cordia africana*)	26.0	1.8			Elias, 2002 Ethiopia
Parthenium	29.5	8.2	13.9		Channappagoudar, 2007 India

*Organic matter by dry weight

The 6.4 t.ha^{-1}.yr^{-1} compost can be prepared easily by improving biomass management. Therefore, promotions for farmers should be done through the extension services of the government and NGOs. This is during the biomass collection, proper storage techniques and compost pit management, and improve the nutrient quality through the proportion of carbon and nitrogenous materials during compost making.

5.3 The effect of compost

As stated by Tulema et al. (2007) soil nutrient status is widely constrained by nutrient loss and the limited use of inorganic and organic fertilizers. The focus of this discussion is to see the change of soils and yield by the use of compost and mineral fertilizer.

5.3.1 Changes in the soil characteristics

According to Bationo and Mukwunye (1991) the addition of organic materials has beneficial effects on soil properties. But the experimental sites of this research showed no significant changes of the pH, bulk density and moisture contents of the soils over the research period and treatments. There are other similar results. For example, Stamatiadis et al. (1999) reported that the pH value with 22 and 44 $t.ha^{-1}.yr^{-1}$ compost applications in one growing season did not change. The study by Epstein et al. (1976) also showed a 240 $t.ha^{-1}.yr^{-1}$ application of sludge compost resulted in moisture differences between the treatments (control, sludge and sludge compost) were not significant throughout the growing season.

The organic matter content of all the experiments of the study showed no significant changes over the three years. Rather it showed a reduction through time (Table 4.10). This result goes in line with the study by Ouedraogo et al. (2001) that there was no significant difference as short-term effect in soil organic matter content between the 5 and 10 $t.ha^{-1}.yr^{-1}$ compost application and the non-composted. The study by Epstein et al. (1976) also showed the organic carbon at 80 $t.ha^{-1}.yr^{-1}$ compost application was not different from the unamended soil, while the 240 $t.ha^{-1}.yr^{-1}$ sludge compost application increased 2 percent organic carbon (Epstein et al., 1976). However, there are some different results. For instance, the study conducted in Egypt by Wahba (2007) reported a significant change of organic matter at 20 $t.ha^{-1}.yr^{-1}$ compost application. This might be because the compost used were rich organic carbon (30%) and nitrogen (1.53%). This is an indication that higher rates of compost application and using compost rich in OM significantly raise organic matter.

The nitrogen content of the last research period in all the experimentation plots was significantly higher than the previous years. But N was not significantly different in the first two years. According to Butler et al. (2008) application of higher amount of compost, 70 $t.ha^{-1}.yr^{-1}$ and above, increased nitrogen content in the soil. The study by Epstein et al. (1976) attained a different result that nitrogen for all treatments with 40 and 80 $t.ha^{-1}.yr^{-1}$ rate compost applications decreased with time, while the nitrogen for the 240 $t.ha^{-1}.yr^{-1}$ sludge compost treatment was significantly higher. This indicates that there is no guarantee for an increase of N with the application rate of this study. The increase observed in all treatments of this study including the control plot may be due to the mulching of the barley straw after the second harvest. This is because the straw of barley has high nitrogen content. The increase of nitrogen content of the final year might be due to the addition of inputs, mulching of the residue and the planting of legume, because legume crops increase N significantly through biological N-fixation (Table 4.11). Kikafunda et al. (2001) reported that using nitrogen fixing legumes are a possible solution to the nitrogen problem for the resource constrained smallholder farmers. Studies undergone to investigate the N-fixation capacity by above ground legumes especially faba bean showed to be 10 to 350 kg N ha^{-1} in Australia; 85-181 kg N ha^{-1} in the Europe and 54–133 kg N ha^{-1} in the Middle East (Rochester *et al*., 1998). Another study by Carranca et al. (1999) in Portugal showed the N-fixation by faba bean varied from 76 to 125 kg N ha^{-1}.

There is a significant increase in the phosphorus of the plots applied with mineral fertilizer and 6.4 $t.ha^{-1}.yr^{-1}$ compost as compared to the control and 3.2 $t.ha^{-1}.yr^{-1}$ compost application. However, in all treatments P declined slowly till the end of the experimentation period (Table 4.12). The study by Butler et al. (2008) goes in line with the result of this study, that all composted plots increased phosphorous in the soil after the third growing season. The increase in P in the study area was higher in the first and second experimentation periods but declined in the third growing season. It is also supported by the study of Spiers and Fietje (2000) that phosphorous was absorbed quickly by the plant, and then required extra phosphorous to be added for compensation. The study by Nandwa and Bekunda (1998) held in Kabete, Kenya, indicated P levels were maintained or increased only in treatments where mineral fertilizer P inputs were applied.

The potassium level of the experiments does not show any significant change over time and treatment. However, there is an indication of a constantly increasing trend in the 6.4 $t.ha^{-1}.yr^{-1}$ compost application than other applications. This result is supported by the study of Smiciklas et al. (2008) that highest available K contents from the 45 and 134 $t.ha^{-1}.yr^{-1}$ compost applications were achieved. Again the study by Butler et al. (2008) reported that potassium in soil increased in the higher compost applications i.e. 70 and 105 $t.ha^{-1}.yr^{-1}$. Even though it is generally believed that Ethiopian soils are rich in potassium but the soils do not confirm this (Table 4.5). Moreover, even if it is true that eventually it would be depleted unless the soils are enhanced by other means such as compost or mineral fertilizer applications. However, there is no K mineral fertilizer application in Ethiopia (MOARD, 2007).

The CEC of this study is not significantly different over the experimentation period and all the treatments. This may be due to the insufficient amounts of compost applied to the soil. Because changes are observed with higher compost applications. For example, the study of Ouedraogo et al. (2001) reported that CEC was significantly different between 0 and 10 $t.ha^{-1}.yr^{-1}$ compost application rates but not between 0 and 5 $t.ha^{-1}.yr^{-1}$. Garcia et al. (1991) also reported that CEC increase with 30-180 $t.ha^{-1}.yr^{-1}$ compost application. Wahba (2007) from Egypt also found CEC changed after two years at 20 $t.ha^{-1}.yr^{-1}$ compost application. For example, most of the studies reported that applying higher amounts of compost significantly raised nutrient levels (Smiciklas et al., 2008; Garcia et al., 1991). Another example is the ten year study conducted in Austria with 9, 16 and 23 $t.ha^{-1}.yr^{-1}$ compost application revealed that nitrogen content and organic carbon were significantly higher than in the untreated control (Harti and Erhart, 2005). The significant TOC and NPK increase within three months was found to be in the 15 $t.ha^{-1}.yr^{-1}$ application (Azarmi et al., 2008), the effect of 44 $t.ha^{-1}.yr^{-1}$ compost amended soil is doubled in its EC (Stamatiadis et al., 1999).

Generally the unchanged situation in the physical and chemical properties of the soil might be due to: firstly, the small amount of compost application. Secondly, the low nutrient level of the compost applied to the soil. Thirdly, there could be high mineralization of OM in the incorporated compost to release higher nutrient to the plants (Garcia et al., 1991). It is previously shown (Section 5.1) that 3.2 $t.ha^{-1}.yr^{-1}$ compost application is very low application. But the 6.4 $t.ha^{-1}.yr^{-1}$ compost application gives almost similar yield to the mineral fertilizer. Therefore, this could be due to fast mineralization. Even though it is unusual trend that compost releases its nutrients slowly but mineralization occurs when C:N is low. The C:N ratio of the farm residue compost (Annex 7.1), almost all farmers use, are between 7 and 8. It is only one compost recorded with C:N value of 15. This may be the case for the study area to have good mineralization and little may be left in the soil. Fourthly, the research period is too short for the soil to respond. And fifthly, related to the long years of cultivation of the Northern Ethiopia for thousands of years. This is because longer years of cultivation are highly related with organic materials are removed (Tewolde Berhan, 2006).

5.3.2 Changes in yield

Application of any amounts and types of input brings better yields. But the yield increase is proportional to the amount of input e.g. compost, used (Garcia et al., 1991). For example, this study showed that the yields of the (150 kg) mineral fertilizer and 6.4 $t.ha^{-1}.yr^{-1}$ compost applications are significantly higher than the yields of the control plots and 3.2 $t.ha^{-1}.yr^{-1}$ compost applications. The yields of the 3.2 $t.ha^{-1}.yr^{-1}$ compost applications are higher than the control plots. Similarly, Eghball and Power (1999) reviewed, that when application rate is based on correct N or P availability manure or compost can produce corn grain yields equal or greater than the mineral fertilizer application. Short-term effect of compost can result in yield production increase. The study by Ouedraogo et al. (2001) in Burkina Faso reported an increase of sorghum yield by 45% and 300% through the 5 and 10 $t.ha^{-1}.yr^{-1}$ compost application respectively over the no-compost plots. A similar result was found in a study by Diop (1999) in Senegal that an increase of 42% (millet) and 45% (groundnut) by applying manure and compost respectively.

These are clear indications that the soils require inputs to increase their yields. It shows that soils have reached a level where they give low yields, if there is no or inadequate input application (Odhiambo and Magandini, 2008). For example, the yields of this research showed in all the three crops (teff, barley and faba bean) under control plots were constantly low. It is proved by many researchers that in many African countries low soil nutrients are the root causes of the low agricultural production (Shepherd, 1998; Stoorvogel et al., 1993). The existing situation in Tigray also show fields are highly eroded, devoid of organic matter and then crop productivity is very low (Tewolde Berhan, 2006; Virgo and Munro, 1978; Tegene, 1996). Therefore, improving food production and soil resources in the smallholder sector is an enormous challenge (Snapp et al., 1998). For example, this research showed that the plough layers are deficient in organic matter and nitrogen (chapter 4.1). The study by Mitiku et al. (2003) and Tegene (1996) also reported that the soils in Tigray are nitrogen and phosphorous deficient. The research by Eghball and Power (1999), Smiciklas et al. (2008) and Mugwe et al. (2007) showed lowest yields were recorded in control plots. Otherwise smallholder farms will face a constant decline in their yields such as study by Nandwa and Bekunda (1998) in Kenya declined by over 70% in 17 years i.e., from 3.8 $t.ha^{-1}$ to

0.9 $t.ha^{-1}.yr^{-1}$ from the no-input. This study showed it is not only the yield but also the kernel weight and harvest index that control plots are inferior to any type of input (Section 4.3.2.3; Ouedraogo et al., 2001).

However, some times it may be difficult to judge, which type of input out-yielded over another without getting the right information. For example, the assessments by Araya and Edwards (2006) and SSNC (2008) reported that the yields of the usual farmers' compost application rate (3.2 $t.ha^{-1}.yr^{-1}$) are higher than the yields from the applications of mineral fertilizer (Edwards et al., 2007). It is only right when compared with sufficient application of mineral fertilizer. Because many farmers in the study area and some where else do not use the recommended rate of the mineral fertilizer (MOARD, 2007; Elias, 2002; Nandwa and Bekunda, 1998). But generally crop production in Ethiopia is increasing through time. For example, the grain production in Tahtai Maichew increased from 26,640 by 2005 into 28,860 t by 2007 (Table 3.5). While the amount of mineral fertilizer used in the Tahtai maichew is insignificant (Section 4.5). Therefore, the production increase in the district could be due to addition of all types of inputs and farmers' local soil fertility management practices than the application of mineral fertilizer alone. For example, the agricultural sample survey of CSA showed that the grain production between 2007/8 and 2008/9 increased by 4.75 % and 6.71% while the expansion of cultivated land by 2.33% and 0.86% in Ethiopia and Tigray respectively (CSA, 2009).

Yield is a complex matter among economists, experts, researchers and policy makers as compared with farmers. Farmers in the Ethiopian Highlands see yield in relation to the advantage of their cattle as well because they are very important in their agriculture. For example, about 58 percent of the respondent farmers prefer for a relatively equal yield of both grain and straw. Only 31 percent of the farmers wanted higher amount of grain than biomass yields (Table 5.3). However, the yield preference varies based on the crop type. For example, about 70 percent of the farmers wanted to get higher yield of faba bean grain than straw because the straw is not palatable for animals. While 30 percent, who own equines, prefers to get an equal amount of straw yield with the grain. Between 70 and 74 percent of the respondent farmers prefer in producing equal amount of straw and grain of barley and teff because they wanted the straw for their cattle especially feed for oxen (Table 5.3).

Table 5.3 - Farmers' response (n=96) for yield preference based on crop type in Tahtai Maichew district.

Crop type	**Yield preference**		
	High grain than biomass	**High biomass than grain**	**Equal both grain and biomass**
Teff	8 (8.3)	17 (17.7)	71 (74.0)
Barley	15 (15.6)	14 (14.6)	67 (69.8)
Faba bean	67 (69.8)	-	29 (30.2)
Total	**90 (31.2)**	**31 (10.8)**	**167 (58.0)**

The main question in the hypothesis was to see "if applying compost has a dramatic effect on the soil fertility, yield and economy of the farmers." This is a fundamental question raised by many farmers, researchers, policy-makers, development workers and scientists. Application of compost has positive effects in the soil properties, the yield and family economy but it is not dramatic in the soil fertility enhancement as expected in the hypothesis. This is because the effect mainly depends on the quality and amount of the compost used. The yields through application of 3.2 $t.ha^{-1}.yr^{-1}$ is generally low in teff and barley but not for the faba bean. While the yields from applications of 150 kg mineral fertilizer (DAP and Urea) and 6.4 $t.ha^{-1}.yr^{-1}$ compost were higher and almost similar. Therefore, the 6.4 $t.ha^{-1}.yr^{-1}$ compost has almost equal yield with the 150 $kg.ha^{-1}.yr^{-1}$ mineral fertilizer. It is unlike with the findings of Smiciklas et al. (2008) that compost application rates of 34.6 and 44.8 $t.ha^{-1}.yr^{-1}$ are optimal application rates resulting in similar yields as 180 $kg.ha^{-1}.yr^{-1}$ N fertilizer. This means applying good quality and better amount of compost attains better effect or profit. Therefore, focuses should be on produce higher amounts of compost (at least 6.4 $t.ha^{-1}.yr^{-1}$), which are also rich mainly in organic matter, N, P and K level.

5.4 Partial input-output balance

5.4.1 The input-output nutrient balance

Based on the partial input-output nutrient balance the study area is at a very high depletion (Table 4.31). Many nutrient depletion results of Ethiopia are reported with negative values but they are lower than the results of this study. For example, it varies from the -47 kg N, -7 kg P and -32 kg K $ha^{-1}.yr^{-1}$ by Stoorvogel et al. (1993) to -122 kg N, -13 kg P and -82 kg K $ha^{-1}.yr^{-1}$ by Haileslassie et al. (2007; 2005). While the field scale study by Elias et al. (1998) for the mixed farming in Southern Ethiopia N and P were more of equilibrium or positive.

In many studies partial nutrient balance are negative (Van Dung Bosch et al., 2008; Dechert et al., 2005). However, the study by Haileslassie (2005) reported that the partial nutrient balance is showing positive for the Tigray Region (+10 N, +6 P, +10 K $kg.ha^{-1}.yr^{-1}$) and (+10 N, +11 P, +7 K $kg.ha^{-1}.yr^{-1}$) for Ethiopia at national level. Where as the full nutrient balance is negative for Tigray Region (-41 N, -1 P, -36 K $kg.ha^{-1}.yr^{-1}$) and the national level (-122 N, -13 P and -82 K $kg.ha^{-1}.yr^{-1}$). It may be because other factors, like inputs through deposition, sedimentation and outputs like leaching, erosion, or gaseous losses are not calculated (Dechert et al., 2005; Haileslassie, 2005; 2007). For example, the report of another study by Haileslassie (2007) showed the wet deposition (IN3) in the Woina Dega (mid-land) could make the difference, which contributes 4.7 N, 3 P and 4 K $kg.ha^{-1}.yr^{-1}$.

However, so far there is no detail study conducted in the study area except the plot level study in the region by Hengsdijk et al. (2005) reported only -27 N $ha^{-1}.yr^{-1}$ of the partial input-output balance. This report shows a lower estimate as compared to the national level. Therefore, they are very low estimates because Tigray region is regarded as a severely degraded region (Tewolde, 2006; Mitiku et al., 2003; Hagos et al., 2002), as compared to the other well endowed areas of Ethiopia (Elias et al., 1998). On the other hand the study by Aseffa (2005) in Teghane Atsbi, Tigray Region, reported nutrient depletion between -65.5-(-115) kg N $ha^{-1}.yr^{-1}$, 0-(-5.8) kg P $ha^{-1}.yr^{-1}$ and -34.6-(-112) kg K $ha^{-1}.yr^{-1}$. The high nutrient depletion in the country in general and Tigray Region in particular are because of limited applications of organic fertilizer like crop residues and manure, and the socio-economic problems in the mineral fertilizer (Aseffa, 2005).

The results of the partial nutrient balance showed that the nutrient removals by the crop harvest are highly negative except the phosphorous in barley crop under mineral fertilizer application. They vary based on crop type. For example, the partial nutrient balance of this study for nitrogen varies from -204-(-228) in the faba bean to -59-(-69) $kg.ha^{-1}.yr^{-1}$ in the barley. The phosphorous (P) varied from -6-(-23) in the faba bean and to (+)8-(-9) $kg.ha^{-1}.yr^{-1}$ in the barley. The partial nutrient balance for potassium also ranges from -236-(-269) for the faba bean to -188-(-247) $kg.ha^{-1}.yr^{-1}$ in the barley (Table

4.31). Similar to this study the results of the partial nutrient balances under different cereal crops were different per crop. For example, Haileslassie (2007) reported from his research in the Central Highlands of Ethiopia that the nutrient balance for barley as -29 (N), -11 (P) and -46 (K) $kg.ha^{-1}.yr^{-1}$ and for beans in general as -56 (N), -8 (P) and -41 (K) $kg.ha^{-1}.yr^{-1}$ under partial balance. The positive P result (+7.8 $kg.ha^{-1}$) in barley under mineral fertilizer application may be because the mineral fertilizer application is higher than the nutrient demand of the barley. This is similar to the result of the faba bean, which also shows a very low depletion i.e., about -6 $kg.ha^{-1}.yr^{-1}$ as compared to over the -20 $kg.ha^{-1}.yr^{-1}$ in other applications and the control plots (Table 4.31). Other example from Haileslassie (2005) is maize (usually grown as homestead on the highlands) had a strongly positive partial nutrient balance. On the other hand teff, sorghum, millet and oat had negative balances. This is because homestead farms are over manured unlike the distant farms (Haileslassie et al., 2005; Elias et al., 1998). But mostly the negative net balance for potassium in the mineral fertilizer applied plots in this study is likely to be attributed to the no K mineral fertilizer application in Ethiopia (NFIA, 2001).

5.4.2 Improving the nutrient management

The findings of this study strongly indicate that soil nutrients are highly exploited by the crop production system, which is supported by domestic animals. Regardless of the type of input applied for the NPK amendment, the results indicate that the amount of both compost (even the 6.4 $t.ha^{-1}.yr^{-1}$ application) and mineral fertilizer applications are not enough to compensate the nutrient removal. Reports of many studies reviewed that mostly recommended applications compensate partial of the removal (Drechsel *et al*., 2001Bationo *et al*., 1998). These all indicated that there is an urgent need to improve the soil nutrient removal and then yield.

Some nutrient depletion reduction strategies can be suggested. For instance convincing farmers about the importance of leaving of biomass especially straw like about 20 percent in the field during cutting for mulching in the soil (Table 5.4). Because in both crops there is a higher proportion of the nutrient removal by the straw during harvest than by the grain (Annex 11.2-11.3).

Table 5.4 - The N, P and K balances as improved by leaving 20 percent straw in the field and applying the high NPK composts for barley and faba bean crops (kg.ha^{-1}.yr^{-1})

Nutrient	Treatment	Barley		Faba bean	
		PB	PBM	PB	PBM
N	Control	-69	-60	-204	-155
	Mineral fertilizer	-59	-47	-205	-152
	3.2 t.ha^{-1}.yr^{-1} compost	-62	-46	-228	-170
	6.4 t.ha^{-1}.yr^{-1} compost	-62	-43	-225	-164
P	Control	-8	-6	-21	-17
	Mineral fertilizer	8	10	-6	-1
	3.2 t.ha^{-1}.yr^{-1} compost	-9	-6	-21	-17
	6.4 t.ha^{-1}.yr^{-1} compost	-8	-6	-23	-19
K	Control	-188	-144	-236	-186
	Mineral fertilizer	-247	-190	-269	-213
	3.2 t.ha^{-1}.yr^{-1} compost	-211	-147	-264	-194
	6.4 t.ha^{-1}.yr^{-1} compost	-214	-135	-254	-173

Key: PB (partial balance from table 4.31); PBM (partial balance modified - table 4.31 improved by both leaving 20 percent straw in the field and taking the best NPK content compost).

This type (20 percent) modification reduces the nitrogen depletion due to crop production from 69 to 60 in barley and from 204 to 155 kg.ha^{-1}.yr^{-1} for faba bean in the control plot, the plots with the mineral fertilizer treatment from 59 to 47 in barley and from 205 to 152 kg.ha^{-1}.yr^{-1} for faba bean. The nitrogen depletion in the compost application in both crops has also reduced very much.

The phosphorous depletion in the control plots is reduced from 8 to 6 kg.ha^{-1}.yr^{-1} in the barley and from 21 to 17 kg.ha^{-1}.yr^{-1} in the faba bean in the control plot. On the other hand mineral fertilizer increased its positive balance from +8 into +10 in barley while faba bean keeps its negative balance from 6 to 1 kg.ha^{-1}.yr^{-1}. This is almost in the equilibrium level nutrient balance in both crops.

The potassium depletion is too much but reduced from 188 to 144 in barley and from 236 to 186 kg.ha^{-1}.yr^{-1} for the faba bean in the control plot. Under the mineral fertilizer it is reduced from 247 to 190 in barley and from 269 to 213 kg K ha^{-1}.yr^{-1} in the faba bean, while the highest depletion is in the 6.4 t.ha^{-1}.yr^{-1} compost application, i.e. barley from 214 to 135 and faba bean from 254 to 173 kg N ha^{-1}.yr^{-1}.

Generally nutrient depletion can partly be reversed by this method, but it is not enough to equalize the balance. P supply shows that it is near to the equilibrium. But as long as the P contents of the composts are not improved, the P availability for crops may require additional dressing of mineral fertilizer.

Many times researchers, experts and policy makers recommended applications of high external inputs to sustain agricultural production and achieve positive nutrient balances (Bindraban et al., 2000). But others disagree due to the negative implications in the socio-economy of smallholder farmers. Farmers in the study area are frustrated to use mineral fertilizer. This is because of the high prices and the unreliable rainfall. Fallowing is also recommeded for restoration of nutrients such as Jones (1972) suggested a 3 year fallow to restore the soil organic carbon, N, P, K and Mg that were depleted in a 3 year growth period. This is very short period to restore when we compare with the amount of nutrient continuously depleted every year (Table 4.31). Harris (1998) also recommeded as extended resting period. But this is impossible in Ethiopia because of the land shortage, which pushed farmers into non-fallowing intensive cultivation (Bationo and Mukwunye, 1991; Saleem, 1998; Snapp et al., 1998). Moreover, fallowing can not restore P, K and Mg in soils. However, there are inputs especially of K and Mg through weathering and dust deposition (Landon, 1991).

The other option is using the existing farming technologies. This research assessed that almost 100% of the farmers are implementing crop-rotation to renew their soil fertility (Table 4.33). This is known, supported and advised by many people throughout all farming systems. Therefore, generally the easy and affordable technologies already practiced by farmers can be suggested to be promoted farther. Synergizing all locally available technologies and practices to improve the soil nutrient depletion and then increase grain and straw production would be accepted by farmers. Because if only mineral fertilizer is advised for farmers while they do not apply would be useless.

5.5 Sustaining the smallholder agriculture

5.5.1 Sustaining the socio-economic of smallholder farmers

The amount of mineral fertilizer used by farmers is known to be nill or insufficient. The report of Vlek (2005) confirms this that "the rain-fed areas of Sub-Saharan Africa receive little or no mineral fertilizer." Farmers in Ethiopia use 7 $kg.ha^{-1}.yr^{-1}$ of mineral fertilizer (MOARD, 2007; Elias, 2002). It is almost similar (8 kg.ha^{-1}.yr^{-1}) to the findings of Stoorvogel et al. (1993) and Oluoch-Kosura et al. (2001), which is the average consumption of Sub-Saharan Africa and an average for Africa is 10 kg.ha^{-1}.yr^{-1} (Vlek, 2005; Nandwa and Bekunda, 1998). On the other hand the world average application rate is 96 kg.ha^{-1}.yr^{-1} (Kimani and Lekasi, 2004; Oluoch-kosura et al., 2001).

According to the farmers of the study area using mineral fertilizer requires reliable rainfall and good soil; otherwise it upsets farmers socially and economically if used in degraded and moisture stress areas. This is mainly because of the consistently increasing prices of the mineral fertilizer (Müller-Sämann and Kotschi, 2004; Elias, 2002; Nandwa and Bekunda, 1998). Such as the 264% (DAP) and 319% (Urea) increase in the cost of mineral fertilizer between 1999/2000 and 2008/9 in Tahtai Maichew, Ethiopia (Figure 4.15; Annex 12.1). Many farmers quiet buying mineral fertilizer and shifted into other options. For example, between 2005 and 2007 in the study district mineral fertilizer use increased from 166 to 320 t; compost from 7,685 to 28,071 t and animal manure from 13,722 to 34,190 t (Table 4.35).

Furthermore, the increasing costs of production leads to a lower agricultural return and disturb food security by reducing family income (Ong'wen and Wright, 2007; Sanchez et al., 1997). This creates unfavorable crop/fertilizer price ratios (Vlek, 2005). This problem may lead to an unbalanced situation in the net income (Araya and Edwards, 2006). Gruhn et al. (2000) reported the domestic prices of mineral fertilizer in Africa are such that one kg of nitrogenous fertilizer can cost between 6 and 11 kgs of grain. However, mineral fertilizer can produce more but in the study area depends on the relibility of rainfall. That is why sometimes farmers complain that using mineral fertilzer is a waste of money (Harris, 1998). Consequently, they are reluctant to buy and use mineral fertilizer even with the opportunities of access to financial institutions. Therefore, they are more inclined into locally available resources and technologies such as compost, animal manure, SWC and planting multipurpose trees than using mineral fertilizer (Table 4.33-4.34).

The other serious reality in the study area is that many places in the Tigray Region are succeptible to drought especially shallow soils. Farmers said that "AFERU TSEHAY YIFERAL" meaning the soils can not withstand the sun, and crops fail (Tegene, 1998b). Therefore, crops planted with mineral fertilizer wilt faster than the crops planted with compost or animal manure (Araya and Edwards, 2006; SSNC, 2008). Using compost improved the problems due to the early stop of rain. From this farmers realize the role of compost in sustaining yield and improving the soil (Ouedraogo et al., 2001).

This study identified that the net incomes and marginal returns of the teff and barley under 6.4 $t.ha^{-1}.yr^{-1}$ compost applications are similar with the national recommended mineral fertilizer rate i.e., 150 $kg.ha^{-1}.yr^{-1}$. Both are higher in their net income and marginal return than the control and the 3.2 $t.ha^{-1}.yr^{-1}$ compost application plots.

The net income of the faba bean is higher in the 6.4 $t.ha^{-1}.yr^{-1}$ compost application while marginal rate of return is higher for the 3.2 $t.ha^{-1}.yr^{-1}$ compost application (Annex 10.4-10.7). This shows compost application at 6.4 $t.ha^{-1}.yr^{-1}$ rate is improving yields and family incomes equal or greater than the recommended rate of mineral fertilizer. But it depends on the crop type. The study conducted by Devi et al. (2007) during 2005-2006 in Ethiopia reported that the production cost of organic farming were about 41 percent less than the production costs for inorganic farming. Similar results are also reported by Wortmann and Kaizzi (1998). The high net income and marginal return especially from the faba bean is very important because farmers look for their socio-economic independence. Since their income is mainly dependent on the return of the crops (Kikafunda et al, 2001; Somda et al., 2002) they try to achieve higher returns without being trapped into debt from credit associations (Somda et al., 2002).

There are some constraints of compost rised by experts and researchers. In the other hand farmers witnessed that compost making is difficult only at the beginning, after compost making training, which includes digging a pit, collecting all biomass for compost making and filling with out earlier preparation. But composting is an easily understood technology for farmers, which can be prepared any time of the year (Somda et al., 2002; Kikafunda et al., 2001; Ouedraogo et al., 2001; Diop, 1999; Tegene, 1998b). The labour requirement is one constraint but mainly for digging compost pits (Briggs and Twomlow, 2002), which serve for many years once constructed. But for many farmers labour is not a big obstacle because it is available (Table 4.15). The need for turning of a compost is not a problem, if the compost is well started (Diop, 1999). Labour shortage can also be minimized by the practice of female farmers in Senegal through group work (Diop, 1999). Group work is also the practice in Tigray. It is especially appreciated since farmers blieved that it increases their social interaction with their neighbours and participation within the family. It is also good opportunity for the youth enrolled in formal education to participate in compost making to connect them with what their families are doing.

This is generally an indication of social sustainability and community empowerment with diverse and resilient communities with in which local population can access services and meet their needs at their own decision (Ong'wen and Wright, 2007).

5.5.2 Sustaining agricultural yield

As observed in section 4.3.2 production in this research varied according to crop type and treatment. But the Cumulative Productivity Index (CPI) of all the three field crops (teff, barley and faba bean) grown over the three years (2005-2007) clearly showed highest production from the application of 6.4 $t.ha^{-1}.yr^{-1}$ compost continuously. This means using compost at 6.4 $t.ha^{-1}.yr^{-1}$ rate is sustaining yield longer than the other applications and the control. Similarly Zvomuya et al. (2006) reported that the cumulative biomass yield of composted fields were significantly higher than the control, non-composted manure and mineral fertilizer yields. The study held in Kabete, Kenya, also showed that treatments with only mineral fertilizers initially out-yielded the no-input and FYM treatments but yields tended to decline rapidly (Nandwa and Bekunda, 1998). This may be because compost accumulates nutrient in the soil, improves soil structure and then moisture holding capacity.

Therefore, compost is the technology that is affordable for poor, economically and socially feasible and effective, which can achieve improvements in food productivity under their own choices (Pretty, 2008; Saleem, 1998; Smaling et al., 1993).

5.5.3 Recycling organic matter

Recycling of organic materials is practiced through out human life. The break in this trend will break the natural cycle. The following two figures (5.1 and 5.2) show the nutrient flow of biomass at farming family level. The significant increase in the compost and animal manure applications by farmers in the study area indicate the high recycling of smallholder farmers in the farming system (Table 4.35). At the same time this trend contradicts to the research findings reported as if farmers use all the animal dung for cooking (Mati, 2005; Tefera et al., 2002). Instead the results show farmers use biowaste especially animal manure for amending soils and increasing crop yields.

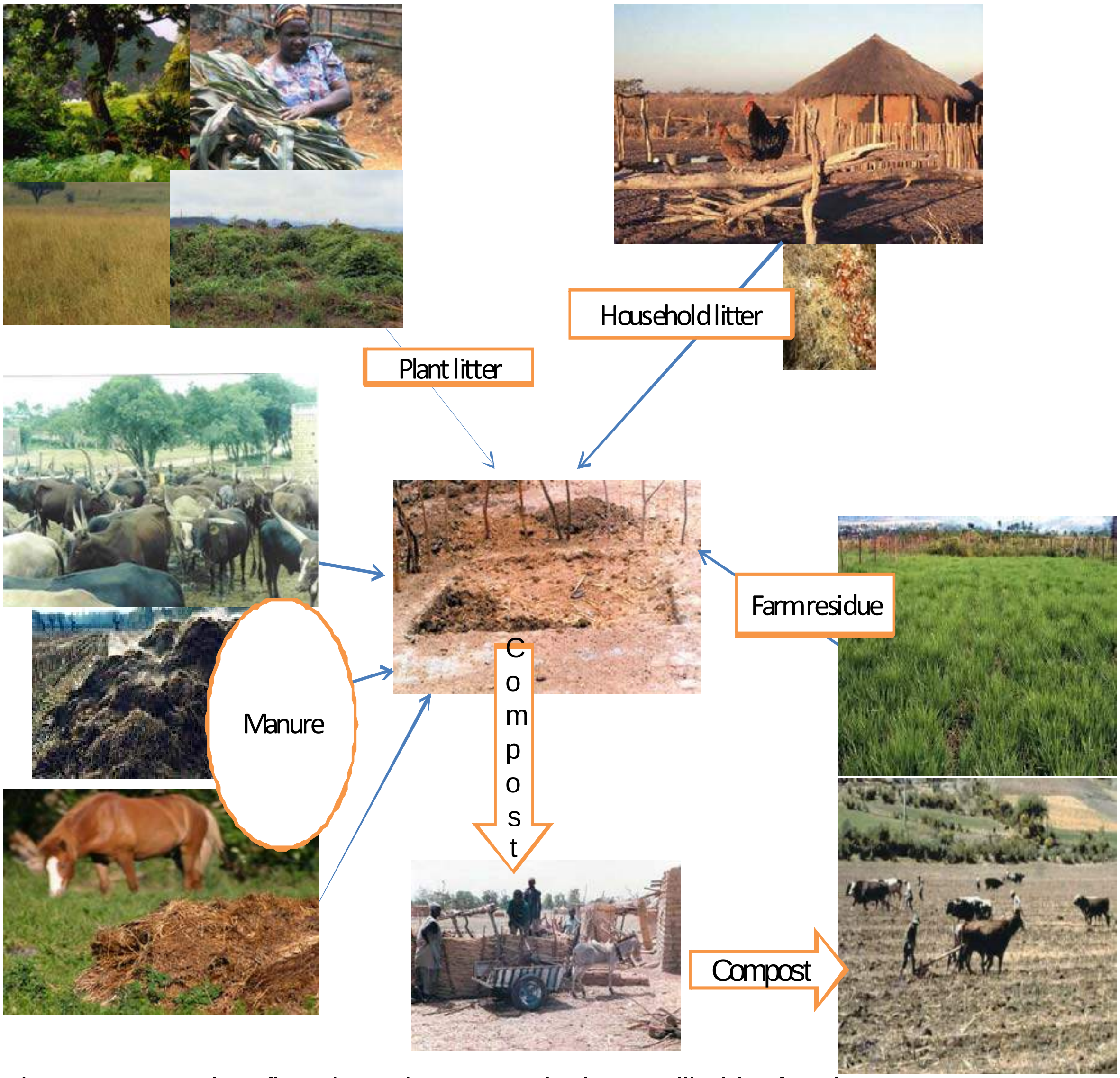

Figure 5.1 - Nutrient flow through compost in the smallholder farming system

The mixed farming practice of Ethiopian farmers is a system of removing biomass from one place, to feed human and domestic animals in another place. The three year average production of the three crops (teff, barley and faba bean) in this study is 2.5 t grain and 10.4 t straw. Based on farmers' estimation about 20 percent of the straw and 10 percent of the grain are wasted during threshing and transportation. Therefore, 2 t straw and 0.3 t grain are left in their farms (Figure 5.2).

About 0.8 t of the grain is assumed to be sold to towns for different purposes but it is assumed that only 25 percent (0.2 t) of it wiill be back to the rural as urban waste. This estimate is too low because of the weak rural and urban communication and wastage. Where this needs enhancement in connecting their nutrient flow. The rest 1.4 t grain reaches the family as human food. From this only 50 percent (0.7 t) is expected to be used for compost as household refusal, faeces and urine.

About 40 percent (3.4 t) of the 8.4 t straw are wasted during feeding (result of group discussion). This has to go to the compost pit. The rest (5.0 t) feed is eaten by the cattle. Farmers collect different green plants from their homesteads, farms and surroundings. This includes fresh weeds, tree branches, leaves, etc. Some of the farmers already planted multipurpose trees in their farm-lands (Edwards et al., 2007; Belete, 2003). All will be totalled into 2 t in one year. Mostly they are collected during compost making. Therefore, about 1.2 t is assumed directly to go to the compost pit while the rest (0.8 t) used by cattle (Figure 5.2).

Totally the domestic animal in a family feed about 5.8 t of biomass. There is no clear research conducted about how much of the biomass is retained in their body, how much is lost to the atmosphere and how much become dung. This is because biological and scientific process is complex to calculate. Families are also to use the dung for cooking. All together may account about 50 percent of the total consumed by the cattle. It varies from family to family depending on the initiatives a family have to make compost. Then by good composter family about 2.9 t dung is going to the compost pit.

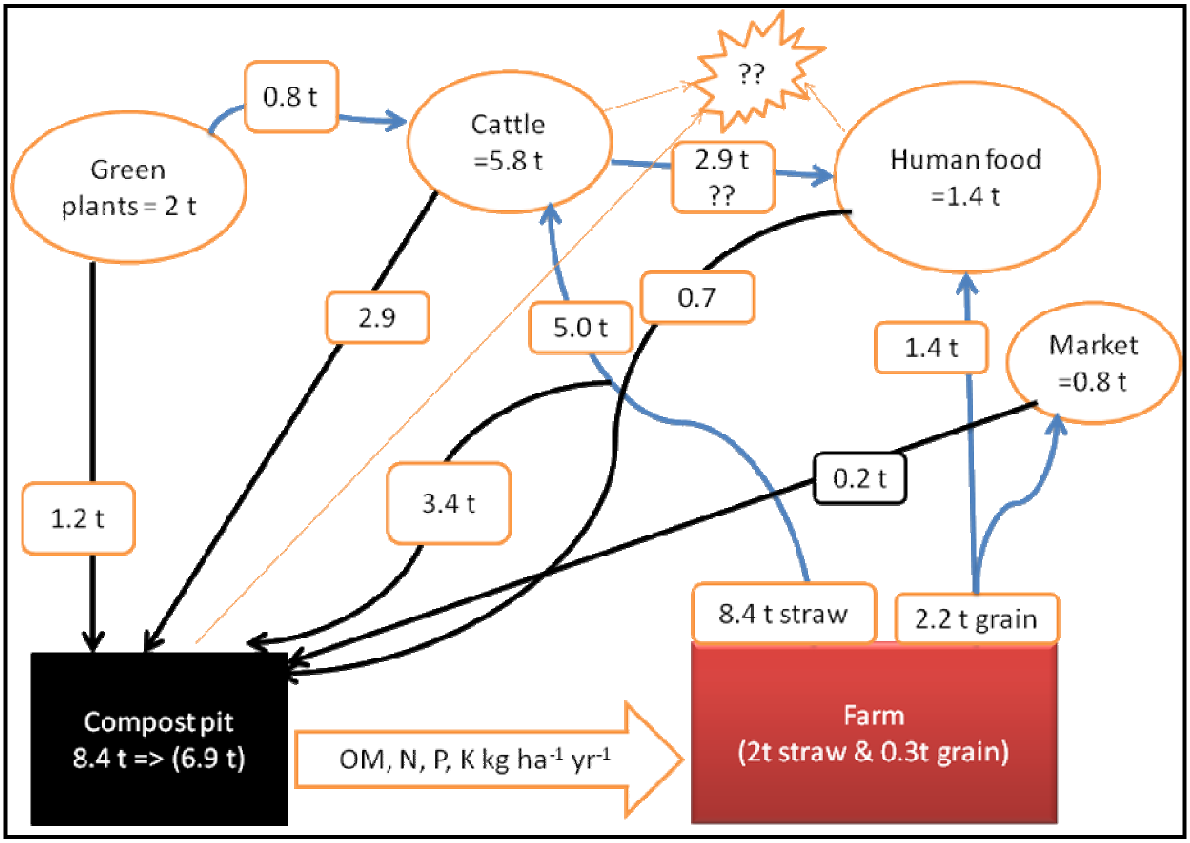

Figure 5.2 - Ideal integrated family-level nutrient flow model to sustain smallholder agriculture

The compost pit has got 8.4 t biomass, which does not include water. These are different sources in diverting organic waste into compost (Smiciklas et al., 2008). According to the research conducted by Eghball et al. (1997) the mass loss during his composting was about 18 percent ranging between 15-20 percent. Therefore, the etimated compost of the 8.4 t biomass will be 6.9 or 7.0 t matured compost.

The quality of compost vary very much but this research is to consider the best farm residue compost. The farm residue compost indicated as FR4 (Annex 7.1) better especially in organic matter and nitrogen. It has OM (14.74%), OC (8.55%), TN (1.05%), P (382 mg.kg^{-1}) and K (2,888 mg.kg^{-1}).

This type of recycling process produces about 7 t of compost. It attains 1,029 kg organic matter, 602 kg organic carbon, 77 kg total nitrogen, 2.7 kg phosphorous and 20.3 kg potassium. This model compost has good amounts of organic matter and nitrogen than the average 6.4 t.ha^{-1}.yr^{-1} compost application and mineral fertilizer used in this study. It is almost doubled. But the phosphorous content is still insignificant amount. Soils with this problem will be deficient in phosphorous. However, the phosphorous content even of an improved compost variety will still be insignificant amount to replenish soils which are poor in phosphorous or compensate the normal depletion (Tables 4.31; 5.4). Therefore, supporting farmers through trainings in proper biomass production and management for the production of quality compost should be the priority by GOs and NGOs.

6. CONCLUSIONS AND RECOMMENDATION

Based on the results of the research, the following conclusions and recommendation can be drawn:

The character of the top soil of the study area, loam and silt loam shows more the colluvial character of deposition from erosion. These soils are usually linked to a higher fertility but the properties at the plough layer soil (OM, N, P and K content) are dominantly low for crop production. Therefore, there is no guarantee for a sustainable production unless maintained by better nutrient replenishment strategies.

The availability of biomass depends on the animal holding, season and biomass management. Even though the quality of compost varies from farmer to farmer there are farmers produce good amount of compost, where their nitrogen and potassium is comparable with mineral fertilizer. The effect of compost on the soil and yield shows that the average amount of compost which is applied by farmers, 3.2 $t.ha^{-1}.yr^{-1}$, is insufficient. However, the over-all more positive effects (soil, yield and income) of 6.4 $t.ha^{-1}.yr^{-1}$ indicated that the need to improve the production of compost at least to this level.

The partial input-output nutrient balances and the existing NPK stock in the plough layer soils indicate that high nutrient depletion is common in the soils of the study area and nutrient levels in general are insufficient. Their low nutrient status requires enhancement by applying sufficient and integrated inputs. But the present low input practice by farmers and their low effect on yields is showing that crop production at this stage is not sustainable.

The above conclusions advice farmers to improve the quantity and quality of their compost production. There are many possibilities in increasing their compost production. In the rural areas over 92 percent of the farmers have cattle and over 83 percent of the families have sufficient human labour. Proper biomass management requires of the recycling of biomass in the rural areas and to create a two way rural-urban communication can bring the nutrient removed by the food system back to the farm. Improving the P level of the compost is very crucial. However, if it is not possible to replenish soil phosphorous by compost, therefore the phosphorous deficiency should be supported by other means such as dressing P inorganic fertilizer. This approach will create resilience in the farming communities to meet their needs at their own decisions.

Future prospects

The results and conclusions of this research indicate the following points to be addressed for further research. These are:

- Further research about the effect of compost in different soils, agro-ecological and farm management practices is required.
- Conduct research on improving the quality and quantity of compost especially enhancing available phosphorous.
- Identify the type, decomposability level, side-effect, nutrient level, etc. of the different composting biomasses used by farmers.
- Conduct further long-term and short-term research on socio-economic conditions and effects on soils by creating synergies between organic and inorganic fertilizers.
- Identify the willingness level of farmers in using animal manure for soil amendment and/or household energey. This includes the level of family conflict about animal dung and strategies for its management.
- Identfy the above-ground and below ground effects of legume crops.

7.1 SUMMARY

The effect of compost on soil fertility enhancement and yield increment under smallholder farming - A case of Tahtai Maichew District - Tigray Region, Ethiopia

The government of Ethiopia has launched an agricultural package during the previous decade focused on a package of mineral fertilizer and high yielding varieties to increase crop production. However, farmers have been reluctant in using mineral fertilizer because of the high price, weak delivery, a sharp drop of crop prices after harvests and unreliable rainfall. Instead farmers are highly inclined into locally available soil fertility management and yield increment practices including composting, because they require high labor and low capital, which are risk avoidance strategies of Ethiopian farmers. Therefore, the significance of this study is to assess the effect of compost application in smallholder farming without upsetting their usual living. Its results are supposed to benefit farmers and come up with a policy briefing that policy makers give a better support for its implementation.

The study was conducted in three communities (Adi Nefas, Kewanit and Mai Siye) of the Tahtai Maichew District of Tigray Region. Soil samples were collected before sowing and after harvest each year (2005-2007). Compost samples were also collected from farmers' houses. Different crops were sown in different years using local knowledge on the sequence of crop rotation. The following methodologies were used during laboratory analysis: particle size distribution was determined by *Bouyoucos* hydrometer method, pH in a 1:2.5 soil-water suspension, electrical conductivity in 1:2.5 extracts from soil:H_2O mixtures, organic carbon by Walkley-Black, total nitrogen with Kjeldahl procedure, available phoshporus after Olsen, available K was extracted by ammonium acetate method, CEC and exchangeable bases were also determined by this method. The conntent of the total nitrogen in plant was determined by the Kjeldahl method, while phosphorous and potassium were analysed by using an ashing method.

The Relative Productivity Index (RPI) has been employed to overcome the difficulty of comparing different crops. The partial input-output nutrient analysis was used to determine the nutrient balance. The net income of grain and straw yield was calculated based on the Partial Budget Analysis. The analysis of the data was conducted by multivariate statistical approaches using the SPSS system; Sigmasta and SAS system. All data were subjected to Analysis of Variance by ANOVA.

The study had 5 different objectives.

The first objective was to assess the present soil fertility status of the plough layer soils of the study area. The soils in the study area are Vertisols, Luvisols and Cambisols. All the soil profiles of the study area are deeper than one meter (110-207cm). The plough layers of all soils are dominated by loam and silt loam texture. They are soil sediments derived from the adjacent hills. Bulk densities (1.05-1.34 $g.cm^{-3}$) indicate that soils are not compacted despite the long cultivation period. The weakly alkaline and moderately alkaline pH values and low levels of EC are not problematic for any type of crop cultivation. However, the OM, N, P and K level of the plough layer soils are too low for continuous crop cultivation.

The second objective was to see the situation of compost and composting materials in the study area. From the three types of compost (farm residue, weed or *Parthenium* and urban waste) used in the study area almost all the farmers use the farm residue compost. At present over 88 percent farmers in the study area prepare and use compost with an average application rate of 3.2 $t.ha^{-1}.yr^{-1}$. However, the compost application rates vary (2.8-6.0 $t.ha^{-1}.yr^{-1}$) based on soil and crop types. Generally more compost is applied on sandy soil and higher plants, and less amount of compost on clay soils and smaller plants. Many farmers mix compost with mineral fertilizer.

The amount of compost the farmers of the study area apply is insufficient as compared the application of mineral fertilizer. The yields of the different crops indicate the need to improve the amount of compost production at least to the 6.4 $t.ha^{-1}.yr^{-1}$. By improving the biomass management, over 68 percent of the farmers can produce more than 6.4 t compost per year. This is because they own the recommended number of animals, which are very fundamental to produce at least 6.4 t to apply into one hectare per year. Labour is not a critical problem that expected to limit the production of compost because more than 83 percent of the farming families have sufficient labour for compost making. Moreover, 38 percent of the farming families own donkeys or camels as additional support for labour.

The average pH values of composts are between 7 and 8. The pH of *Parthenium* compost is significantly higher than the other types of composts. But they do not have significant differences in their EC. There is also no significant difference in the organic matter (carbon) content of the different composts, but highest records are observed in the farm residue and *Parthenium* composts. The N content of the composts also vary from each other and within their groups. However, the farm residue compost has high nitrogen content (1.05 percent). *Parthenium* compost has significantly higher C:N ratios (19) than the other composts, while all the composts other than *Parthenium* have a C:N ratio below 8, which leads to a fast mineralization of organic matter. The average phosphorous, potassium and CEC contents of all composts show higher levels.

The quality of compost varies depending on the composting materials. Green materials such as Tamboukh (*Croton macrostachyus*), Awhi (*Cordia africana*) and *Sasbenia sasba are* N rich between 28.4-36.3 $g.kg^{-1}$ plants. Animal manure especially poultry manure is also rich in N (25.1 $g.kg^{-1}$). The nutrient rich weeds available in the study area are *Parthenium* and Mestenagir (*Datura stramonium*) contain 39-51 g K kg^{-1}, while Medafe (*Argemone mexicana*) contains 23-39 g N kg^{-1}. In Ethiopia these weeds are not only good in their nutrient contents but also in available volume because they are not used as animal feed. Therefore, the quality of compost can be improved by selecting nutrient rich composting materials and improving biomass management.

The third objective was to investigate, if the present farmers' compost application rate has impressive effects on soils, yields and income. The results of this research showed there are no significant changes of the pH, bulk density and moisture contents of the soils over the research period and treatments. The organic matter content of all the experiments of the study showed no significant changes over the three years; rather it showed a reduction trend through time. This may be due to high mineralization. The nitrogen content of the last research period in all the experimentation plots was significantly higher than for the previous years. This might be due to the combined effect of the addition of the amended inputs, mulching of the residue and the planting of legume (faba bean).

There is a significant increase in P contents for the plots applied with mineral fertilizer and 6.4 $t.ha^{-1}.yr^{-1}$ compost applications but not in the control plots and the 3.2 $t.ha^{-1}.yr^{-1}$ compost application. However, in all treatments P declined slowly till the end of the experimentation period. The potassium level of the experiments does not show any significant change over time and treatment. However, there is an indication of a consistently increasing trend in the 6.4 $t.ha^{-1}.yr^{-1}$ compost application than other applications.

Generally the unchanged situation in the soil properties might be due to insufficient application of compost and/or the research period is too short for the soils to respond.

The yields of the (150 kg) mineral fertilizer and 6.4 $t.ha^{-1}.yr^{-1}$ compost applications are significantly higher than the yields of the 3.2 $t.ha^{-1}.yr^{-1}$ compost applications, which are all higher than the control plots. This shows any amount and type of input applications can bring better yields. It also shows that soils of the study area require inputs to increase their yields.

The results of the agronomic performance of the crops as affected by different treatments show that 6.4 $t.ha^{-1}.yr^{-1}$ compost application is chosen by farmers mainly because of the higher yields through better crop performance by being able to cope with the delay and/or early halt of rainfall, which is a serious problem in the study area.

The fourth objective was to assess the input-output nutrient balance on farm level. The partial input-output nutrient balances are dominated by negatives, -69-(-228) N, -6-(-23) P and -188-(-269) K $kg.ha^{-1}.yr^{-1}$. The nutrient removal by crop harvest is very high. It varies based on the crop type. For example: nitrogen varies from -204-(-228) in the faba bean and -59-(-69) $kg.ha^{-1}.yr^{-1}$ in the barley; phosphorous vary -6-(-23) in the faba bean and (+)8-(-9) $kg.ha^{-1}.yr^{-1}$ in the barley; and potassium -236-(-269) in the faba bean to -188-(-247) $kg.ha^{-1}.yr^{-1}$ in the barley. Although negative nutrient balances are commonly reported about Ethiopia but there was no such values reported have ever been as low as in this study.

A positive balance for the barley under the mineral fertilizer application could have occurred because the phosphorous application by mineral fertilizer was higher than the P required by barley. The negative net balance for potassium in the mineral fertilizer trials can be explained by the cumulative previous K depletions of soils, which never been replenished in Ethiopia by additions of K.

The nutrient depletion in Ethiopia is due to the total removal of the straw and grain without adding enough inputs and/or soil fertility management practices. Application of animal manure is also limited because of the competition for animal feed and/or household energy. Also problems in the mineral fertilizer sector have restricted the wider use of inorganic fertilizers.

The existing NPK stock in the plough layer soils of the study area are 1220, 50 and 390 $kg.ha^{-1}$ of N, P and K respectively. They are at a low level which requires enhancement by applying sufficient inputs. More or less all the macro-nutrients (NPK) do not sustain their production capacity for crops except the P under mineral fertilizer application.

The findings of this study strongly indicate that the amount of both compost (even the 6.4 $t.ha^{-1}.yr^{-1}$ application) and mineral fertilizer applications are not enough to compensate the high nutrient removal. These indicates that there is an urgent need to improve the soil nutrient management primarily to achieve higher yields. Therefore some nutrient depletion reduction strategies can be suggested, which are:

1. Produce and use N, P and K rich composts.
2. Synergizing all locally available technologies and practices to improve the soil nutrient depletion and then increase production.
3. Convincing farmers to leave some biomass such as 20 percent of the straw in the field during harvest. This would minimize the nutrient removal significantly especially in the 6.4 $t.ha^{-1}.yr^{-1}$ compost application.

The fifth objective was assessing, if smallholder agriculture can sustain under the present low external input application. In the study area the prices of mineral fertilizer increased by 264% (DAP) and 319% (Urea) within ten years (1999/2000 and 2008/9). This shows us that the price of mineral fertilizer increase pushed many farmers to shift into other soil fertility management and yield increment practices and reduced the amount of mineral fertilizer supply in the district. For example, between 2005 and 2007 in the district mineral fertilizer use increased from 166 to 320 $t.yr^{-1}$, which means it only doubled, while compost increased from 7,685 to 28,071 $t.yr^{-1}$ and animal manure increased from 13,722 to 34,190 $t.yr^{-1}$, showing that the use of organic amendmends tripled or quadrupled.

The net incomes and marginal returns of the teff and barley under the recommended rate of mineral fertilizer and 6.4 $t.ha^{-1}.yr^{-1}$ compost applications are equally higher than the control and the 3.2 $t.ha^{-1}.yr^{-1}$ compost application. The faba bean has a higher average net income with 6.4 $t.ha^{-1}.yr^{-1}$ compost applications while the 3.2 $t.ha^{-1}.yr^{-1}$ compost application has higher marginal rate of returns. This shows us that compost application at 6.4 $t.ha^{-1}.yr^{-1}$ rate has improved yields equally or higher than the recommended rate of mineral fertilizer application and improves family incomes.

The Cumulative Productivity Index (CPI) of the three field crops (teff, barley and faba bean) grown over the three years (2005-2007) clearly shows that the applications of the 6.4 $t.ha^{-1}.yr^{-1}$ compost has been leading continuously higher production. This means that compost applications at 6.4 $t.ha^{-1}.yr^{-1}$ rate is sustaining yields over a longer time period than the other applications and the control.

The calculation for an ideal compost production in quantity and nutrient composition showed, that through recycling of organic materials about 7 t of compost can be produced. This amount of compost can generate 1,029 kg organic matter, 602 kg organic carbon, 77 kg total nitrogen, 2.7 kg phosphorous and 20.3 kg potassium. This type of compost has better amounts of organic matter and higher nitrogen content than the average 6.4 $t.ha^{-1}.yr^{-1}$ compost application and the mineral fertilizer applied in this study. It is almost doubled. However, the phosphorous content of this compost is still insignificant and will be insufficient to provide for the phosphorus deficient soils with the necessary quantities of this nutrient.

7.2 ZUSAMMENFASSUNG

Der Einfluss von Kompost auf die Verbesserung von Bodenfruchtbarkeit und Ertrag bei kleinbäuerlicher Landwirtchaft - ein Beitrag aus dem Tahtai Maichew Distrikt in der Tigray Provinz, Aethiopien

Die äthiopische Regierung führte im Anfang dieses Jahrzehntes zur Steigerung der landwirtschaftlichen Produktivität ein Input-Paket bestehend aus Mineraldüngern und Hochleistungsertragssorten ein. Nach kürzester Zeit jedoch hörten viele Farmer auf, dieses Paket anzuwenden, wegen des hohen Düngemittelpreises, einer nur geringen Ertragssteigerung und eines ungünstigen Input-Output-Verhältnisses u. a. bedingt durch einen rapiden Verfall der Getreidepreise nach der Ernte sowie Ertragsausfällen aufgrund von erratischen oder ausbleibenden Niederschlägen.

Stattdessen bekundeten Farmer ein großes Interesse, mit lokal vorhandenen Inputs Bodenfruchtbarkeit und Erträge zu steigern. Viele Farmer interessierten sich daher für Kompostherstellung, weil diese Methode zwar arbeitsintensiv ist, aber nur geringes oder gar kein Kapital erfordert.

In Bezug auf die optimale Anwendung und Handhabung von Kompost ergaben sich sowohl für die Praxis als auch für künftige agrarpolitische Strategien viele Fragen, die in der vorliegenden Arbeit geklärt werden sollen, um sie Bauern, Beratern und Politikern zur Verfügung stellen zu können.

Die Untersuchung wurde in drei Gemeinden (Adi Nefas, Kewanit and Mai Siye) des Tahtai Maichew Districtes der Region Tigray in Äthiopien durchgeführt. Farmer praktizieren verschiedene Fruchtfolgen, die auf jahrhundertealter Erfahrung basieren.

Bodenproben wurden jeweils vor der Saat und nach der Ernte in jedem Jahr zwischen 2005 bis 2007 genommen. Kompostproben wurden direkt von den Farmen gesammelt und im Labor nach folgenden Methoden untersucht:

- Korngrößenanalyse nach der Bouyoucos Hydrometermethode;
- pH-Bestimmung in einer 1:2.5 Boden-Wasser Suspension
- Elektrische Leitfähigkeit wurde in einem 1:2.5 - Extract einer Boden-Wasser-Mischung gemessen.

- Organischer Kohlenstoff wurde nach Walkley-Black, Gesamtstickstoff nach Kjeldahl und verfügbarer Phosphor mit der Olsenmethode bestimmt. Verfügbares Kalium wurde mit der Ammonium-Acetat Methode extrahiert und anschließend spektralphotometrisch bestimmt.
- Die Kationenaustauschkapazität und austauschbare Basen wurde mit derm Ammonium-Azetat-Methode bestimmt.

Die Nährstoffgehalte in Pflanzen wurden wie folgt bestimmt:

- Gesamtstickstoff ebenfalls nach Kjeldahl, Phoshpor und Kalium nach vorheriger Veraschung spektralphotometrisch bestimmt.

Um in der Auswertung verschiedene Pflanzenarten vergleichen zu können, wurde der relative Produktionsindex (RPI) verwendet Die partielle Input-Output-Nährstoffanalyse wurde zur Ermittlung der Nährstoffbilanz verwendet. Netto-Einkommen aus Korn- und Stroherträgen wurden mit der Partiellen Budget Analyse bestimmt, die mit multivariaten Statistikprogrammen wie SPSS, Sigmasta und SAS durchgeführt wurde, mit denen auch Varianzanalysen (ANOVA) vorgenommen wurden.

Das erste Ziel der Untersuchung war die Erfassung des gegenwärtigen Bodenfruchtbarkeitsstatus der Pflughorizonte im Untersuchungsgebiet, wo als Bodentypen Vertisole, Luvisole und Cambisole dominieren, die alle eine Profiltiefe von mehr als einem Meter aufweisen (110-207cm). Vorherrschende Bodentexturen sind Lehm und schluffiger Lehm, entstanden aus Bodensedimenten angrenzender Hügel. Die geringen Lagerungsdichten zwischen 1.05-1.34 g.cm^{-3} deuten an, dass die Böden nach jahrhundertelanger Kultivierung nicht verdichtet sind. Schwach und mäßig alkaline pH-Werte und niedrige elektrische Leitfähigkeiten bedeuten keine Einschränkungen für die landwirtschaftliche Produktion. Generell sind die Werte für die organische Substanz, N, P und K-Gehalte im Oberboden aber im allgemeinen gering.

Das zweite Ziel war, die Qualität von verwendetem Kompost und Kompostmaterialien einzuschätzen. Von den drei untersuchten Komposttpyen (Farmrückstände, Unkraut bzw. *Parthenium* und urbane Abfälle) wurden von fast allen Farmern Farmrückstände kompostiert. Zur Zeit bereiten und verwenden über 88% der Farmer im Studiengebiet Kompost mit durchschnittlichen Applikationsraten von 3.2 t.ha^{-1}.a^{-1}. Insgesamt variieren aber die Kompostapplikationsraten zwischen 2.8 und 6.0 t.ha^{-1} pro Jahr je nach Boden und angebauten Kulturen. Auf Sandböden und beim Anbau von hochwüchsigeren Pflanzen werden im allgemeinen höhere Kompostmengen ausgebracht, geringere Mengen auf tonigen Böden und für niederwüchsige Pflanzen. Viele Farmer verwenden auch Kompost zusammen mit Mineraldünger.

Wie sich zeigte, ist die angewendete Kompostmenge im Untersuchungsgebiet niedriger als anderswo und auch unzureichend, und die erzielten Erträge deuten darauf hin, dass mindestens eine Kompostmenge von 6.4 $t.ha^{-1}$ pro Jahr ausgebracht werden sollte. Die Untersuchung ergab, dass es für mehr als 68% der Farmer möglich sein sollte, diese Menge Kompost zu produzieren bei entsprechenden Verbesserungen ihres Biomassemanagements. Um dieses gewährleisten zu können, müssen pro Farm und Familie mindestens 3 Großvieheinheiten vorhanden sein. Verfügbare Arbeit ist kein begrenzender Faktor, 83 % der bäuerlichen Familien steht genügend familiäre Arbeitskraft zur Verfügung, 38% besitzen Esel oder Kamele für den Transport zu den Feldern.

Die durchschnittlichen pH-Werte des Komposts liegen zwischen 7 und 8. Der pH-Wert des *Parthenium* Komposts liegt signifikant höher als diejenigen der Komposte aus Farmrückständen. Die elektrische Leitfähigkeiten zwischen den Komposten unterscheiden sich nicht signifikant, ebenso wenig die Gehalte an organischer Substanz und organischem Kohlenstoff. Die Stickstoffgehalte der Komposte unterscheiden sich zwischen und innerhalb der einzelnen Untersuchungsgruppen, Kompost aus Farmrückständen hat hohe Stickstoffgehalte (1.05 %) und. Parthenium hat significant weitere C-N-Verhältnisse (19) als andere Komposte, deren C:N-Verhältnis oft unter 8 liegt, was die Mineralization organischer Substanz beschleunigt. Alle anderen Komposte haben auch höhere Gehalte an Phosphor und Kalium und höhere Austauschkapazitäten.

Die Kompostqualitäten variieren entsprechend der verwendeten Materialien. Grüne Materialien wie Tamboukh (*Croton* macrostachyus), Awhi (*Cordia africana*) and *Sasbenia sasba* sind sehr reich an Stickstoff mit Gehalten zwischen 28.4-36.3 $g.kg^{-1}$ in der pflanzlichen Trockenmasse. Tierdung besonders von Geflügel ist ebenfalls stickstoff reich (25.1 $g.kg^{-1}$). Die stickstoffreichsten Unkräuter, die verwendet wurden sind *Parthenium*, Mestenagir (*Datura stramonium*), beide enthalten zwischen 39 - 51g N kg^{-1} und Medafe (*Argemone mexicana*) haben Gehalte von 23-39 g N kg^{-1}. Diese Pflanzen fallen auch in großen Mengen in Äthiopien an, da sie von Tieren gemieden werden. Die Kompostqualität kann daher verbessert werden durch Selektion von nährstoffreichen Materialien und verbessertem Biomassemanagement.

Das vierte Ziel war, festzustellen, welche Wirkungen die von Farmern applizierten Kompostmengen auf Boden und Erträge erzielten. Die Ergebnisse dieser Forschungsarbeit zeigten keine signifikaten Einflüsse auf pH, Lagerdichte und Bodenwassergehalte über die Untersuchungsperiode und innerhalb der einzelnen Versuchsgruppen. Auch der Gehalt an organischer Substanz zeigte keine signifikanten Anstiege, eher verringerte dieser sich während der drei Untersuchungsjahre. Dieses kann auf eine erhöhte Mineralisation zurück zu führen sein. Jedoch war der Stickstoffgehalt in der letzten Untersuchungsperiode in allen Testplots signikant höher als in den Vorjahren. Dies mag auf den kombinierten Effekt zugeführter Inputs, Mulchen und den Reststickstoffgehalten von Leguminosen (Faba-Bohne) zurück zu führen sein.

Signifikante Anstiege von Phosphor konnten in den mit Mineraldünger und mit 6.4 $t.ha^{-1}.a^{-1}$ Kompost behandelten Flächen beobachtet werden, jedoch nicht auf den Kontrollflächen und den mit nur 3.2 $t.ha^{-1}.a^{-1}$ behandelten Plots. Aber in allen Varianten verringerten sich die Phosphorgehalte langsam zum Ende der Untersuchungsperiode hin. Der Kaliumgehalt der Experimente zeigt keine signifikante Änderung innerhalb und zwischen den Versuchsgruppen über den untersuchten Zeitraum. Jedoch zeichnet sich ein leicht steigender Trend in der 6.4 $t.ha^{-1}.a^{1}$ Kompostapplikation in Vergleich zu den anderen Varianten ab.

Generell unveränderte Bodeneigenschaften könnten in der geringen Menge der Kompostapplikationen und/oder der Kürze der Untersuchungsperiode begründet sein, in der noch keine Änderungen in den Bodeneigenschaften bewirkt werden konnte.

Die Erträge aus den 150 kg Mineraldünger- und 6.4 $t.ha^{-1}.a^{-1}$ Kompostapplikationen sind signifikant höher als die Erträge der 3.2 $t.ha^{-1}.a^{-1}$ Kompostapplikationen, die wiederum höher sind als die Kontrollvarianten. Dies zeigt, dass eine Anwendung von Kompost auf jeden Fall eine Erhöhung der Erträge bewirkt, und dass die Böden im Untersuchungsgebiet auf die Zugabe nährstoffreicher Inputs angewiesen sind, um Erträge steigern zu können. Eine Anwendung von 6.4 $t.ha^{-1}.a^{-1}$ Kompost wird von Farmern bevorzugt vor allem wegen der höheren Erträge, die sich auch bei verspäteten oder ganz ausbleibenden Niederschlägen einstellen, die ein großes Problem in der Untersuchungsgegend darstellen.

Das vierte Ziel war, die Input-Output Nährstoffbilanz auf Farmlevel zu untersuchen. Die partiellen Input-Output-Nährstoffbilanzen sind vorwiegend negativ: -69-(-228) N, -6-(-23) P and -188-(-269) K kg.ha^{-1}.a^{-1}. Der Nährstoffentzug durch die Ernte ist sehr hoch und variiert je nach angebauter Kulturart, und beträgt z. B. für Stickstoff. -204-(-228) bei Fababohnen und -59-(-69) kg.ha^{-1}.a^{-1} bei Gerste; für Phosphor (+)6-23 bei Fababohnen und (+)8-9 kg.ha^{-1}.a^{-1} bei Gerste; für Kalium -236-(-269) bei Fababohnen bis -188-(-247) kg.ha^{-1}.a^{-1} für Gerste. Viele Studien berichten über negative Bilanzen, besonders auch in Äthiopien, aber keine davon ist so niedrig wie die Nährstoffbilanzen dieser Studie.

Ein positives Ergebnis bei der Mineraldüngervariante für Gerste ist damit zu erklären, dass die gedüngte Menge höher ihr Bedarf. Die negativen K-Bilanzen auch bei der Mineraldüngervariante dürften darauf zurück zu führen sein, dass Böden völlig verarmt waren, weil ihnen bislang noch niemals Kalium zugeführt worden war.

Der NPK-Vorrat der Oberböden im Untersuchungsgebiet beträgt 1220, 50 and 390 kg.ha^{-1} N, P und K. Dieses niedrige Nährstofflevel erfordert die Anwendung weiterer Inputs. Mehr oder weniger ist keine keiner der Makro-Näherstoffe in einer ausrecheichen Menge vorhanden, um erfolgreiche Erträge zu gewährleisten mit Ausnahme von Phosphor in der Mineraldüngervariante.

Die Ergebnisse dieser Studie zeigen, dass noch nicht einmal die höchste der ausgebrachten Kompostmengen von 6.4 t.ha^{-1}.a^{-1} und eben so wenig die Mineraldüngerapplikationen den hohen Nährstoffentzug kompensieren können. Dies belegt die dringende Notwendigkeit, den Bodennährstoffstatus zu verbessern, um danach höhere Erträge erzielen zu können. Daher werden die folgenden Strategien zu einer Minderung der Nährstofferschöpfung der Böden vorgeschlagen:

1. Produktion und Verwendung von NPK-reichen Kompostarten.
2. Mobilisierung aller lokal verfügbaren Technologien und Praktiken zur Erzeugung von Synergien um den Bodennährstoffstatus zu verbessern.
3. Überzeugungsarbeit bei Farmern, etwas Biomasse, wie z. B. 20% Stroh nach der Ernte auf dem Feld zurück zu lassen. Dies würde signifikant den Nährstoffentzug vermindern, insbesondere die 6.4 t.ha^{-1}.a^{-1} Kompostapplikation.

Das fünfte Ziel war, abzuschätzen ob kleinbäuerliche Landwirtschaft unter den gegenwärtigen Bedingungen überdauern kann. Im Untersuchungsgebiet stieg der Mineraldüngerpreis um 264% für DAP und 319% für Urea in 10 Jahren (1999/2000 bis 2008/9). Diese Preisanstiege zwangen Farmer zum Einsatz alternativer Bodenmanagementstrategien, die durch den Einsatz lokal verfügbarer Inputs den Verbrauch von Mineraldüngern verringerten und trotzdem Erträge auf gleichbleibendem Niveau hielten oder steigerten. Zum Beispiel, zwischen 2005 und 2007 stieg der Mineraldüngerverbrauch im Distrikt nur um das Doppelte von ca. 166 to 320 $t.a^{-1}$; Kompost von 7 685 auf 28 071 $t.a^{-1}$ und Tierdung von 13 722 auf 34 190 $t.a^{-1}$., also eine Steigerung der Verwendung organischer Dünger um das drei- bis vierfache.

Nettoeinkommen und Grenzerträge aus Teff und Gerste unter den empfohlenen Mineraldüngermengen und 6.4 $t.ha^{-1}.a^{-1}$ Kompost sind gleichwertig höher als die 3.2 $t.ha^{-1}.a^{-1}$ Kompostvariante und die Kontrolle. Absolute Erlöse liegen höher für Fababohnen, während die 3.2 $t.ha^{-1}.a^{-1}$ Variante höhere Grenzerlöse aufweisen.. Dies zeigt, dass Kompostapplikation von 6.4 $t.ha^{-1}.a^{-1}$ Erträge in gleichem oder höhererem Maße steigern als die empfohlenen Mineraldüngermengen und auch die Familieneinkommen erhöhen.

Der Kumulative Produktivitätsindex der drei kultuvierten Arten – Teff, Hafer und Faba-Bohne zeigten, dass eine Applikation von 6.4 $t.ha^{-1}.a^{-1}$ Kompost die Produktionsraten kontinuierlich erhöhte, was belegt, dass diese höheren Anwendungsmengen langfristig höhere Erträge erzielen als niedrigere Kompostmengen.

Eine Modellrechnung, wie eine optimale Kompostmenge und –qualität aus lokal vorhandenen Materialien erzeugt werden könnte, ergab, dass durch das recycling von organischen Materialien 7 t Kompost (pro Farm) produziert werden, darin enthalten sind 1029 kg organische Substanz, 602 kg Kohlenstoff, 77 kg Gesamtstickstoff, 2.7 kg Phosphor und 20.3 kg Kalium.

Ein solcher Kompost hat ungefähr doppelte Gehalte an organischer Substanz und Stickstoff gute Gehalte an organischer Substanz im Vergleich zu der hier untersuchten 6.4 $t.ha^{-1}.a^{-1}$ untersuchten Variante und der Mineraldüngergaben. Die Phosphorgehalte sind aber dennoch nicht ausreichend, um phoshporarme Böden ausreichend zu versorgen.

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Appendix - 1

1.1 - List of figures

1.2 - List of tables

1.3 - List of abbreviations

ADLI	Agricultural Development Led-Industrialization
C	control
CEC	cation exchange capacity
CPI	Cumulative Productivity Index
CSA	Central Statistics Authority
DAP	diammonium-phosphate
EC	Electrical Conductivity
EPA	Environmental Protection Authority
ESP	exchangeable sodium percentage
ETB	Ethiopian Birr
FAO	Food and Agriculture Organization
FC	Fixed costs
FR	farm residue
FYM	Farm Yard Manure
GDP	Gross Domestic Product
GPS	Global Positioning Systems
HI	harvest index
IIRR	International Institute for Rural Reconstruction
ISD	Institute for Sustainable Development
MF	mineral fertilizer
MOARD	Ministry of Agriculture and Rural Development
MOFED	Ministry of Finance and Economic Development
MRR	marginal rate of return
NFIA	National Fertilizer Industry Agency

NI	net income
NS	not significant
RCBD	Randomized Complete Block Design
RPI	Relative Productivity Index
SOM	Soil Organic Matter
SSNC	Swedish Society for Nature Conservation
SWC	Soil and Water Conservation
TARI	Tigray Agriculture Research Institute
TBPED	Tigray Bureau of Planning and Economic Development
TC	Total Cost
TR	Total Revenue
USD	United States Dollar
UW	urban waste
VC	variable costs
WBISPPO	Woody Biomass Inventory and Strategy Planning Project Office
WRB	World Reference Base of Soil Resources
WWDSE	Water Works, Design and Supervision Enterprise

Appendix 2 - Rainfall in Wuqro Marai in 2005-07

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
2005	0	0	31	38	69	271	161	234	60	0	0	0	864
2006	0	7	7	50	56	272	269	240	69	0	0	0	969
2007	0	0	16	17	70	260	527	531	39	0	0	0	1459
Average	0	2	18	35	65	268	319	335	56	0	0	0	1097

Source: Tahtai Maichew District Agriculture Office.

Appendix 3.1 - Characteristics of the soil profile in Kewanit (Gebreyesus)

Depth	0-20	20-53	53-81	81-129	129-169
Sand (%)	4	1	12	16	47
Silt (%)	44	34	29	5	33
Clay (%)	52	65	59	79	20
Texture Class	SiC	C	C	C	L
Bulk Density - $g.cm^{-3}$	1.34	1.26	1.26	1.24	1.21
P^H-H_2O (1:2.5)	7.08	7.05	7.09	6.89	6.83
P^H-KCL (1:2.5)	6.88	6.86	6.87	6.66	6.55
EC ($mS.cm^{-1}$) (1:2.5)	0.20	0.12	0.18	0.12	0.12
Exch. Na (mmol/100g soil)	0.51	0.55	0.68	0.74	0.86
Exch. K (mmol/100g soil)	0.54	0.39	0.42	0.31	0.38
Exch. Ca (mmol/100g soil)	36.40	36.40	34.20	34.20	43.20
Exch. Mg (mmol/100g soil)	16.69	19.26	18.40	17.98	18.40
Sum of Cations (mmol/100g soil)	54.14	56.60	53.70	53.23	62.84
CEC (mmol/100g soil)	54.43	55.36	52.10	53.97	66.06
Organic Carbon (%)	1.10	0.88	0.83	1.11	0.97
Nitrogen (%)	0.06	0.07	0.04	0.07	0.04
Available P (mg P_2O_5/kg soil)	22.40	6.40	18.50	43.60	39.00
Available K (mg K_2O/kg soil)	221.24	155.83	160.94	128.94	156.17
$CaCO_3$ (%)	7.49	12.79	6.40	11.22	9.57
Exchangeable Sodium % (ESP)	0.94	0.99	1.30	1.38	1.30

Appendix 3.2 - Characteristics of the soil profile in Kewanit (Gebreyesus)

Depth	**0-22**	**22-53**	**53-88**	**88-122**	**122-149**
Sand (%)	41	52	37	51	32
Silt (%)	43	36	41	29	50
Clay (%)	16	12	22	21	18
Texture Class	L	SL	L	L	L
Bulk Density - $g.cm^{-3}$	1.23	1.28	1.25	1.35	1.30
P^H-H_2O (1:2.5)	5.60	6.35	5.90	6.54	5.90
P^H-KCL (1:2.5)	5.35	5.97	5.70	5.99	5.60
EC ($mS.cm^{-1}$) (1:2.5)	0.04	0.05	0.04	0.07	0.04
Exch. Na (mmol/100g soil)	0.33	0.45	0.54	0.34	0.37
Exch. K (mmol/100g soil)	0.25	0.17	0.16	0.24	0.30
Exch. Ca (mmol/100g soil)	27.40	21.40	23.10	25.70	27.40
Exch. Mg (mmol/100g soil)	8.56	9.42	9.42	11.56	8.56
Sum of Cations (mmol/100g soil)	36.54	31.44	33.22	37.84	36.63
CEC (mmol/100g soil)	44.20	41.40	35.82	46.99	40.94
Organic Carbon (%)	0.82	0.51	0.31	0.58	0.69
Nitrogen (%)	0.04	0.04	0.22	0.04	0.06
Available P (mg P_2O_5/kg soil)	8.20	6.10	3.60	6.10	23.20
Available K (mg K_2O/kg soil)	101.51	101.34	72.69	120.31	118.94
$CaCO_3$ (%)	_	_	_	5.35	_
Exchangeable Sodium % (ESP)	0.76	1.08	1.51	0.73	0.91

Appendix 3.3 - Characteristics of the soil profile in Adi Nefas (Tsige)

Depth	**0-20**	**20-60**	**60-110**
Sand (%)	33	50	86
Silt (%)	49	46	13
Clay (%)	18	4	1
Texture Class	L	SL	SL
Bulk Density - $g.cm^{-3}$	1.05	1.22	0.82
P^H-H_2O (1:2.5)	5.42	5.67	6.59
P^H-KCL (1:2.5)	5.18	5.46	6.10
EC ($mS.cm^{-1}$) (1:2.5)	0.05	0.04	0.07
Exch. Na (mmol/100g soil)	0.32	0.43	0.45
Exch. K (mmol/100g soil)	0.52	0.57	0.49
Exch. Ca (mmol/100g soil)	24.80	34.20	41.90
Exch. Mg (mmol/100g soil)	9.42	9.42	14.52
Sum of Cations (mmol/100g soil)	35.06	44.62	57.36
CEC (mmol/100g soil)	27.45	50.71	63.74
Organic Carbon (%)	0.75	0.83	0.16
Nitrogen (%)	0.06	0.04	0.01
Available P (mg P_2O_5/kg soil)	34.30	41.20	22.20
Available K (mgK_2O/kg soil)	210.03	223.07	196.70
$CaCO_3$ (%)	_	_	11.35
Exchangeable Sodium % (ESP)	1.15	0.84	0.70

Appendix 3.4 - Some characteristics of the soil profile in Adi Nefas (Abbadi)

Depth	**0-18**	**18-43**	**43-68**	**68-104**	**104-132**
Sand (%)	29	21	37	27	17
Silt (%)	45	45	35	33	37
Clay (%)	3	34	28	40	46
Texture Class	L	CL	CL	C	C
Bulk Density - $g.cm^{-3}$	1.10	1.45	1.34	1.37	1.23
P^H-H_2O (1:2.5)	5.79	5.86	5.97	5.92	5.86
P^H-KCL (1:2.5)	5.46	5.66	5.88	5.70	5.65
EC ($mS.cm^{-1}$) (1:2.5)	0.01	0.10	0.13	0.11	0.08
Exch. Na (mmol/100g soil)	0.32	0.65	0.71	0.57	0.53
Exch. K (mmol/100g soil)	0.56	0.32	0.32	0.59	0.65
Exch. Ca (mmol/100g soil)	18.80	23.10	21.60	27.90	25.90
Exch. Mg (mmol/100g soil)	7.70	5.99	6.05	7.85	5.18
Sum of Cations (mmol/100g soil)	27.38	30.06	28.68	36.91	32.26
CEC (mmol/100g soil)	32.10	34.43	32.87	42.18	37.57
Organic Carbon (%)	1.38	0.74	0.44	0.43	0.37
Nitrogen (%)	0.07	0.04	0.04	0.03	0.03
Available P (mg P_2O_5/kg soil)	46.90	18.00	2.40	1.80	1.90
Available K (mgK_2O/kg soil)	235.02	136.53	131.56	223.41	270.76
$CaCO_3$ (%)	_	_	_	_	_
Exchangeable Sodium % (ESP)	0.99	1.89	2.17	1.35	1.40

Appendix 3.5 - Characteristics of the soil profile in Mai Siye (Nursery)

Depth	**0-18**	**18-33**	**33-110**	**110-159**	**159-205**
Sand (%)	57	53	36	42	45
Silt (%)	36	36	38	34	42
Clay (%)	12	11	26	24	14
Texture Class	L	SL	L	L	L
Bulk Density - $g.cm^{-3}$	1.26	1.41	1.34	1.35	1.29
P^H-H_2O (1:2.5)	5.22	5.28	5.42	5.54	5.86
P^H-KCL (1:2.5)	5.01	5.10	5.28	5.35	5.70
EC ($mS.cm^{-1}$) (1:2.5)	0.05	0.05	0.04	0.04	0.05
Exch. Na (mmol/100g soil)	0.20	0.23	0.31	0.32	0.44
Exch. K (mmol/100g soil)	0.31	0.26	0.30	0.29	0.28
Exch. Ca (mmol/100g soil)	17.10	18.50	28.90	29.40	22.70
Exch. Mg (mmol/100g soil)	6.85	7.04	12.66	8.64	11.34
Sum of Cations (mmol/100g soil)	24.46	26.03	42.17	38.65	34.76
CEC (mmol/100g soil)	28.84	30.61	46.18	43.67	31.75
Organic Carbon (%)	0.73	0.67	1.28	0.88	0.64
Nitrogen (%)	0.06	0.04	0.07	0.06	0.06
Available P (mg P_2O_5/kg soil)	12.90	14.80	6.60	12.20	10.20
Available K (mgK_2O/kg soil)	126.60	114.49	121.46	129.06	117.80
$CaCO_3$ (%)	_	-	-	-	-
ESP (%)	0.71	0.75	0.68	0.73	1.37

Appendix 3.6 - Characteristics of the soil profile in Mai Siye (Embaye)

Depth	0-13	13-44	44-90	90-139	139-207
Sand (%)	41	28	38	46	43
Silt (%)	41	43	26	32	33
Clay (%)	18	29	36	22	23
Texture Class	L	CL	L	L	L
Bulk Density - $g.cm^{-3}$	1.18	1.31	1.43	1.32	1.39
P^H-H_2O (1:2.5)	5.41	5.48	5.80	5.69	6.95
P^H-KCL (1:2.5)	5.13	5.20	5.39	5.45	5.99
EC ($mS.cm^{-1}$) (1:2.5)	0.10	0.14	0.05	0.05	0.08
Exch. Na (mmol/100g soil)	0.25	0.34	0.39	0.35	0.36
Exch. K (mmol/100g soil)	0.50	0.38	0.31	0.28	0.43
Exch. Ca (mmol/100g soil)	19.40	28.20	30.70	29.70	37.40
Exch. Mg (mmol/100g soil)	8.80	9.68	9.94	10.18	17.06
Sum of Cations (mmol/100g soil)	28.95	38.60	41.34	40.51	55.25
CEC (mmol/100g soil)	36.38	45.91	51.59	45.17	59.24
Organic Carbon (%)	0.75	1.07	0.77	1.01	0.69
Nitrogen (%)	0.04	0.07	0.04	0.05	0.05
Available P (mg P_2O_5/kg soil)	12.90	8.40	8.50	10.30	9.50
Available K (mgK_2O/kg soil)	188.66	152.89	131.59	121.46	125.18
$CaCO_3$ (%)	-	-	-	-	-
ESP (%)	0.68	0.75	0.76	0.78	0.61

Appendix 4 - Amount of compost produced by respondants in 2008 G.C.

Amount of compost	Families (n=116)		Percentage of the compost users (n=103)	Compost pit size (m)
	Number	Percent		
No compost	13	11.2	-	-
Less than 1 ton	20	17.2	19.4	1x1x1/1x1.5x1
1-1.99 t*	40	34.5	38.8	1x1.5x1.5
2-2.99 t**	21	18.1	20.4	2x(1x1.5x1.5)
3-3.99 t***	19	16.4	18.5	3x(1x1.5x1.5)
4-4.99 t	2	1.7	1.9	4x(1x1.5x1.5)
≥ 5 ton	1	0.9	1.0	5x(1x1.5x1.5)
Total	**116**	**100**	**100**	

Appendix 5.1 - NPK level of crop residue used for composting materials ($g.kg^{-1}$)

Local name	**Scientific name**	**N**	**P**	**K**
Teff	*Eragrostis tef*	3.5	1.0	10.4
Maize	*Zea mays*	3.5	2.5	17.2
Sorghum	*Sorghum bicolor*	3.6	0.6	9.2
Wheat	*Triticum spp.*	4.6	0.3	12.5
Barley	*Hordeum vulgare*	6.4	1.2	29.8

Appendix 5.2 - NPK level of weeds composting materials ($g.kg^{-1}$)

Local name	**Scientific name**	**N**	**P**	**K**
Tihag	*Graminae grass*	2.9	0.3	2.6
Tinigta	*Guizotia scabra*	17.9	2.9	16.1
Dandier	*Echinops sp.*	17.2	2.1	16.4
Wazwazo	*Unidentified*	3.6	2.5	29.3
Parthenium	*Parthenium hysterophorus*	38.5	2.8	51.2
Medafe	*Argemone mexicana*	22.8	1.1	15.3
Mestenagir	*Dotura stramonium*	37.3	2.4	39.2
Mugya	*Snowdenia ploystachya*	1.8	1.0	15.9

Appendix 5.3 - The NPK level of leaves and branches ($g.kg^{-1}$)

Local name	**Scientific name**	**N**	**P**	**K**
Fresh Hohot	*Rumex nervosus*	19.0	2.0	35.2
Tambokh	*Croton macrostachyus*	28.4	4.2	14.3
Awhi	*Cordia Africana*	35.4	4.7	44.2
Akacha	*Acacia saligna*	19.5	0.5	9.6
Sasbania	*Sasbenia Sesban*	36.3	2.8	29.3
Kliaw	*Dodonea angusitofilia*	13.2	0.6	13.5
Kulkual	*Euphorbia*	11.0	2.1	8.4

Appendix 5.4 - The NPK level of animal waste ($g.kg^{-1}$)

Local name	**N**	**P**	**K**
Cow dung	12.9	3.8	12.3
Goat manure	28.4	3.7	8.6
Sheep manure	23.2	6.3	8.2
Chicken droppings	25.1	7.7	12.9
Old cow dung	8.1	4.0	3.7
Fresh cow dung	11.9	6.2	8.0

Appendix 6.1 - The possibility of compost preparation under different conditions

R.N.	Conditions for compost	Amount of compost ($t.yr^{-1}$)			
		<2	2-3.2	3.21-6.4	>6.4
1	Without any domestic animal	124 (73)	38 (22)	9 (5)	0 (0)
2	With existing domestic animals	96 (56)	43 (25)	31 (18)	1 (1)
3	With existing animals + good biomass management	26 (15)	29 (17)	48 (28)	68 (40)
4	Existing domestic animals + planting trees[1] without good biomass management	8 (5)	78 (46)	62 (36)	23 (13)
5	Existing domestic animals + planting trees + good biomass management	0 (0)	33 (19)	52 (31)	86 (50)

Appendix 6.2 - Family size and their animal-holding by number (n=205) and percent

	Cattle					Sheep/ goat	Equines	Chicken
Family size	No	1-2	3-4	≥5	**Total**	**Total**	**Total**	**Yes**
≤3	12	8	12	2	**34 (16.6)**	**14 (9.8)**	**5**	**26**
4-7	2	38	70	20	**130 (63.4)**	**96 (67.1)**	**51**	**105**
≥8	2	4	20	15	**41 (20.0)**	**33 (23.1)**	**22**	**36**
Total (%)	**16 (7.8)**	**50 (24.4)**	**102 (49.8)**	**37 (18.0)**	**205 (100.0)**	**143 (69.8)**	**78 (38.0)**	**167 (81.5)**

Appendix 7.1 - The pH, EC, OM, OC, TN, C:N, P and K contents of different types of composts

Comp. type	pH (H_2O)	EC ($mS.cm^{-1}$)	OM (%)	OC (%)	TN (%)	C:N	P ($mg.kg^{-1}$ compost)	K ($mg.kg^{-1}$ compost)
FR1	7.2	0.7	9.98	5.79	0.38	15	525	1 880
FR2	7.7	2.9	7.24	4.2	0.54	8	357	5 156
FR3	6.8	0.7	7.81	4.53	0.59	8	297	1 313
FR4	7.2	2.8	14.74	8.55	1.05	8	382	2 888
FR5	7.5	0.6	8.95	5.19	0.7	7	321	2 888
P1	7.7	1.8	8.48	4.92	0.24	21	342	6 681
P2	7.9	4.7	15.03	8.72	0.43	20	393	10 218
P3	7.9	3.9	13.57	7.87	0.44	18	369	8 481
UW1	7.7	0.7	9.01	5.23	0.67	8	260	3 854
UW2	7.6	0.7	7.53	4.37	0.7	6	357	3 518

Key: FR – farm residue:- which is 50 percent farm residues, green matter especially weeds, leaves and tree branches 30 percent and 20 percent animal manure. **P** – from parthenium dominated area and compost are made from green and dry parthenium weed. **UW** – urban was with about 75 percent house litter and vegetable waste and 25 percent are animal manure.

[1] Refers to trees that can be used for firewood to make free the competition for animal dung and other multipurpose trees as animal forage, compost making and improve soil fertility such as Sasbania sesban.

Appendix 7.2 - The exchangeable base cations, CEC, BS and ESP contents of different types of composts

Comp. type	Exchangeable Base Cations (mmol.kg^{-1} compost)						BS (%)	ESP (%)
	Na	K	Ca	Mg	Sum of cations	CEC		
FR1	4.8	42.9	360.0	135.7	543.4	539.2	101	0.89
FR2	13.4	98.7	233.0	167.0	513.0	459.1	112	2.92
FR3	3.8	43.4	356.0	110.0	514.0	406.5	126	0.94
FR4	12.9	87.4	422.0	119.0	642.0	487.8	132	2.65
FR5	12.4	119.6	308.0	211.0	651.0	555.0	117	2.23
P1	4.5	179.0	295.0	179.0	657.5	721.1	91	0.62
P2	3.6	309.0	270.0	183.0	765.6	538.1	142	0.67
P3	4.4	293.0	286.0	205.8	788.9	588.9	134	0.74
UW1	8.1	91.4	317.0	74.8	491.0	449.6	109	1.81
UW2	8.1	78.4	378.0	119.0	583.7	444.8	131	1.83

Key: FR – farm residue:- which is 50 percent farm residues, green matter especially weeds, leaves and tree branches 30 percent and 20 percent animal manure. **P** – from *Parthenium* dominated area and compost are made from *Parthenium*. **UW** – urban waste - with about 75 percent house litter and vegetable waste and 25 percent are animal manure.

Appendix 8 - Bulk Density (g.cm^{-3}) by year and treatment

Mean	C	MF	3.2 t/ha	6.4 t/ha
2005 BP	1.38 ± 0.17^a	1.40 ± 0.22^a	1.46 ± 0.14^a	1.40 ± 0.23^a
2005 AH	1.36 ± 0.07^a	1.36 ± 0.27^a	1.42 ± 0.20^a	1.46 ± 0.15^a
2006 BP	1.44 ± 0.21^a	1.37 ± 0.21^a	1.36 ± 0.19^a	1.36 ± 0.21^a
2006 AH	1.40 ± 0.16^a	1.42 ± 0.12^a	1.36 ± 0.13^a	1.42 ± 0.10^a
2007 BP	1.40 ± 0.16^a	1.45 ± 0.13^a	1.36 ± 0.13^a	1.42 ± 0.10^a
2007 AH	1.45 ± 0.14^a	1.46 ± 0.05^a	1.45 ± 0.14^a	1.42 ± 0.10^a

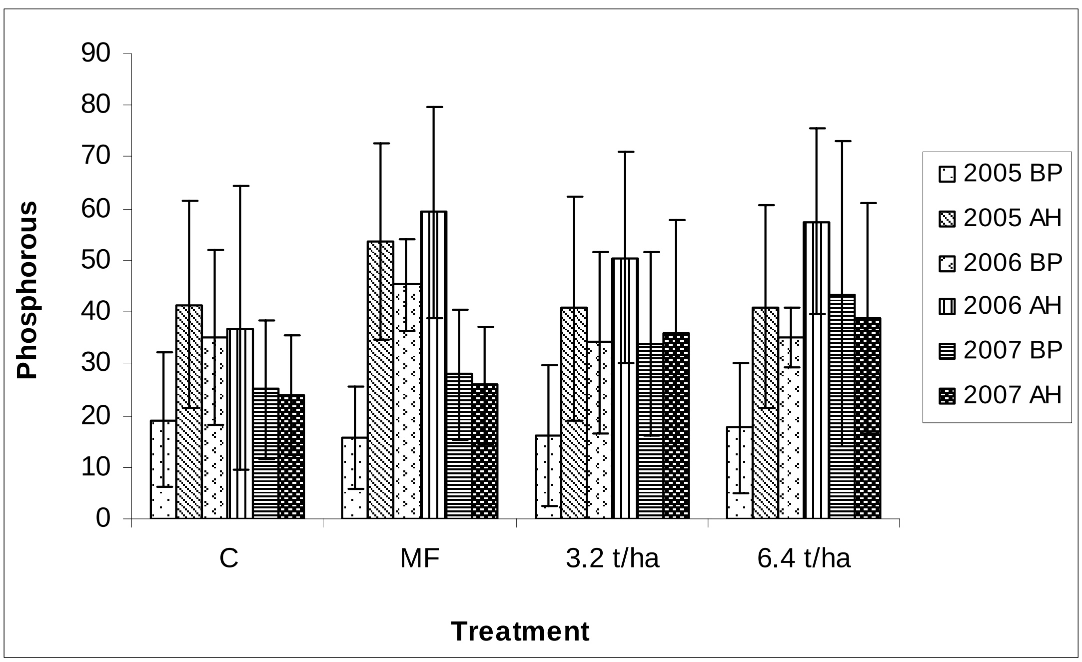
Appendix 9.1 - pH situation over time and treatment

	C	MF	3.2 t/ha	6.4 t/ha
2005 BP M	6.83+0.64[a]	6.79+0.64[a]	6.82+0.66[a]	6.82+0.64[a]
2005 AH M	6.27+0.71[a]	6.34+0.65[a]	6.42+0.46[a]	6.74+0.47[a]
2006 BP M	6.34+0.67[a]	6.30+0.81[a]	6.34+0.69[a]	6.51+0.66[a]
2006 AH M	6.02+0.96[a]	6.04+0.73[a]	6.31+0.67[a]	6.36+0.80[a]
2007 BP M	6.31+0.75[a]	6.40+0.79[a]	6.43+0.77[a]	6.27+0.66[a]
2007 AH M	6.26+0.61[a]	6.37+0.97[a]	6.38+0.62[a]	6.31+0.53[a]

Appendix 9.2 - The trend of organic carbon (%) over experimental period (2005 – 2007)

Mean	**C**	**MF**	**3.2 t/ha**	**6.4 t/ha**
2005 BP	0.81+0.18[a]	0.79+0.19[a]	0.89+0.16[a]	0.82+0.17[a]
2005 AH	0.93+0.25[a]	0.98+0.32[a]	1.09+0.37[a]	1.16+0.40[a]
2006 BP	0.96+0.25[a]	0.90+0.32[a]	0.99+0.22[a]	1.01+0.27[a]
2006 AH	0.89+0.27[a]	0.95+0.32[a]	0.98+0.36[a]	1.03+0.32[a]
2007 BP	0.72+0.17[a]	0.67+0.24[a]	0.76+0.18[a]	0.73+0.27[a]
2007 AH	0.70+0.14[a]	0.70+0.17[a]	0.79+0.15[a]	0.81+0.22[a]

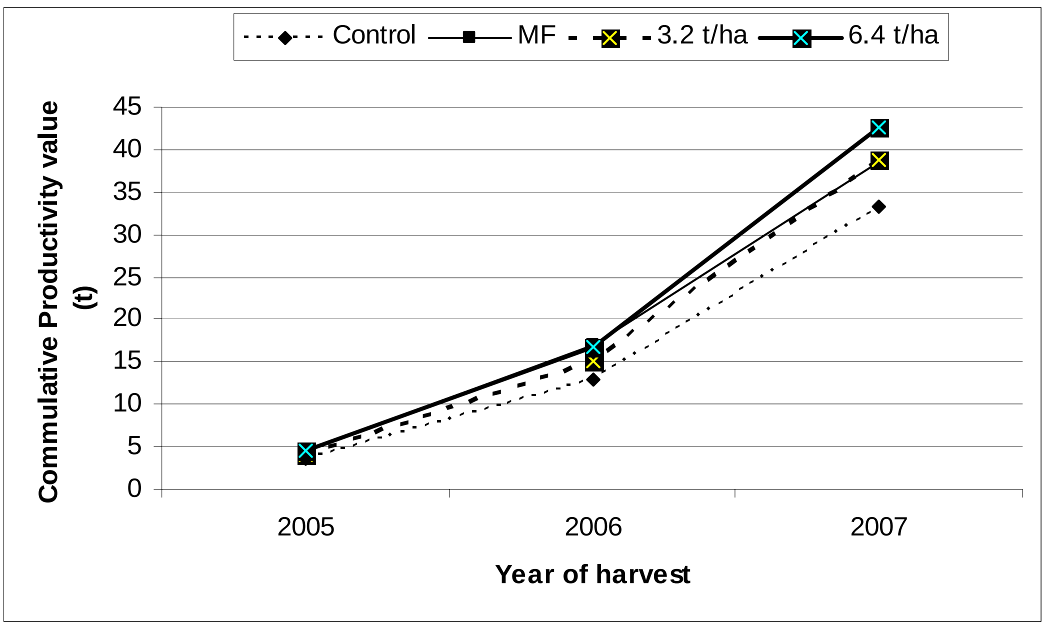
Appendix 9.3 - The phosphorous trend over 2005-2007 in the experimental plots



Appendix 9.4 - Trend of Potassium (mg.kg^{-1}) during the experimentation period (2005-2007)

Mean	C	MF	3.2 t/ha	6.4 t/ha
2005 BP	204.53+32.75	198.47+64.86	199.68+44.63	216.57+37.56
2005 AH	225.11+44.80	227.13+50.08	208.36+52.97	243.24+48.29
2006 BP	251.59+45.29	210.85+33.89	239.37+36.72	260.79+23.09
2006 AH	230.74+52.42	254.30+66.12	249.32+31.71	265.02+64.31
2007 BP	235.55+47.64	254.23+30.45	256.62+37.86	259.06+50.39
2007 AH	217.35+49.12	194.82+27.28	214.27+30.22	248.85+56.47
LCD	NS	NS	NS	NS

Appendix 10.1 - Cumulative productivity index of grain and straw production for teff, barley and faba bean crops (ton)



Appendix 10.2 - Cumulative productivity index of grain and straw production for teff, barley and faba bean crops (percent in relation to the production of mineral fertilizer)

Year	Control		Mineral fertilizer		3.2 t.ha^{-1}.yr^{-1}		6.4 t.ha^{-1}.yr^{-1}	
	t.ha^{-1}	%	t.ha^{-1}	%	t.ha^{-1}	%	t.ha^{-1}	%
2005	3.7	80	4.6	100	4.1	89	4.5	98
2006	12.9	76	16.9	100	15.0	89	16.7	99
2007	33.3	87	38.5	100	38.7	101	42.6	111

Appendix 10.3 - Farmers' cost analysis (expenditures) for different inputs per hectare of land

Item	**Mineral fertilizer**			**Compost**				**Control**
	Per ha	Cost /100 kg	Total cost	3.2 $t.ha^{-1}$	Unit cost	Total	6.4 $t.ha^{-1}$	Total cost
DAP***	100 kg	341	341	-	-	-	-	-
Urea***	50 kg	312	156	-	-	-	-	-
No. of days to buy - At cash purchase - At credit purchase	 2 3	 15 15	 30** 45**	-	-	-	-	-
Donkey working days to transport	3	10	30	4	10	40	80	-
Human labor needed with donkey	1	15	15	-	-	-	-	-
Human labor for applying during planting	1	15	15	2	15	30	60	-
Digging a pit (persons per day)	-	-	-	6	15	80/4 =20*	160/4= 40*	-
Biomass collection & pit filling ($per.day^{-1}$)	-	-	-	12	15	160	320	-
Turning over ($persons.day^{-1}$)	-	-	-	4	15	60	120	-
Total cost of expenditures			594			310	620	00

Source: survey data in the study area in 2007.
Key: * One pit serves a minimum of 4 years and a maximum of six years, once dug for use. Therefore, the minimum is taken into consideration. ** 37.5 ETB is an average value of the two options of column 5. *** Average prices of mineral fertilizer of the last five years (between 2003 and 2007).

Appendix 10.4 - Net income of teff in Ethiopian Birr ($ETB.ha^{-1}$) under different treatments

Particulars	**Control**	**Mineral fertilizer**	**3.2 $t.ha^{-1}$ compost**	**6.4 $t.ha^{-1}$ compost**
Average grain yield ($t.ha^{-1}$)	0.87	1.12	0.94	1.11
Average straw yield ($t.ha^{-1}$)	2.81	3.49	3.20	3.43
Gross benefit from grain (ETB/ha)	4 520	5 807	4 848	5 768
Gross benefit from straw (ETB/ha)	2 751	3 410	3 127	3 354
Total Benefit (ETB/ha)	7 272	9 217	7 974	9 122
Cost of fertilizer (ETB/ha)	-	594	-	-
Cost of compost (ETB/ha)	-	-	310	620
Total costs (ETB/ha)	0	594	310	620
Net Benefit (ETB ha^{-1})	**7 271$\pm$687^{b}**	**8 623$\pm$662^{a}**	**7 664$\pm$639^{b}**	**8 502$\pm$100^{ab}**

Key: Control - with out any input; CF - chemical fertilizer. The average market price of 100kg grain and straw of teff in 2005 and 2006 was 518.47 and 97.86 ETB respectively (10ETB is equivalent with 1USD).

Appendix 10.5 - Net income of Barley in Ethiopian Birr (ETB.ha^{-1}) under different treatments

Particulars	**Control**	**Mineral fertilizer**	**3.2 t.ha^{-1} compost**	**6.4 t.ha^{-1} compost**
Average grain yield (t.ha^{-1})	2.17	3.03	2.33	2.95
Average straw yield (t.ha^{-1})	7.09	9.28	8.58	9.23
Gross income from grain (ETB/ha)	8 998	12 525	9 626	12 214
Gross income from straw (ETB/ha)	4 868	6 366	5 886	6 332
Total Benefit (ETB/ha)	13 866	18 891	15 512	18 546
Cost of fertilizer (ETB/ha)	-	594	-	-
Cost of compost (ETB/ha)	-	-	310	620
Total costs (ETB/ha)	0	594	310	620
Net Benefit (ETB/ha)	**13 866±2276^{bc}**	**18 297±1218^{a}**	**15 202±1670^{b}**	**17 926±1467^{ab}**

Key: Control - with out any input; CF - chemical fertilizer. The average market price of 100kg grain and straw of barly in 2006 and 2007 was 414.04 and 68.64 ETB respectively (10ETB is equivalent with 1USD).

Appendix 10.6 - Net income of faba bean in Ethiopian Birr (ETB.ha^{-1}) under different treatments

Particulars	**Control**	**Fertilizer**	**3.2 t.ha^{-1} compost**	**6.4 t.ha^{-1} compost**
Average grain yield (t.ha^{-1})	3.33	3.83	3.886	4.23
Average straw yield (t.ha^{-1})	17.07	19.73	19.82	21.04
Gross income from grain (ETB/ha)	19 363	22 257	22 574	24 567
Gross income from straw (ETB/ha)	3 203	3 703	3 721	3 949
Total Benefit (ETB/ha)	22 566	25 960	26 294	28 516
Cost of fertilizer (ETB/ha)	-	594	-	-
Cost of compost (ETB/ha)	-	-	310	620
Total costs (ETB/ha)	0	594	310	620
Net Benefit (ETB/ha)	**22 566±2008^{a}**	**25 366±3492^{a}**	**25 984±4890^{a}**	**27 896±4736^{a}**

Key: Control - with out any input; CF - chemical fertilizer. The average market price of 100kg grain and straw of faba bean in 2007 and 2008 was 580.85 and 18.77 ETB respectively (10ETB is equivalent with 1USD).

Appendix 10.7 - The Marginal Rate of Return in relation to crop and treatment

Crop type	Treatment	TR	TC	NI	MRR
Teff	Control	0	0	0	0
	Mineral Fertilizer	1 946	594	1 352	2.3
	3.2 t/ha^{-1}	703	310	393	1.3
	6.4 t/ha^{-1}	1 851	620	1 231	2.0
Barley	Control	0	0	0	0
	Mineral Fertilizer	5 025	594	4 431	7.5
	3.2 t/ha^{-1}	1 646	310	1 336	4.3
	6.4 t/ha^{-1}	4 680	620	4 060	6.6
Faba bean	Control	0	0	0	0
	Mineral Fertilizer	3 394	594	2 800	4.7
	3.2 t/ha^{-1}	3 729	310	3 419	11.0
	6.4 t/ha^{-1}	5 950	620	5 330	8.0

Key: TR - Change in Total Revenue; TC - Change in Total Cost; NI - Change in Net Income; MRR - Marginal Rate of Revenue

Appendix 11.1 - The NPK application through different inputs

NPK / Compost	**Nitrogen (Kg/ha)***				**Phosphorous (kg/ha)****				**Potassium (kg/ha)*****			
	Cont	Compost 3.2t	Compost 6.4t	MF	Cont	Compost 3.2t	Compost 6.4t	MF	Cont	Compost 3.2 t	Compost 6.4t	MF
100(D) +50(U)	-	-	-	39	-	-	-	18	-	-	-	-
Farm residues	-	21	42	-	-	1.2	2.4	-	-	9	18	-
Parthenium	-	12	24	-	-	1.2	2.4	-	-	27	54	-
Urban waste	-	22	44	-	-	1.0	2.0	-	-	12	24	-
Average	**-**	**18**	**37**	**39**	**-**	**1.1**	**2.3**	**18**	**-**	**16**	**32**	

N.B.: Based on table 4.31 the average nitrogen (*) for farm residues, parthenium and urban waste compost are respectively 0.65, 0.37 and 0.69 percents of their nitrogen. The average phosphorous (**) for farm residues, parthenium and urban waste compost are respectively 376.44, 368.10 and 308.95 mg P_2O_5/kg. The average potassium (***) from farm residues, parthenium and urban waste compost are respectively 2824.56, 8460.06 and 3685.50 mg P_2O_5/kg of compost.

Key: MF - DAP and Urea; Cont. - control; 100(D) +50(U) - 100 kg DAP and 50 kg Urea

Appendix 11.2 - Partial input-output nutrient balance for barley (grain and straw) (kg.ha^{-1}.yr^{-1})

	Treatment	**Input**	**Output**			**Net balance**
			Grain	**Straw**	**Total**	
N	Check	**0**	32	38	69	**-69**
	Mineral fertilizer	**39**	49	50	98	**-59**
	3.2 t/ha compost	**18**	34	46	80	**-62**
	6.4 t/ha compost	**37**	50	49	99	**-62**
P	Check	**0**	0.7	7	7.7	**-7.7**
	Mineral fertilizer	**18**	1	9.2	10.2	**7.8**
	3.2 t/ha compost	**1**	1.2	8.6	9.7	**-8.6**
	6.4 t/ha compost	**2**	1	9.2	10.2	**-7.9**
K	Check	**0**	14	174	188	**-188**
	Mineral fertilizer	**0**	18	229	247	**-247**
	3.2 t/ha compost	**16**	14	213	227	**-211**
	6.4 t/ha compost	**32**	18	228	246	**-214**

Appendix 11.3 - Partial input-output nutrient balance for faba bean (grain and straw) (kg.ha^{-1}.yr^{-1})

	Treatment	Input[2]			Output			**Net balance**
		Input	N-fix	**Total**	Grain	Straw	**Total**	
N	Check	0	125	**125**	135	194	329	**-204**
	Mineral fertilizer	39	125	**164**	156	213	370	**-205**
	3.2 t/ha compost	18	125	**143**	157	214	371	**-228**
	6.4 t/ha compost	37	125	**162**	173	213	386	**-225**
P	Check	0	0	**0**	6	15	21	**-21**
	Mineral fertilizer	18	0	**18**	7	17	24	**-6**
	3.2 t/ha compost	1	0	**1**	6	16	22	**-21**
	6.4 t/ha compost	2	0	**2**	7	19	26	**-23**
K	Check	0	0	**0**	38	198	236	**-236**
	Mineral fertilizer	0	0	**0**	45	224	269	**-269**
	3.2 t/ha compost	16	0	**16**	45	235	280	**-264**
	6.4 t/ha compost	32	0	**32**	49	237	286	**-254**

[2] N of faba bean is increased due to the atmospheric N fixation capacity of legumes. The N fixation of faba bean is extrapolated as 125 kg N ha^{-1}, which is calculated from overall average of 10-350 kg N ha^{-1} in Australia and 54-133 kg N ha^{-1} in the Middle East study by Rochester et al., (1998) and 76-125 kg N ha^{-1} of the study by Carranca et al., (1999).

Appendix 11.4 - The input and output parameters determining the soil nutrient balance

Input type	Input		Output
	Barley	Faba bean	Barley/faba bean
Control	-	IN4- N fixation by faba bean.	Out1- Nutrient content of grain x grain yield + Out2- Nutrient content of straw x straw yield.
Mineral Fertilizer	IN1 -100 kg DAP and 50 kg Urea.	IN1-100 kg DAP and 50 kg Urea + IN4- N fixation by faba bean.	Out1- Nutrient content of grain x grain yield + Out2- Nutrient content of straw x straw yield.
3.2 $t.ha^{-1}.yr^{-1}$ compost	IN2 - compost at 3.2 $t.ha^{-1}.yr^{-1}$ rate	IN2- compost 3.2 $t.ha^{-1}.yr^{-1}$ rate + IN4- N fixation by faba bean.	Out1- Nutrient content of grain x grain yield + Out2- Nutrient content of straw x straw yield.
6.4 $t.ha^{-1}.yr^{-1}$ compost	IN2 - compost at 3.2 $t.ha^{-1}.yr^{-1}$ rate	IN2- compost 6.4 $t.ha^{-1}.yr^{-1}$ + IN4- N-fixation by faba bean.	Out1- Nutrient content of grain x grain yield + Out2- Nutrient content of straw x straw yield.

Input: IN1- Mineral fertilizer; IN2- Organic fertilizer; IN3- Wet and dry deposition; IN4- Nitrogen fixation; IN5- Sedimentation. **Output**: Out1 - Grain yield; Out2 - straw yield; Out3 - Leaching; Out4 - Gaseous losses; Out5 - Soil erosion. (Adapted from: Stoorvogel & Smaling, 1998; Bationo et al., 1998; de Jager, 1998; Folmer et al., 1998).

Appedix 12.1 - Mineral fertilizer price (ETB per 100 kg) between 1998 and 2009 at regional (Tigray-Ethiopia) level

Year	Urea	DAP
1999/2000	206.5	288.35
2000/1	206.5	288.35
2001/2	202.5	267.7
2002/3	216.05	267.7
2003/4	283.65	316.45
2004/5	327.9	374.9
2005/6	332.5	377.5
2006/7	360.8	401.1
2007/8	589.5	660.15
2008/9	659.5	760.15

Appendix 13 - Tigray Region compost application by district (Wereda)

Wereda	Compost applied				t.ha^{-1}
	ha	t	farmer	pits used	
Alamata	314	628	314	-	2.0
Ofla	618	1 112	188	-	1.8
Imba Alaje	3 654	13 467	5 229	6 635	3.7
Kilte Awla'elo	1 978	3 953	2 387	-	2.0
Atsbi Wemberta	5 480	14 796	7 390	7 398	2.7
Sa'esi'e Tsa'eda Imba	1 127	2 818	4 025	4 025	2.5
Hawzien	9 724	-	19 562	-	0
Kolla Tembien	4 195	10 487	16 630	-	2.5
Wer'e Lekhe	3 386	10 159	10 153	10 153	3.0
Laelai Maichew	5 788	24 726	8 240	17 493	4.3
Tahtai Maichew	6 106	28 071	11 736	11 200	4.6
Tahtai Adiabo	478	717	478	478	1.5
Raya Azebo	131	314	87	262	2.4
Inda Mekhoni	162	562	566	776	3.5
Hintalo Wejerat	1 898	3 702	1 950	-	2.0
Seharti Samre	4 640	11 601	7 321	-	2.5
Inderta	5 254	4 532	5 291	5 136	0.9
Ganta Afeshum	2 907	5 932	4 512	1 496	2.0
Gulo Mekheda	200	375	430	-	1.9
Irob	181	-	180	-	0
Degu'a Tembien	1 560	3 275	2 589	4 536	2.1
Tankua Abergelle	4 130	2 100	5 763	-	0.5
Adwa	4 500	11 250	11 250	22 500	2.5
Ahferom	3 886	1 660	5 830	5 830	3.0
Mereb Lekhe	713	713	1 307	-	1.0
Na'eder Adet	5 125	18 276	17 936	-	3.6
Medebai Zana	6 192	12 384	8 797	9 907	2.0
Tahtai Koraro	2 225	7 260	7 325	8 980	3.3
La'elai Adiabo	6 502	16 256	20 319	25 009	2.5
Asgede Tsimbla	2 556	5 342	2 556	5 342	2.1
Tselemti	5 227	10 455	-	9 676	2.0
Kafta Humera	29	77	63	63	2.7
Welqayit	225	674	345	562	3.0
Tsegede	9	12	41	-	1.3
Total	**101 099**	**237 684**	**190 790**	**157 457**	

Appendix 14 - questionnaire

1. Family size ____ Male ____ Female _____ Total
2. Age - Under 5 _____ 6 - 18 ____ Over 18 _____
3. Education - do not read and write ____; read and write _______; 1-4 ____; 5-8_____; 9-12 ____; over 12 _____
4. Land size: own ______; rented ____
5. Domestic animal size: by type ______________________________________
6. Amount of compost produced per year________________________________
7. Amount of compost used per crop and land size ________________________
8. Frequency and amount of input used _________________________________
9. Amount of composting materials collected by type _______________________
10. Amount of chemical fertilizer you buy 1997 _____; 1988 _______; 1999________; 2000__________
11. Amount of chemical fertilizer you used 1997 _____; 1988 _______; 1999________; 2000__________
12. The local price of grain and straw by type __________________________

Discussion points

13. What are the main soil types, soil fertility levels and characteristics in your locality?
14. What is the characteristics and relations of compost and rainfall?
15. What is the compost application rate in the family and your community?
16. What is the availability status of compost materials?
17. What are the main constraints of compost making?
18. What are the suggested solutions for the challenges in making compost?
19. What is the compost production capacity of the farmers in your location?
20. What is the net grain and straw of rural farming families production?
21. What is the recycling level of biomass in mixed-farming families?
22. What are the local prices of mineral fertilizer?
23. The traditional soil fertility management practices of farmers by type and frequency of use?

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Publications - articles

- **Community Participation on Watershed Management Practices in Grahutsa-Korir Catchment**, 2002. Proceedings of the 6th International Symposium on High Mountain Remote Sensing Cartography. University of Graz, Austria.
- **Ecological Agriculture with Smallholder Farmers in Ethiopia,** 2004. ISD, Addis Ababa. (With Tewolde Berhan and Sue Edwards)
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- **The Impact of Compost Use on Crop Yields in Tigray, Ethiopia, 2000-2006 inclusive.** Environment and Development Series 10, Third World Network, Penang. (with Sue Edwards, Arefayne Asmelash and Tewolde Berhan Gebre Egziabher). Available at http://www.twnside.org.sg/title/end/ed04.htm

Trainings and workshops participated and organized

- **Sixth International Symposium on "High Mountain Remote Sensing Cartography". -** September/2000, Addis Ababa, Ethiopia. (Organizer and participant).

- **Community and Individual Innovations in Improving Land Management and Promoting Low Input Agriculture,** 14-20 November 2001. Axum, Ethiopia. Prepared by Mekelle University, Tigray Bureau of Agriculture and Natural Resources (TBoANR), and Institute for Sustainable Development (ISD). (Organizer and participant).

- **Eastern Africa Indigenous People's Earth Summit:** 8-11 July 2002. Nairobi, Kenya.

- **Compost Preparation and Forage Tree Development Training Workshop:** 1-7 September 2002. Axum, Ethiopia. (Organizer and participant).

- **Field Training Experience on "Minimum/ Conservation Tillage Practices in Ethiopia"**. 30 September- 3 October 2002.

- **Regional (Great Horn of Africa) Consultative Workshop on "Food Security and Conflict Management":** 8-15 February 2003. Arusha, Tanzania; 16-20 June 2003. Kigali, Rwanda. By PELUM-Kenya; 23-26 September 2003. Nairobi, Kenya. By PELUM-Kenya

- **Participatory Innovation Development Facilitators' Course.** 26 June - 12 July 2006. Kampala, Uganda.

- **Analogue Forestry workshop.** September 30 - 6 October 2007. Harare, Zimbabwe

- **KM4DEV – Knowledge Management for Development**: 18 – 20 June, 2007. *Driebergen-Zeist, Th*e Netherlands. Organized by a joint initiative of Bellanet, DFID, Hivos, ICA, ICCO, IICD, OneWorld, UNAIDS and World Bank a joint initiative of Bellanet, DFID, Hivos, ICA, ICCO, IICD, OneWorld, UNAIDS, World Bank and IRC.

- Learning sustainability from the south: Sustainable food systems developed out of local recourses with participatory approaches in Ethiopia and Brazil.

Theses

- The Cause and Consequences of the 1984/85 Drought in Kilte Awla'elo Awraja (District) – Tigrai, 1980 (First Degree Dissertation).
- Community Participation on Watershed Management Practices in Grahutsa-Korir Catchment, 2001 (Master Thesis).
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Languages skill: Tigrigna and Amharic - Excellent, English - Very good

Hobby

Smallholder farming

- Beekeeping,
- Dairy farm
- Growing fruits and vegetables
- Nursery development
- Commercializing compost

Experiencing and discussion with smallholder farmers
Fieldwork with smallholder farmers
Writing about events
Learn from smallholder farmers
Enhancing the yield of smallholder farming