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I) Soil Fertility Management

Effect of Adaptable Green Manuring Plants on Soil Fertility and Sorghum Yield

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Abstract

A study was conducted in 2008-2010 at Habru District, North Wollo Zone. Its objective was to evaluate the effect of green manuring plants (Tephrosia vogelii, Tithonia diversifolia and Leucenea palida) as intercrop and green manure integrated with N and P on soil fertility and sorghum yield. The results showed that intercropping Tephrosia v. and Leucenea p. with sorghum didn't have significant ($p > 0.05$) impact on sorghum yields. Whereas, intercropping Tithonia d. with sorghum showed significant ($p \leq 0.05$) negative effect on sorghum yields probably due to its vigorous growth and higher biomass which leads to significant nutrient and moisture competition against the test crop. Tephrosia v. and Tithonia d. green manures alone gave significantly ($p \leq 0.05$) higher sorghum grain yield than the control and gave similar grain yield with full recommended N and P and their combination with 100% and 50% of the recommended N and P. Whereas, Leucenea p. didn't have significant effect on grain yield than the control due to its poor growth. Tephrosia v. and Tithonia d. alone gave 104.7% and 85.4% grain yield advantage over the control respectively. The soil analysis result also showed that Tephrosia v., Tithonia d. and Leucenea p. improved soil OC by 9.5%, 8.1% and 2.9% over the control respectively. At the end of the experiment, 8.1% and 7.3% residual deposition of soil OC was recorded in the plots under Tephrosia v. and Tithonia d. respectively. Thus, it is possible to conclude that Tephrosia v. and Tithonia d. alone can give comparable sorghum grain yield with full recommended N and P. However, due to its potential to be a weed, Tithonia d. should be used as a green manure only by biomass transfer. Further investigation on the cost benefit analysis of using green manures alone and their interaction with chemical fertilizer is required.

Key words: intercropping, green manure, biomass transfer, chemical fertilizer

INTRODUCTION

Ethiopia faced a wide set of soil fertility issues that require approaches that go beyond the application of chemical fertilizers; the only practice applied at scale to date. Core constraints include topsoil erosion; some sources list Ethiopia among the most severely erosion-affected countries in the world (FAO, 1998), soil acidification with acidity-affected soils covering over 40 percent of the country, significant depletion of soil organic matter due to widespread use of biomass as fuel; the use of dung as fuel instead of fertilizer is estimated to reduce Ethiopia's agricultural GDP by 7 percent (Zenebe, 2007), depletion of macro and micro-nutrients, deterioration of soil physical properties and soil salinity. Hence, integrated soil fertility restoration and soil and water conservation practices should be implemented to improve soil's resistance to erosion, ameliorate soil acidity and alkalinity and eventually improve the productivity of soils.

Low soil fertility is among the major factors limiting crop production and productivity in Eastern Amhara. This is common in many tropical cropping systems where fertilizer use is low and little or no agricultural residues are returned to the soil for maintaining soil fertility. Besides, long aged continuous cultivation with nutrient-depleting crops and complete removal of crop residues from farmlands and absence of crop rotation result in irreversible nutrient mining by plant uptake (Kidane and Getachew, 1994; Heluf, 2005). As a consequence of these and the prevailing very intense rate of surface soil erosion in the Ethiopian highlands, declining soil fertility is a fundamental impediment to agricultural development and the major reason for the slow growth rate in food production and food insecurity both at household and national levels.

Most soils in the semi-arid areas of northeastern Ethiopia, where the present study area lies, are heavily depleted of plant nutrients and are characterized by low total N, available phosphorus (P) and organic carbon (OC) contents leading to substantial decline in crop productivity (Hailu, 1988; Asnakew, 1994). Hence, to increase crop productivity, the depleted soil plant nutrients should be replenished with chemical and organic fertilizers. Use of chemical fertilizers has been proved to significantly increase productivity of crops in Eastern Amhara (Yared et al., 2003).

However, use of chemical fertilizers to a degraded land and to a soil with a substantially depleted content of organic matter could not give the expected yield return due to the vulnerability of the added chemical fertilizers to losses through erosion and leaching leading to significantly low nutrient recovery efficiency of chemical fertilizers. Thus, as it was suggested by Palm et al. (1997), as cited by W. Bayu et al (2005), an integrated nutrient management program in which both organic and inorganic fertilizers are used is an ideal strategy not only to boost crop productivity but also to restore the physical, biological and chemical soil fertility sustainably.

In traditional agriculture, arable land could be left fallow for some years to allow soil to acquire self-rejuvenation, but increased population pressure leads to little fallow periods, which are not sufficient to restore the soil nutrient pools and soil organic matter levels sufficient to support economic crop yields. In Ethiopia, 95% of the farmers are classified as small-scale who cannot afford high input investments (CSA, 2010). There is, therefore, a need to examine crop production systems that could promote sustainable crop production in Ethiopia. The organic system favours the use of renewable resources and emphasizes the use of techniques that integrate natural processes such as nutrient cycling, biological nitrogen fixation and soil regeneration.

This research, therefore, provides a case study of how the leguminous green manures (*Tephrosia vogelii* and *Leucenea palida*) and a non-legume (*Tithonia diversifolia*) species alone or in combination with chemical fertilizers (N and P) can sustainably increase the yields of sorghum and improve soil organic matter base the in Eastern Amhara region.

2. Materials and Methods

2.1 Experimental Site Description

The study was conducted on the main research station of Sirinka Agricultural Research Center (SARC) in the 2008-2010 main cropping seasons. The study site, Sirinka, is located about 508 km away from Addis Ababa the capital city of Ethiopia in the north east direction, at an altitude of 1850 masl and at $11^0$45'00''N latitude and $39^0$36'36''E longitude. The average annual rainfall of the study area was 945 mm and the mean maximum and minimum temperatures were 26 and 13^{o}C, respectively. The rainfall distribution across months and main crop growing seasons (July-December) during the three experimental years was depicted below in Figure 1.

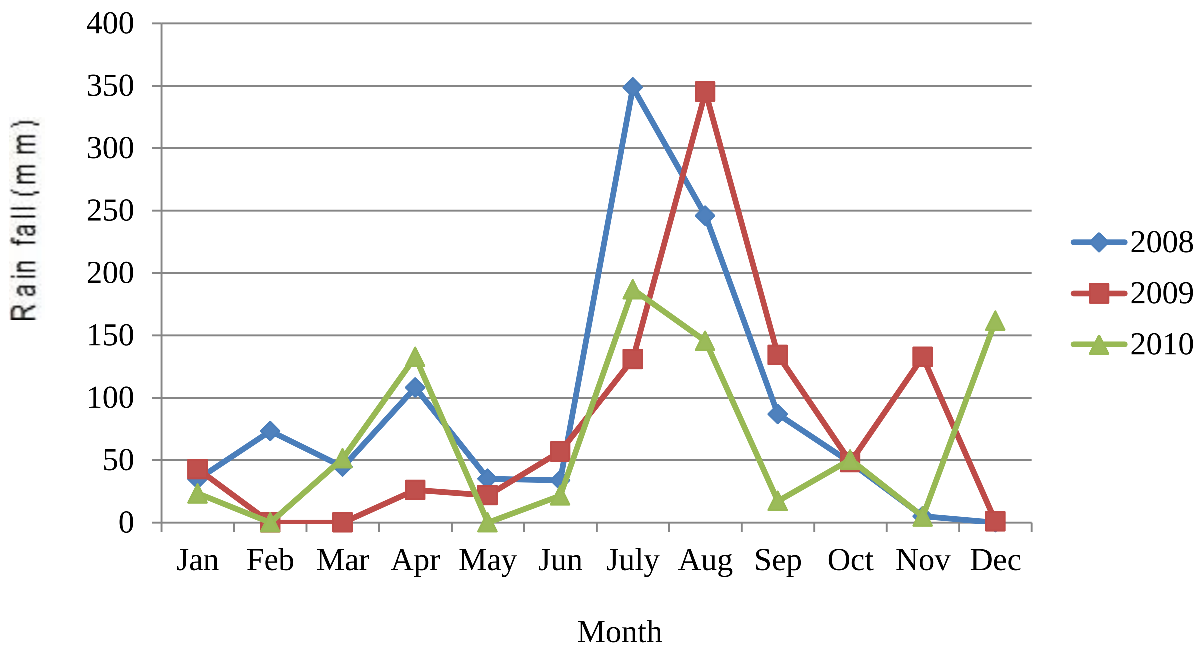

Fig 1. Rainfall distribution across months in the three experimental seasons

The soils of the study site are characterized as a clay to clay loam texture with black to brown color, conducive pH condition for most crop growth, low organic carbon, low total nitrogen and medium available phosphorus (Table 1). The dominant soil type in the study area, based on the FAO/UNESCO System (FAO-UNESCO, 1994), is Eutric Vertisol.

Table 1. Physical and chemical properties of the surface soils (0-20 cm) at the study site

Property	**Value/Result**
pH (H_2O)	6.98
OC (%)	1.35
Total N (%)	0.07
Available P. (mg kg^{-1})	11.77
CEC ($cmol_C$ kg^{-1})	56.44
Texture	Clay to Clay loam
Exchangeable K ($cmol_C$ kg^{-1})	1.27
Exchangeable Ca ($cmol_C$ kg^{-1})	36.85
Exchangeable Mg ($cmol_C$ kg^{-1})	12.61

2.2 Experimental Design and Procedures

The study was conducted in two phases; Intercropping phase and Green manuring (Biomass transfer) phase.

I. The Intercropping Phase

The intercropping phase of the study was comprised of four treatments; three green manures species (*Tephrosia vogelii*, *Leucenea palida* and *Tithonia diversifolia*) intercropped with sorghum and the control (Sorghum without green manure intercrop). The treatments were laid in a randomized complete block design with three replications.

The green manures were planted in the middle of the sorghum plant rows, two weeks after planting sorghum. Uniform rates of the full recommended N/P chemical fertilizers (69/46 N P_2O_5) were applied to all experimental plots. The N fertilizer was applied in a split, half at planting and the remaining half at tillering, while DAP was applied all at planting. The variety of sorghum used for the study was Teshale; it was planted in a row with the spacing of 75 cm between rows and 15 cm between plants.

II. The Green Manuring (Biomass transfer) Phase

In the second phase of the study, the green manures, which had been intercropped with sorghum in the intercropping phase of the study, were chopped at their flowering stage and incorporated in to the soil in the respective plots. After incorporation, but before sowing the subsequent test crop-sorghum, the plots were divided in to three subplots. The subplots were assigned to three levels of N/P fertilizers (0, 50% and 100% of the recommended N/P). The design of the green manuring phase of this study was a split plot design with three replications. The P-fertilizer was applied all at planting while the N-fertilizer was applied in a split (half at planting and the remaining half at knee height).

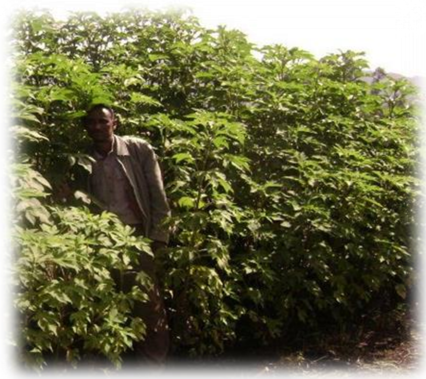

Fig 2. *Tithonia diversifolia*

Fig. 4. Chopping the green manures before incorporation

Fig 3. *Tephrosia vogelii*

2.3. Soil Sampling and Analysis

Soil samples at a depth of 0-20 cm were collected from each plot before planting in the intercropping phase and before and after incorporation of the green manure but before sowing of the test crop during the second phase of the study.

The collected soil samples were analyzed for texture, pH, organic matter (OM), total nitrogen (TN) available P, Ca, Mg and CEC. Soil pH was measured potentiometrically using a digital pH meter in a 1:2.5 soil water suspension (Van Reeuwijk, 1992). Organic carbon (OC) was determined by wet digestion method, and following the assumptions that OM is composed of 58% carbon, the conversion factor, 1.724 was used to convert the OC in to OM (Walkley and Black, 1934). Determination of total N of the soil was carried out through Kjeldahl digestion, distillation and titration procedures of the wet digestion method (Black, 1965). Available P was determined colorimetrically using Olsen's method (Olsen, 1952).

Exchangeable Ca and Mg were extracted with 1M buffered ammonium acetate extractant and were measured using atomic absorption spectrophotometer (Chapman, 1965). Similarly, CEC was determined by 1M buffered ammonium acetate extraction method and distillation of the ammonium saturated soil in a Kjeldahl distillation apparatus while receiving the distillate in boric acid and then titrating with sulfuric acid (Chapman, 1965).

2.4 Crop Data Collection

Plant height was measured at maturity, from five random plant samples of the harvestable rows, from the ground level to the tip. Straw yield was obtained as the difference of the total above ground plant biomass and grain yield, and adjusted for the moisture content. Whereas, 1000 seed weight was measured by weighing 1000 seeds from the harvest. Grain yield was measured by taking the weight of the grains threshed from the central harvestable rows of each plot and converted to kilograms per hectare after adjusting the grain moisture content to 12.5%. Biomass was measured by weighing the total above ground plant biomass within the harvestable rows.

3. Results and Discussions

3.1. Effects of Green Manures on Sorghum Yields

3.1.1. Effects of intercropping green manuring plants on the grain yield and biomass weight of sorghum

The first experimental year data analysis results as shown in Table 2 revealed that there was statistically significant ($P \leq 0.05$) difference in the grain yield of sorghum due to the effect of intercropping green manures with sorghum. However, there was no significant ($p > 0.05$) effect of intercropping green manures on the biomass weight of sorghum (Table 2). The highest grain yield (3540 kg ha^{-1}), which was statistically similar ($P > 0.05$) with the grain yields obtained from the *Tephrosia v*. and *Leuceneap*. intercropped with sorghum the lowest grain yield was obtained from the control. This was accounted for there was no moisture and nutrient competition in the control treatment as compared to the green manure intercropped treatments.

The grain yield obtained from the *Tephrosia v*. and *Leuceneap*. intercropped with sorghum might be due to the nitrogen fixing ability of both green manuring plant species and the subsequent probability of supply of N to the test crop-sorghum. The lowest grain yield which was significantly different from the other treatments was obtained from the Tithonia d.-sorghum intercropped treatment (Table 2). While, in the second experimental year, intercropping green manures with sorghum did not have significant effect on the grain yield and biomass weight of sorghum (Table 2). This might be accounted for the lower rainfall in the second experimental year which resulted in slower growth and lower biomass yields of the green manures. As a result, the green manures did not have a significant impact on the nutrient and moisture uptake by sorghum.

The combined analysis over the two experimental years as shown in Table 2, however, revealed that the mean effect of intercropping green manures on the grain yield and biomass weight of sorghum were statistically significant ($p \leq 0.05$). The control (non-intercropped) treatment was the highest yielder though it was statistically similar with the grain yield obtained from the Tephrosia v. intercropped with sorghum. The grain yield obtained from *Tithonia d*. intercropped with sorghum (2780 kg ha^{-1}), was by 18.8% lower than that obtained from the control plot and by 12.7% than *Tephrosia v*. intercropped with sorghum (Table 2). This might be attributed to the vigorous growth of *Tithonia d*. which leads to high competition for nutrient and moisture against sorghum. While, the highest biomass weights of sorghum were measured from the control and *Leuceneap*. intercropped with sorghum (Table 2). The growth performance and the biomass return of *Leuceneap*. was by far lower than the other green manure species which made it the least in putting pressure on the moisture and nutrient uptake of sorghum.

Tabel 2. Effects of intercropping green manures on sorghum grain yield and biomass weight (kg ha^{-1})

Treatment*	2008 Grain yield	2008 Biomass weight	2009 Grain yield	2009 Biomass weight	Combined over years Grain yield	Combined over years Biomass weight
Control	3535.2a	22217	3321.6	12431.5	3428.4a	17324.4ab
Tephrosia v.	3135.0a	21366	3239.2	11500.7	3187.1ab	16433.4b
Leuceneap.	3405.9a	23766	2717.7	12893.2	3061.8bc	18329.7a
Tithonia d.	2408.8b	20281	3033.1	11945.6	2783.4c	16113.5b
GM	3186.0	21907.8	3077.9	12192.8	3129.6	17050.3
CV	6.6	7.03	9.4	4.7	8.7	6.3
LSD	468.6	3076.6ns	576.9ns	1146.3ns	349.4	1338.3

** Treatments within a column followed by the same letter are not significantly (p > 0.05) different; ns-non significant (p > 0.05)*

3.1.2. Effects of incorporating green manuring plants with different rates of N and P on sorghum yield and biomass weight

3.1.2.1 Grain yield of sorghum

The statistical result showed that there was a highly significant ($P \leq 0.01$) difference in the grain yield and biomass weight of sorghum due to the interaction effects of the green manure species and chemical fertilizers. As it is depicted in Table 3, in the first experimental year, the highest grain yield (4580 kg ha^{-1}) was obtained from the combined application of *Tithonia d*. with 100% the recommended N and P followed by 100% of the recommended N and P alone, *Tithonia d*. combined with 50% of the recommended N and P, *Tithonia d*. and *Tephrosia v*. alone.

The vigorous growth and relatively higher biomass obtained from *Tithonia d*. enabled it to be the higher nutrient supplier, up on decomposition, to sorghum. Moreover, different studies showed that *Tithonia d*. had high concentrations of N, K, Ca and low concentrations of P and Mg and could supply significant amount of the mentioned nutrients to the subsequent crop up on decomposition and mineralization (Rutunga et al., 1999; Olabode et al., 2007). The green manuring plants, *Tithonia d*. and *Tephrosia v*. alone increased the grain yield of sorghum by 66.0% and 44.3%, respectively over the control. Whereas, in the second year, *Tephrosia v*. + 50% recommended N and P gave the highest grain yield (2470 kg ha^{-1}) followed, by *Tephrosia v*. + 100 % recommended N and P, *Tephrosia v*. alone and

100% recommended N and P (Table 3). Due to low amount of rainfall (Fig 1) that caused moisture deficit in the late growth stages of the test crop, lower grain yield was measured from the entire experiment in the second year as compared to the first year.

Unlike *Tithonia d*., *Tephrosia v*. was not affected much by the moisture deficit during the second year (Fig.1). Hence, the plots under *Tephrosia v*. gave significantly higher grain yield than those under the other green manuring plants. Nevertheless, *Tephrosia v*. and *Tithonia d*. green manures alone increased sorghum grain yield by 209.8% and 64.0%, respectively over the control during the second year. This result is supported by Rutunga et al. (1999) who conducted a study on biomass production and nutrient accumulation by *Tephrosia vogelii* and *Tithonia diversifolia* and reported that *Tephrosia v*. performed better than *Tithonia diversifolia* in a low rainfall during the growing season.

Table 3. Effects of combined use of green manures and chemical fertilizers on the grain yield (kg ha^{-1}) of sorghum in the 2009 and 2010 experimental seasons

Green Manure*	**2009**			**2010**		
	0% N/P	**50% N/P**	**100% N/P**	**0% N/P**	**50% N/P**	**100% N/P**
Control	2493.7d	3497.2abcd	4570.2a	756.2e	1670.0cd	2022.9abc
Tephrosia v.	3598.8abcd	2943.3cd	3108.6bcd	2342.6ab	2465.7a	2378.1ab
Leuceneap.	2884.5cd	4078.6abc	3023.9bcd	773.7e	1188.2de	1898.9bc
Tithonia d.	4140.4ab	4251.0ab	4579.4a	1240.4de	1539.0cd	1978.7abc
GM		3574.0			1679.6	
CV (%)		11.3			15.5	
SEM		402.9			260.6	

** Treatments within a column followed by the same letter are not significantly (p > 0.05) different.*

On the contrary, according to a research report from Fungameza (1991) and Drechsel *et al*. (1996), the amount of biomass produced by *Tephrosia v*. was influenced by the fertility status of the soil and the amount of rainfall. According to a study report by Rutunga *et al*. (1999), the above ground biomass of both *Tephrosia v*. and *Tithonia d*. could accumulate higher amounts of N, K, Ca and Mg than the natural fallow and maize. The same authors also justified that *Tithonia d*. had higher concentration of the aforementioned nutrients than *Tephrosia v*. However, as *Tephrosia v*. is a leguminous plant, if there is adequate soil moisture and relatively fertile soil conducive for microbial growth, it has got a special merit of fixing atmospheric N apart from taking up soil N.

Sorghum under *Tephrosia v*. alone gave the highest and more stable grain yield in both years despite the insignificant difference with some of the treatments as mentioned above. This might be accounted for better and stable biomass yields of *Tephrosia v*. in both years due to its relatively better tolerance to low soil moisture.

The combined analysis result over the two years, as it is depicted in Table 4, indicated that the highest grain yield was obtained from *Tithonia d*. + 100% recommended N and P followed by 100% of the recommended N and P alone, *Tephrosia v*. alone, *Tithonia d*. + 50% recommended N and P, *Tephrosia v*. + 50% recommended N and P and *Tithonia diversifolia* alone. Thus, *Tephrosia v*. and *Tithonia d*. alone could give statistically similar grain yields with 100% recommended N and P and all green manure species + 100% and 50% recommended N and P. In general, *Tephrosia v*. and *Tithonia d*. alone gave a grain yield advantages of 104.7 and 85.4% over the control respectively (Table 4).

Table 4. Effects of the combined use of green manures and chemical fertilizers on the grain yield (kg ha^{-1}) of sorghum pooled over the two experimental years

	Combined over years		
Green Manure*	**0% N/P**	**50% N/P**	**100% N/P**
Control	1451.2c	2400.9b	3041.8ab
Tephrosia v.	2970.7ab	2704.5ab	2743.3ab
Leucenea p.	1829.1c	2633.4b	2461.4b
Tithonia d.	2690.4ab	2895.0ab	3279.1a
GM		2584.4	
CV (%)		17.6	
SEM		455.5	

** Treatments within a column followed by the same letter are not significantly (p > 0.05) different.*

3.1.2.2. Biomass weight of sorghum

In the first year, there was statistically significant ($p \leq 0.05$) interaction effects of the green manures with the chemical fertilizers on the biomass weight of sorghum. As it is shown in Table 5 below, *Tithonia d*. + 50% recommended N and P gave the highest sorghum biomass yield followed by *Tithonia d.* + 100% recommended N and P, 100% recommended N and P, *Tephrosia v.* alone and *Tithonia diversifolia* alone (Table 5).

Table 5. Effects of the combined use of green manures with chemical fertilizers on the biomass weight (kg ha^{-1}) of sorghum in 2009

	2009		
Green Manure*	**0% N/P**	**50% N/P**	**100% N/P**
Control	11778de	13056bcde	14481abc
Tephrosia v.	15111ab	12278cde	12630bcde
Leucenea p.	11148e	14111bcd	11111e
Tithonia d.	14235abcd	16741a	14778abc
GM		13581.84	
CV (%)		9.15	
SEM		1242.57	

** Treatments within a column followed by the same letter are not significantly (p > 0.05) different.*

In the second year, however, there was no significant interaction effect of the green manures with the chemical fertilizers on the biomass weight of sorghum. Nevertheless, the main effects of both the chemical fertilizers and the green manures had significant effects on the sorghum biomass (Table 6). Among the green manures, *Tephrosia v*. alone gave the highest sorghum biomass weight of 9890 kg ha^{-1}, followed by *Tithonia d*. alone. As mentioned above, the low rainfall in the second year contributed to the significantly lower sorghum biomass weight measured from the green manure *Tithonia d*. than *Tephrosia v*. due to its better tolerance to moisture stress. There was no significant difference between 100% recommended N and P and 50% recommended N and P in sorghum grain yield.

Table 6. Effects of the combined use of green manures with chemical fertilizers on the biomass weight (kg ha^{-1}) of Sorghum in 2010

NP levels	**Biomass weight (kg ha^{-1})**
0%	6777.8b
50%	7800.0a
100%	8314.8a
GM	7620.915
CV	12.4
LSD	947.7
Green Manure	
Control	6765.4bc
Tephrosia vogelii	9888.9a
Leuceneapalida	6333.3c
Tithonia diversifolia	7604.9b
GM	7620.915
CV (%)	12.4
LSD	947.7

** Treatments within a column followed by the same letter are not significantly different.*

The pooled analyses over years indicated that there was no significant (P > 0.05) interaction between the green manures and chemical fertilizers on the biomass weight. However, as it was elucidated in Table 7, the main effect of both the green manures and the chemical fertilizers on biomass weight was significant. Among the green manure species, *Tephrosia v*. recorded the highest biomass weight (114.5 qt ha^{-1}) followed by *Tithonia d*. while the lowest biomass weight was obtained from the control and *Leuceneapalida*. There was no significant difference between 50% recommended N and P and 100% recommended N and P in biomass weight though relatively higher biomass weight was recorded by 50% recommended N and P (Table 7).

Table 7. Effects of the combined use of the green manures with N and P on the biomass weight (kg ha^{-1}) of sorghum combined over years

NP levels	**Biomass weight (kg ha^{-1})**
0%	9602.7b
50%	11061.1a
100%	10768.1a
GM	10463.82
CV	10.88
LSD	705.06
Green Manure	
Control	9625.0b
Tephrosia v.	11451.9a
Leucenea p.	9291.7b
Tithonia d.	11428.0a
GM	10463.82
CV (%)	10.88
LSD	814.51

**Treatments within a column followed by the same letter are not significantly (p > 0.05) different.*

3.2 Effects the Green Manures on Soil Organic Matter

The soil analyses results after the incorporation of the green manuring plants in 2009 and 2010 indicated that there was a slight increase in the soil organic carbon (OC) due to the addition of the green manures in to the soil (Table 8) compared to the control. However, there was no significant (P > 0.05) difference among the green manuring plants. The combined analysis over years revealed that *Tephrosia v., Tithonia d*. and *Leucenea p*. improved the soil OC (%) by 9.5, 8.1% and 2.9% over the control respectively (Table 9).

While, 8.1% and 7.3% residual deposition of soil OC was obtained from the plots under *Tephrosia v*. *Tithonia d*. respectively, at the end of the experiment (Table 9).

Table 8. Effect of the green manures on soil organic carbon (% SOC) in each experimental year

		Before planting	After harvesting		Before planting	After harvesting
Green Manure	2008	2009 (After incorporation)	2009	2009	2010 (After incorporation)	2010
Control		1.20	1.30		1.45	1.41
Tephrosia v.		1.39	1.38		1.61	1.57
Leucenea p.	1.23	1.29	1.26	1.51	1.53	1.46
Tithonia d.		1.36	1.39		1.60	1.54
GM		1.31	1.33		1.55	1.50
CV (%)		3.6	6.4		12.5	13.4
LSD		0.74ns*	0.17ns		0.36ns	0.36ns

**ns-non significant*

Table 9. Effects of the green manures on soil organic carbon combined over years

Green manure	**Before intercropping**	**Before planting /after incorporation/**	**After harvesting**
Control		1.33	1.35
Tephrosia v.		1.50	1.48
Leucenea p.	1.37	1.41	1.37
Tithonia d.		1.48	1.47
GM		1.43	1.42
CV		10.6	11.7
LSD		0.23ns*	0.19ns

**ns-non significant*

4. Conclusions and Recommendations

Intercropping of *Tephrosia vogelii* and *Leucenea palida* with sorghum did not impose significant negative impact on the growth and yield of sorghum. However, *Tithonia diversifolia*. intercropped with sorghum reduced the growth and yield of sorghum due to its vigorous growth which caused nutrient and moisture competition against sorghum. In addition, *Tephrosia vogelii* and *Tithonia diversifolia* alone as green manure increased sorghum grain yield equally with 100% recommended N and P + green manures and 50%

and 100% of the recommended N and P alone. *Tephrosia vogelii* had better tolerance to low soil moisture than *Tithonia diversifolia*. The soil analyses results also indicated that green manuring plants *Tephrosia vogelii, Tithonia diversifolia* and *Leucenea palida* improved soil organic carbon content over the control.

In general, *Tephrosia vogelii* intercrop and green manure (biomass transfer) gave better sorghum yield equivalent to the use of the full recommended N and P. Due to its potential to be a weed, it is recommended to use *Tithonia diversifolia* as biomass transfer for green manuring whereas *Tephrosia vogelii* is recommended both as an intercrop and as a green manure in areas with similar soil types and agro-climatic conditions. However, the economic profitability of these green manuring plants alone and integrated with N and P should be studied.

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Effect of Green Manuring Plants on Yield and Yield Components of bread wheat (*Triticum aestivum*) and maze (*Zea Mays L.)*

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Abstract

Four introduced and adapted green manuring plant species (Canavalia ensiformis, Tephrosia candida, Tephrosia vogelii, and Mucuna prunensis) were evaluated during 2009-2011 cropping seasons at Adet with the objective of selecting the best suitable species for soil fertility replenishment as intercropped with maize. The species were evaluated for their competition with maize for nutrients when intercropped with. After maize harvest the green manuring plants left on the land were incorporated to the soil during land preparation of the subsequent crop (bread wheat). The experiment was laid down in a split plot design with three replications. The highest grain yield of bread wheat; 3498, 3417, 3390 and 3357 kg ha^{-1} was obtained from the plots incorporated with Canavalia ensiformis, Mucuna prunensis, Tephrosia candida and Tephrosia vogelii with full recommended fertilizer respectively. The lowest yield 1394 kg ha^{-1} was obtained from the control plot (non manured and unfertilized). All green manuring plants with half recommended fertilizers had almost equivalent yield to the full recommended fertilizer without green manure. Therefore, green manuring plants intercropped with maize have the advantage of reducing half of the fertilizer cost for bread wheat with less competition with the associate maize crop.

Key words: intercropping, biomass, green manuring, soil fertility, bread wheat.

Introduction

Depletion of soil fertility, along with the concomitant problems of weeds, insects and diseases, is a major biophysical cause of low per capita food production in Africa (Sanchez *et al*., 1997). Over decades, small scale farmers have removed large quantities of nutrients from their soils without using sufficient quantities of manure or fertilizers to replenish the soil. This has resulted in a very high average annual depletion rate: 22 kg of nitrogen (N), 2.5 kg of phosphorus (P), and 15 kg of potassium (K) per hectare from cultivated lands over the last 30 years in 37 African countries with an annual loss equivalent to 4 billion dollars in fertilizer (Drechsel and Gyiele, 1999). The potential of genetically improved crops can't be realized when soils are depleted of plant nutrients.

The most often way to overcome nutrient depletion is the use of mineral fertilizers. However, fertilizer in Africa costs two to six times as much as those in Europe, North America or Asia due to various socio economic constraints (Sanchez, 2002; David and Swinkel, 1994 and Gezahegn and Tekalign, 1995). Therefore, the integration of organic fertilizers such as green manures in the cropping system is being regarded as alternative to mineral fertilizers in most tropical soils. It is mainly because, green manuring plant species can provide essential nutrients such as N, P, K and trace elements and improve soil structure through intensive root penetration and organic matter accumulation. Some plant species can also access non available P through root exudates or association with mycorhiza (Godbold, 1999 and Rao *et al*., 1999).

A soil fertility replenishment approach has been developed during the last 2 decades by researchers from International Center for Research in Agroforestry and National and International partners working with farmers using resource naturally available in Africa. The practice consists of three components that can be used in combination or separately: i) nitrogen fixing leguminous tree fallows, ii) indigenous rock phosphate in phosphorus deficient soils, and iii) biomass transfer of leaves of nutrient accumulating shrubs (Sanchez and Jama, 2002).

Sanchez (2002) reported that 100 to 200 kg N ha^{-1} was accumulated from inter planting leguminous trees of the genera *Sesbania*, *Tephrosia*, *Crotalaria*, *Glyricida*, and *Cajanus* into a young maize crop and allowed to grow as fallow during dry season in sub humid tropical regions of East and South Africa. The same author added that nitrogen rich leaves, pods and green branches of the tree fallows were hoed into the soil before planting maize at the start of the subsequent rainy season and releases nitrogen and other nutrients to the soil thereby increased maize yield 2 to 4 fold over the control.

Nziguheba *et al*. (2002) also reported that tithonia, lantana and croton recorded larger amount of resin P (112 %, 76 %, and 56 %, respectively) than values predicted by their P content and TSP response curve. They further stated that, the P and N taken up by plants can be turned to the soil in the plant available forms by biomass application. Eastwood and Sartain (1990) also reported that organic anions released from decomposing residues can compete with P for adsorption site making the P more available to crops.

Degradation of soil organic matter (OM) under continuous cropping is a major reason for decreasing soil fertility. Decomposition of OM is the sequence of microbial processes that is enhanced by increasing temperature, aeration, and optimal moisture content. Such conditions prevail particularly under intensive cropping system. Therefore, the most effective means of arranging natural supply of N and organic matter to a soil is the cultivation of suitable legumes and their insitu incorporation at appropriate stage of growth (Tiwari *et al*., 2000).

Nziguheba (*et al*., 2002) reported that despite their P and N concentration, organic residues (green manures) may have additional benefits in increasing P and N availability as compared to chemical fertilizers due to their positive effect on soil physic-chemical properties. In addition, green manuring plants can also be used for different purposes such as human food, animal feed, weed suppression and crop pest control.

Hence, in countries like Ethiopia, the use of green manure alone or in combination with chemical fertilizers seems the best alternative to improve soil fertility and sustain production and productivity. However, the use of plant biomass for nutrient replenishment and other purposes require the identification of species with the ability to increase nutrient availability to crops. The objective of this study was, therefore, to estimate the potential of green manure for yield and yield parameters for sustainable soil management and crop production.

Materials and Methods

Description of the Study Area

The experiment was conducted at Adet Agricultural Research Center, Yilmana Densa district of the Amhara region, Ethiopia from 2008-2010 cropping season. The research center is located 45 km south east of Bahir Dar, the capital city of Amhara National Regional State, via Mota to Addis Ababa. The altitude of the site is 2240 masl, the minimum and maximum rainfall was 860 mm and 1771 mm respectively. The soil type of the site was Nitisols and the major agricultural practice was mixed cropping dominated with cereal crop production. The area has severe soil depletion problem and with no crop rotation, cereal after cereal production system with little or no return of organic matter to the soil.

Figure 1. Green manure plants in left after maize harvest chopped and incorporated in to the soil.

Treatments, experimental design and field layout

The experiment was laid down in a split plot with RCBD arrangement in three replications. There were five main plots of which four were with green manuring plants and the other one without for comparison and the sub plot treatments were 0, half and full recommended rates of N and P fertilizers. The plot size for the main plot was 3mx11m while the sub plots were 3mx3m.

Fertilizer application and cultural practices

The green manuring plant species selected for intercropping with maize were: *Tephrosia vogelii*, *Tephrosia candida*, *Canavalia ensiformis,* and *Mucuna prunensis* based on their better adaptability to the environment, high biomass, vigorous stand, freedom from pest and less palatability (of some) to animals (Tesfaye *et al*., 2008).

The land was prepared as per the recommendation for maize and bread wheat. The main plots were arranged for the green manuring plants and for sole maize during the first year. Maize was planted with a spacing of 75 cm between rows and 30 cm between plants. The recommended nitrogen (N) and phosphorous (P) fertilizer rate (64 kg $ha^{-1}$and 20 kg ha^{-1}) respectively were applied for maize. Full recommended rate of Phosphorous and half recommended N were applied at planting and the other half nitrogen was applied at knee height for maize in the first year. Each green manuring plant was sown a month after planting maize at its recommended seed rate (120 seeds for *Tephrosia vogeliii* and *Tephrosia candida* and 6 seeds for *Canavallia ensiformis* and *Mucuna prunensis* per three meter) and planted to the free space between the maize rows during the first year to reduce competition and allowed to grow after harvesting maize until land preparation for the subsequent crop. Fresh biomass of the green manuring plants was measured, chopped and incorporated to the soil during land preparation for the subsequent crop (bread wheat).

During the bread wheat plantation the main plots were divided to sub plots and land preparation was under taken. Zero, half and full recommended NP fertilizers were applied during planting. The recommended nitrogen (N) and phosphorous (P) fertilizer rate for the area was 92 kg ha^{-1} and 20 kg ha^{-1} respectively. Half of the Nitrogen was applied at planting and the other half after first weeding while all P was applied at planting. Seed rates for green manuring plants vary among the species. One hundred twenty seeds were drilled to 3 m plot length for *Tephrosia vogelii* and *Tephrosia candida.* Whereas six seeds for *Canavallia ensiformis* and *Mucuna prunensis* for similar plot length. The spacing between plants was 50 cm for the later two species while the seed rate for bread wheat was 150 kg ha^{-1}.

Data collected:

At harvesting stage, fresh and dry biomass, plant height, panicle length, number of cobs, 1000 and 100 seed weight and grain yield were taken.

Statistical Analysis

Analysis of variance was carried out for yield and yield components using SAS statistical package (SAS Institute, 2002) following statistical procedure appropriate for the experimental design. Whenever, treatment effects were found statistically significant, the means separation was done using Duncan's Multiple Range Test.

Results and Discussions

The two year results of the experiment indicated that various green manuring plant species except *Canavalia ensiformis* had little negative effect on the maize grain yield but had no effect in stand count and number of cobs. The sole maize crops had only 228, 399 and 342 kg ha^{-1} grain yield advantage compared to that intercropped with *Tephrosia vogelii*, *Tephrosia candida* and *Mucuna prunensis* respectively (Table 1). However, *Canavalia ensiformis* had 228 kg ha^{-1} grain yield advantage over the sole maize crop (Table 1). This means that the competition of the green manuring plants with the maize crop was not as such recognizable. This finding was inconformity with the finding of Ogbonna and Mabbavad (1983) and Tejada *et al*,. 2007 which was conducted in Philippines and India.

Table 1: Plant height, stand count, number of cobs harvested and grain yield kg ha^{-1} of maize intercropped with green manuring plants in 2008 and 2009.

Treatment	Plant height (cm)	Stand count	No of cobs harvested	Grain yield kg ha^{-1}
Control	130.67	4109	4889	6439^{ab}
Tephrosia vogelii	132.67	4277	4798	6211^{b}
Canavalia ensiformis	127.00	4089	5060	6667^{a}
Tephrosia candida	131.00	4277	5014	6040^{b}
Mucuna prunensis	133.00	4089	4740	6097^{b}
Mean	130.87	4168	4900	6291
CV	4.37	6.76	7.62	3.52
Probability	Ns	Ns	Ns	*

The statistical analysis result revealed that there was highly significant difference among green manure plants, level of fertilizer and green manure fertilizer interactions on plant height (Table2, Annex 2 & 3). The tallest plant height was recorded when *Tephrosia vogelii* with full recommended fertilizer applied. On the contrary, the plot without green manure and fertilizer showed the shortest plant height. There was no statistically significant difference among green manuring plants on plant height while there was significant difference among fertilizer rates (Table 2). Using half and full recommended fertilizer rates did not show significant difference when combined with green manuring plants on plant height. There was no significant difference on fresh and dry biomass yields among green manuring plants while significant difference was observed between the fertilizer rates. All green manuring plants with full recommended fertilizer gave significantly higher fresh and dry biomass yields (Table 2). This result was in accordance with the findings of Narayan and Lal, 2006.

Table 2. The effect of green manuring plants, fertilizer rates and their interaction on yield and yield components of bread wheat in 2009.

Green manuring plants	Fertilizer rate			
	No fertilizer	Half of the recommended fertilizer kg ha^{-1}	Full of the recommended fertilizer kg ha^{-1}	
		Plant height (cm)		
Sole crop	40.07^{e}	75.20^{abcd}	82.067^{ab}	65.78^{c}
Tephrosia Vogelii	64.87^{bcd}	79.07^{abc}	84.73^{a}	76.22^{a}
Canavalia ensiformis	65.27^{bcd}	77.60^{abc}	82.60^{ab}	5.16^{ab}
Tephrosia candida	61.13^{cd}	73.07^{abcd}	81.93^{ab}	72.04^{b}
Mucuna prunensis	57.47^{d}	74.40^{abcd}	81.87^{ab}	71.25^{b}
Mean	57.76^{c}	75.87^{b}	82.64^{a}	72.09
CV		13.51		
Probability		**		
		Fresh biomass kg ha^{-1}		
Sole crop	3193^{d}	6325^{b}	8120^{a}	5879.33
Tephrosia Vogelii	3932^{cd}	6581^{b}	8889^{a}	467.33
Canavalia ensiformis	4444^{c}	6581^{b}	9006^{a}	6677
Tephrosia candida	4017^{cd}	6410^{b}	8291^{a}	239.33
Mucuna prunensis	3248^{d}	6068^{b}	9316^{a}	6210.67
Mean	3766.8	6393	8724.4	6294.73
CV		10.48		
Probability		**		
		Dry biomass kg ha^{-1}		
Sole crop	2821^{c}	5556^{b}	7478^{a}	5285
Tephrosia Vogelii	3162^{c}	5897^{b}	8077^{a}	5712
Canavalia ensiformis	3803^{c}	5940^{b}	8248^{a}	5997
Tephrosia candida	3205^{c}	5727^{b}	7778^{a}	5570
Mucuna prunensis	2692^{c}	5299^{b}	7949^{a}	5313.33
Mean	3136.6	5683.8	7906	5575.47
CV		11.36		
Probability		**		
		Grain Yield kg ha^{-1}		
Sole crop	1623^{e}	2821^{d}	3761^{b}	2735
Tephrosia Vogelii	1880^{e}	3419^{c}	4402^{a}	3233.67
Canavalia ensiformis	2051^{e}	3077^{d}	4017^{b}	3048.33
Tephrosia candida	2094^{e}	2821^{d}	4017^{b}	977.33
Mucuna prunensis	1752^{e}	2949^{d}	4101^{ab}	2934
Mean	1880	3017.4	4059.6	2985.67
CV		6.30		
Probability		**		

*** Significant at $P<0.01$*

Statistically there was significant difference ($p<0.05$) among green manuring plants, fertilizer rates and their interaction in 2009 cropping season (Table 2). The interaction result also showed significant yield difference between treatments. The highest grain yield was observed in the plots under *Tephrosia vogelii* with full recommended fertilizer with a mean grain yield of 4402 kg ha^{-1} followed by those under *Mucuna prunensis* with full recommended fertilizer (4106 kgha^{-1}). The lowest grain yield (1624 kgha^{-1}) was recorded for the control plot and without green manuring plants (Table 2). Fully fertilized plots without any green manuring plants gave a mean wheat grain yield of 3761 kg ha^{-1} and *Tephrosia vogelii* with ½ recommended fertilizers gave 3419 kg ha^{-1} (Table 2). There was only 342 kg ha^{-1} yield difference by full recommended fertilizer rate without green manuring plants compared to using *Tephrosia vogelii* with half of the recommended fertilizer rate. Moreover, using *Tephrosia vogelii* with full recommended fertilizer rate gave 641 kg ha^{-1} yield advantage as compared to using only recommended fertilizer rate (Table 2). This result shows that half of the fertilizer can be substituted by green manuring plants.

Table 3. Effect of fertilizer, green manuring plants and their interaction on wheat yield and yield components in 2010

Treatments	Fertilizer rate			
	No fertilizer	Half of the recommended fertilizer	Full of the recommended fertilizer	mean
	Plant height (cm)			
Sole crop	74.87	79.7	79.73	78.1[c]
Tephrosia vogelii	80.33	71.33	78.73	76.80[c]
Canavalia ensiformis	78.20	79.33	80.07	79.2[bc]
Tephrosia candida	80.73	81.67	84.47	82.29[a]
Mucuna prunensis	81.13	83.47	78.87	81.16[ab]
Mean	79.05	79.1	80.37	79.51
CV		8.6		
Probability		NS		
	Fresh biomass kg ha^{-1}			
Sole crop	3504[f]	5812[c]	5983[c]	5099.67
Tephrosia vogelii	4658[d]	6154[c]	8889[a]	6567
Canavalia ensiformis	4017[def]	6581[b]	7308[ab]	5968.67
Tephrosia candida	4017[cd]	6496[bc]	8291[a]	6268
Mucuna prunensis	3590[f]	6496[bc]	7991[a]	6025.67
Mean	3957.2	6307.8	7692.4	5985.8
CV		8.85		
Probability		**		
	Dry biomass kg ha^{-1}			
Sole crop	3249[e]	5556[b]	5641[c]	4815.33
Tephrosia vogelii	4359[d]	5897[c]	7350[a]	5868.67
Canavalia ensiformis	3761[de]	5769[c]	7009[ab]	5513
Tephrosia candida	4145[de]	6111[c]	7521[a]	5925.67
Mucuna prunensis	3291[f]	6239[bc]	7692[a]	5740.67
Mean	3761	5914.4	7042.6	5572.67
CV		9.11		
Probability		**		
	Grain Yield kg ha^{-1}			
Sole crop	1164[g]	1911[cd]	2118[cb]	1731
Tephrosia vogelii	1695[de]	2350[b]	2312[b]	2119
Canavalia ensiformis	1382[fg]	1875[cd]	2978[a]	2078.33
Tephrosia candida	1601[def]	2259[b]	2762[a]	2207.33
Mucuna prunensis	1324[fg]	2385[b]	2732[a]	2147
Mean	1433.2	2197.4	2539	2056.53
CV		8.92		
Probability		**		

**** Significant at $p<0.01$, NS= non significant*

The result from the main plot and sub plot interaction showed significant difference between the treatments (Table 3). The highest bread wheat grain yield was obtained from *Canavalia ensiformis* with full recommended fertilizer (2978 kg ha^{-1}) followed by *Tephrosia candida* and *Mucuna prunensis* with full recommended fertilizer (2762 and 2732 kg ha^{-1}) respectively (Table 3). The lowest grain yield (1164 kg ha^{-1}) was recorded from the plots without fertilizer and green manuring plants. In general, the lowest grain yield was due to yellow rust infestation across the country during the experiment year.

There was no statistically significant difference ($p<0.05$) in plant height for the fertilizer rates and the interaction of the green manure with fertilizer rates. However, incorporation of green manuring plants alone showed statistically significant difference on plant height (Table 3). Fertilizer rates, green manuring plots and their interaction showed statistically significant difference on dry and fresh biomass as well as grain yield of bread wheat (Tables3).

Conclusions and Recommendations

Green manuring plants intercropped with maize had little negative effect on the grain yield of the associate crop (maize). Whereas, the green manuring plants had a positive impact on yield of the subsequent crop (bread wheat). Incorporating the green manuring plants to the soil during the land preparation of the subsequent crop gave additional 662 kg ha^{-1} over the control (without any input). The study indicated that *Tephrosia vogelii* with half recommended nitrogen and phosphorus gave a mean wheat grain yield of 3419 kg ha^{-1} while the plots with full recommended nitrogen and phosphorus alone gave a mean bread wheat grain yield of 3761 kg ha^{-1}. This indicates that besides their role in improving the soil properties (due to the additions) green manuring plants replace almost half of the recommended nitrogen and phosphorus. Therefore, green manuring plants, especially (*Tephrosia vogelii*), with half recommended nitrogen and phosphorus are recommended to achieve high grain and biomass yields of bread wheat for Yilmana Densa (Nitisols) and similar agro-ecologies.

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Annexes

Annex 1. ANOVAs table for combined analysis of yield of bread wheat for the year 2009 and 2010

Source	DF	SS	Mean Square	F Value	Pr > F
Main plot	4	205.75	51.44	20.78	<.0001
Sub plot	2	4081.05	2040.52	824.28	<.0001
Year	1	1942.93	1942.93	784.85	<.0001
Main plot*sub plot	8	118.79	14.85	6.00	<.0001
Year*main plot	4	39.14	9.79	3.95	0.0065
Year*sub plot	2	445.74	222.87	90.03	<.0001
Year*main p*sub plot	8	145.55	18.19	7.35	<.0001

Annex 2 ANOVAs table for yield of bread wheat 2009

Source	**DF**	**SS**	**Mean Square**	**F Value**	**Pr > F**
Main plot	4	205.75	51.44	20.78	<.0001
replication	2	2.42	1.21	0.25	<0.76
Sub plot	2	4081.05	2040.52	824.28	<.0001
main_plot*replication	8	23.66	2.96	0.62	<0.76
sub_plot_*replication	4	10.73	2.68	0.56	<0.69
Main plot*sub plot	8	118.79	14.85	6.00	<.0001

Annex 3 ANOVAs table for yield of bread wheat 2010

Source	DF	Sum of square	Mean Square	F value	Pr>F
main_plot	4	127.0620060	31.7655015	8.30	0.0008
rep	2	1.5390752	0.7695376	0.20	0.8199
sub_plot	2	961.9511506	480.9755753	125.66	<.0001
main_plot*rep	8	19.0851121	2.3856390	0.62	0.7468
main_plot*sub_plot	8	197.4241873	24.6780234	6.45	0.0008
sub_plot_*rep	4	14.0703923	3.5175981	0.92	0.4769

Effects of the Combined Use of Compost, Nitrogen and Phosphorus on the Yield of Barley using tie-ridge

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Abstract

This trial was carried out with the overall objective of assessing the composting potential of the local composting materials and their integration with inorganic fertilizer for improving the productivity of barley. The experiment was undertaken by preparing compost and testing it effect on barley production on two locations for two years. Mean treatment differences were analyzed using ANOVA proc-GLM procedure. The two years combined analysis of the experiment in Dahana and Lalibela areas showed that application of blanket recommended inorganic fertilizer gave the maximum biomass and grain yield. However, using one tonne compost with half recommended N and P gave a comparable biomass and grain yield in addition to improving soil physical and chemical properties through time. Hence, one tonne compost with half recommended N and P is recommended for Wag and Lasta highland and similar agro-ecologies growing barley.

Key words: compost, grain, biomass, barley, organic fertilizer

Introduction

The world's increasing need for food, produced where it is needed, will be largely met by increasing yield on areas now cultivated and to a lesser extent by increasing the area under cultivation. Without the increased use of fertilizers together with optimum moisture in the soil, yield would have been very much less.

Barley is an important cereal crop in unfavorable environments. Its production is also considered relatively stable as compared to other cereals. It can give acceptable grain yield in areas where other crops cannot produce at all. Farmers use their land for barley or tef if rainfall fails to come early in May, to plant sorghum. Sorghum is more drought resistant than wheat and can be growing in regions of even minimum rain fall rainfall (Hailu and Joop, 1996). But in spite of its importance and capability to grow in such environmental condition, barley's productivity is quite very low in this area.

More immediate strategies using farmer available resources are needed that could reach more farmers sooner. Although fertilizers are used in much of Sub Saharan Africa, the amounts applied are insufficient to meet crop demands together with socio-economic and environmental factors aggravating this problem. Organic inputs are often proposed as alternatives to mineral fertilizers (Palm et al, 1997). Most soil fertility management in barley has been seen using inorganic fertilizers. For example, results at Holetta showed that the response to N and P application was significant on the Notosol (Hailu and Joop, 1996).

When the long-term carryover of compost is considered, even a onetime application may become economically viable. Studies have shown that a one-time compost treatment can result in increases in SOM, total N, P, K, and water infiltration many years beyond the initial application year (Butler and Muir 2006; Hartl et al. 2003; Ippolito et al. 2010; Reeve etal. 2012).

Compost is an organic fertilizer that can be made on the farm at low cost. In composting, unlike other organic fertilization process, the natural decomposition process in the soil can be speeded up by man. The most important input in our condition is farmers' labor. While the ingredients such as crop residues and or animal manure, can be easily found around the farmer. In addition to that, composting do have an advantage on further improvement of manure quality i.e weed seed that might exist in the animal dung will lose their viability by composting process. Raussen (1997; 92) states that the weed seeds, that exist in the dung, will germinate in the moist compost and die there as a result of light shortage.

Wag and Lasta area is one the drought affected area in the country. According to the farming system characterization by EARO, 2000, chemical fertilizer usage is not a common practice, because farmers questioned the benefits of fertilizer. It burned their crop substantially reduce the yield especially during shortage of rain or early termination, harvest more yield from the unfertilized field under the same moisture condition, and further associated with crop failure. So that this proposal was initiated to select the best combination of compost and inorganic fertilizers for better yield of barley and soil chemical and physical properties improvement.

Materials and Methods

Geographic Location of the study Area

The study area is located in eastern part of the Amhara National Regional State; Wag-Lasta which is characterized by a unimodal rainfall pattern that extends from late June to late August or early September, where crops are cultivated in summer season. The mean annual rainfall varies from 333 to 1016 mm and the mean minimum and maximum annual temperatures were 8 and 21^{o}C, respectively. The major agro-ecological characteristics of this catchment are hot and warm sub-moist to semiarid lowland with tepid to cool sub-moist environment.

The general slope range on which the farmlands occur varies between 0 and 8%, but could be normally found on 0-25% slope range. The soil type is predominantly locked on alluvial deposits, well drained, light to dark brown in color, and with very shallow-to-shallow soil depth, sandy to sandy clay loam in texture, highly eroded and continuously cultivated, with rock outcrops of basalt and sandstone (Akundabweni, 1984). The study was conducted in 2008/9 and 2009/2010 cropping season on farmers field.

Compost Preparation

To make quality compost from locally available materials, the following procedures were followed: Wood ash, FYM, mixture of straws (collected from cattle feed waste) and maize Stover were collected from different sources and then the following Compost layering trend was followed:

- Two pits with 1m width, 1m length and 1m depth were dug for making compost and used rotationally every 21 days for inverting the compost material and able to get a uniformly decomposed material.
- Sorghum stover cuttings were put in the first layer to improve aeration of the pit. Mound up to 30 cm thick and sprinkled with water.
- Second layer of the mixture was of straws and FYM to about 15 cm and 9 cm thick, respectively and sprinkled with water.
- The next layer, wood ash, was added up to 3 cm thickness.
- 3 cm thick forest top soil was added. The soil contains an essential microorganism that helps in decomposition of fresh and semi-decomposed organic material.
- This layering was continued up to the top of the pit where it reached a meter depth.
- Finally the composting material was covered with grass to avoid moisture loss.

In every layer, water was sprinkled to keep the material moist and hasten the decomposition. Long stick was inserted at an angle of 45^o and removed and checked once a week to improve air circulation and checking for moisture and temperature variation. After one month the compost was turned into the other pit and it was matured within three months.

Field trial

The experiment was laid down in a randomized complete block design with three replications with a gross plot size of 22 m x 11 m. The experimental units were laid on a plot size of 4 m x 3 m.

The treatments were:

1. Control (no fertilizer)
2. Blanket recommendation (41 kg ha^{-1}N + 46 kg ha^{-1} P_2O_5)
3. 20.5 kg ha^{-1}N + 23 kg $ha^{-1}$$P_2O_5$ + 1 tonne compost
4. 13.7 kg ha^{-1}N + 15.3 kg $ha^{-1}$$P_2O_5$ + 3 tonnes compost with four levels of compost
5. 5 t ha^{-1}compost.

The compost was applied to treatment 3, 4 and 5 one month earlier to planting. All phosphorus was applied at planting barley and nitrogen was applied in split, half at planting and half at knee height.

Soil Analysis

From each treatment, disturbed (by using auger) soil samples were collected at a depth of 0-20 cm across the replications and composited to make one composite sample per treatment. The collected samples were air-dried and ground to pass through a 2 mm diameter sieve for laboratory analysis following the standard procedures.

Particle size: Bouyoucos Hydrometre Method (Bouyouces, 1962)

- Soil reaction (pH): pH meter, (Jackson,1958)
- Organic carbon: Walkely and Blank (1934)
- Electrical conductivity (ECe): conductivity meter ,
- Cation exchange capacity (CEC): NH_4^+-acetate method

Statistical Analysis

The data collected from the field study and soil laboratory analysis were subjected for analysis of variance (ANOVA) using SAS software. Whenever treatment effects were significant, mean separations were made using least significant difference (LSD).

Results and Discussions

Soil physical and chemical properties

The mean soil pH was 5.66 which is moderately acidic (Landon, 1991; Tekalign, 1991) with a mean CEC of 25.0. The mean soil organic matter content was 1.88% which is very low due to continuous cultivation, high rate of soil erosion and high temperature with moist and drained soil environment favoring organic matter decomposition than deposition (Table 1). The result is in agreement with Wakene *et al.* (2001) who reported a wide variation among the analyzed samples for organic matter.

Table 1: General selected soil chemical properties of the study areas.

Parameter	mean	mean square	CV %	F value	Pr>F
pH	5.66	0.0433	5.287	0.48	0.75
CEC	25.01	1.866	5.501	0.99	0.49
OM	1.88	1.166	17.21	11.12	0.0105

A significant improvement of organic matter was observed at Dahana wereda with the application of sole recommended N and P fertilizers over the other treatments which are attributed to high root biomass production and addition of organic matter from root decomposition (Table 2).

The overall analysis of variance indicated that there was a significant improvement of soil organic matter after the application of different rates of compost combined with inorganic fertilizers that basically differ from place to place (Table 2). Application of 5 tonnes compost ha^{-1} improved the organic matter status of the soil by 80% and 58% over the unfertilized plots at Lalibela and Dahana, respectively. This organic matter has advantage for CEC, water holding capacity and improvement in nutrient supply.

Table 2: Overall Treatment Effect on selected chemical property Status after the Crop Harvest

Location	Treatment	Depth (cm)	Texture	Mean value of chemical properties				
				pH	EC	CEC	%OC	%OM
Dahana	No fertilizer	0-20	Clay Loam	5.78	45.8	24.2	0.726	1.251
	41 N+ 46 P_2O_5	0-20	Clay Loam	5.60	53.3	26.6	1.265	2.181
	1t compost + 20.5 N+23 P_2O_5	0-20	Clay Loam	5.58	56.6	23	2.478	4.272
	13.7 N + 15.3 P_2O_5 + 3 ton compost	0-20	Clay Loam	5.46	74.5	26.4	1.257	2.168
	5ton compost	0-20	Clay Loam	5.11	139.4	25.6	0.880	1.517
Lalibela	No fertilizer	0-20	sandy clay loam	5.86	29.30	27	0.3235	0.557
	41 N+ 46 P_2O_5	0-20	sandy clay loam	5.79	46.70	25.4	0.7413	1.278
	1t compost + 20.5 N+23 P_2O_5	0-20	sandy clay loam	5.98	16.58	24	0.9357	1.613
	13.7 N + 15.3 P_2O_5 + 3 ton compost	0-20	sandy clay loam	5.53	55.90	24.2	1.5249	2.629
	5ton compost	0-20	sandy clay loam	5.94	43.00	23.8	1.6212	2.794

Responses to yield and yield components

There were treatment effects on barley yield across the years and locations (Table 3 and 4). One tonne compost + 20.5 kg ha^{-1} N + 23 kg ha^{-1} P_2O_5 gave significantly higher grain yields next to the recommended N and P (46 kg ha^{-1} P_2O_5 and 41 kg ha^{-1}N) compared to the other treatments in 2008 cropping season which is in consent with the result reported by Fanuel and Gifole (2012) and Edwards *et.al.* (2007). At Lalibela, the recommended nitrogen and phosphorus fertilizers gave the highest grain yield (1244.44 kg ha^{-1}), biomass (3458.33 kg ha^{-1}) and plant height (91.99 cm) compared to the treatments. Integrating compost with N and P had resulted in 48.6% yield penalty at Lalibela indicating that the combination effects vary from place to place. In similar year at Dahana, reverse results were obtained and the grain yield appreciated combined use of compost and inorganic fertilizers. 1 tonne compost with 20.5 kg ha^{-1} N + 23 kg ha^{-1} P_2O_5 gave a grain yield of 1694.44 kg ha^{-1}. On the other hand, biomass yield (6512.5kg ha^{-1}) and plant height at maturity (108.32cm) were favored by recommended N and P fertilizers (Table 3).

Table 3: Mean biomass and grain yield of five combinations evaluated at Lalibela and Dahana in 2007 cropping season.

Treatments	Lalibela			Dahana		
	Plant height at maturity	Biomass yield in kg^{-1}	Grain yield in kg ha^{-1}	Plant height at maturity	Biomass yield in kg ha^{-1}	Grain yield in kg ha^{-1}
41 kg N+ 46 kg P_2O_5	91.99^{a}	3458.33^{a}	1244.44^{a}	108.32^{a}	6512.5b^{a}	1527.77^{b}
1 t compost + 20.5 kg N+23 kg P_2O_5	70.50^{cb}	1920^{b}	597.22^{b}	98.39^{c}	6841.7^{a}	1694.44^{a}
13.7kg N + 15.3 kg P_2O_5 + 3 t compost	70.50^{c}b	1690.06^{c}	638.89^{b}	105.92^{b}	5908.3^{c}	1524.44^{b}
5 t compost	68.97^{c}	1072.78^{d}	447.22^{c}	105.59^{b}	6491.7^{b}	1267.22^{c}
No fertilizer	73.39^{b}	795.28^{e}	399.44^{c}	93.09^{d}	4908.3^{d}	1205.00^{d}
Mean	75.07	1788.89	665.44	102.26	6132.17	1443.78
CV	2.98	1.84	4.68	0.64	2.87	0.82

The second year results showed similar trend with that of the first year. At Lalibela the recommended N and P favored the plant height at maturity (73.62 cm), biomass yield (6316.39 kg ha^{-1}) and grain yield (2295 kg ha^{-1}) (Table 4). Relatively higher yield increments were observed as compared to year one by applying 1 tonne compost with half recommended N and P fertilizers (Table 4). In Dahana, the recommended N and P resulted in the highest grain yield (1508.33 kg ha^{-1}), biomass yield (5152.78 kg ha^{-1}) and plant height at maturity (91.49cm), followed by 1 tonne compost with half recommended N and P (Table 4).

Table 4: Mean biomass and grain yield of five combinations evaluated at Lalibela and Dahana in 2009 cropping season.

Treatments	Lalibela			Dahana		
	Plant height at maturity	Biomass yield in kg ha^{-1}	Grain yield in kg ha^{-1}	Plant height at maturity	Biomass yield in kg ha^{-1}	Grain yield in kg ha^{-1}
41 N+ 46 P2O5	73.62^{a}	6316.39^{a}	2295^{a}	91.49^{a}	5152.78^{a}	1508.33^{a}
1t compost + 20.5N+23 P2O5	54.62^{b}	4579.44^{b}	1545^{b}	76.44^{c}	3383.33^{c}	989.72^{b}
13.7N + 15.3 P2O5 + 3 ton	52.52^{b}	2023.89^{c}	727.78^{c}	73.14^{d}	4111.11^{b}	903.61^{b}
5tonne compost	51.72^{b}	1945.83^{c}	544.44^{d}	80.74^{b}	3444.44^{c}	955.56^{b}
No fertilizer	55.77^{b}	1213.61^{d}	336.67^{e}	65.84^{e}	1911.11^{d}	675.00^{c}
Mean	57.65	3215.83	1089.78	77.53	3600.55	1006.44
CV	8.57	1.32	3.30	0.70	1.67	6.03

The two years combined analysis over location indicated that using recommended N and P maximized the grain and biomass yields of barley (Table 5). Significant differences were observed among the treatments ($P < 0.05$) in plant height at maturity, biomass and grain yields (Table 5 and 6). From the combination, it was observed that one tonne compost + ½ recommended N and P gave significantly higher grain yield, biomass yield, and plant height at maturity (Table 5 and 6).

Table 5: Mean biomass and grain yield at Lalibela and Dahana combined over years (2007 and 2009) cropping season.

Treatments	Lalibela			Dahana		
	Plant height at maturity	Biomass yield in kg	Grain yield in kg	Plant height at maturity	Biomass yield in kg	Grain yield in kg
41 N+ 46 P2O5	82.80[a]	4887.36[a]	1769.72[a]	99.91[a]	5832.6[a]	1518.06[a]
1t compost + 20.5N+23 P2O5	62.56[b]	3249.72[b]	1071.11[b]	87.42[d]	5112.5[b]	1342.08[b]
13.7N + 15.3 P2O5 + 3 ton	61.51[b]	1860.97[c]	683.33[c]	89.53[c]	5008.9[b]	1214.03c[b]
5tonne compost	60.34[b]	1509.31[d]	495.83[d]	93.16[b]	4968.1[b]	1111.39[c]
No fertilizer	64.56[b]	1004.44[e]	368.06[e]	79.46[e]	3409.7[c]	940.00[d]
Mean	66.36	2502.36	877.61	89.80	4866.36	1225.11
CV	6.62	2.61	8.60	1.53	4.57	9.80

Table 6: Mean biomass and grain yield of five combinations evaluated at Lalibela and Dahana combined over years and locations.

Treatments	Plant height at maturity	Biomass yield kg/ha	Grain yield kg/ha
41 N+ 46 P2O5	91.36[a]	5360.0[a]	1643.89[a]
1t compost + 20.5N+23 P2O5	74.98[b]	4181.1[b]	1206.6[b]
13.7N + 15.3 P2O5 + 3 tonne	76.75[b]	3238.7[c]	803.61[d]
5tonne compost	75.52[b]	3134.7[c]	948.68[c]
No fertilizer	72.02[c]	2207.1[d]	654.03[e]
Mean	78.12	3684.36	1051.36
CV	3.33	7.93	10.66

Conclusions and Recommendations

In general, recommended nitrogen and phosphorus rates gave higher yield as compared to the combinations of compost with N and P fertilizers. However, compost has additional advantage to yield increment i.e. it builds up the physical and chemical properties of soils. The rainfall in the dry land areas is erratic, unpredictable and crop failures were common. Due to the low moisture, application of N and P fertilizers alone is a risk enterprise. Hence, combination of compost and N and P fertilizers was the best option. One tonne compost with half recommended N and P gave a comparable grain and biomass yields to the full recommended N and P in addition to improving soil physical and chemical properties through time. Hence, based on the economic background of the farmers (their poor fertilizer purchasing capacity), half recommended N and P (20.5 N and 23 P_2O_5) + 1 tonne compost is recommended for Wag and Lasta highland area and similar agro-ecologies growing barley.

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II) Soil and Water Conservation Research

Effect of In-situ Rainwater Conservations and Sowing Date on Weed Infestation and Barley Yield

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Abstract

The experiment was conducted at two sites in northern Ethiopia (Maichew and Mekelle). The objective of the research was to evaluate the effect of in-situ rainwater conservation and sowing date on soil water status, barley yield and infestation of weeds. The treatments were three alternative sowing dates (Early sowing date (ESD); Normal sowing date (NSD); and Late sowing date (LSD) and two in-situ rainwater conservation measures (tie-ridge and soil bund) replicated three times. Analysis of variance (ANOVA) was applied to evaluate the effect of the treatments on total biomass and rainwater use efficiency (RWUE) of barley. The average soil water content in the upper 0.6 m root zone in the soil bund and tie-ridge were improved over the control by 14% and 24%, respectively. The grain yield on the tie-ridge was increased significantly (18%) compared to the control at Maichew site. NSD significantly improved the grain yield over LSD in both sites. Neither of the sowing dates nor the in-situ rainwater conservation measures had significantly improved the dry-matter of barley. However, when NSD combined with tie-ridge, the grain yield was significantly improved compared to the LSD. There was no significant difference in weed infestation in both experimental sites due to applying in-situ rainwater conservation. But, numbers of weeds were significantly higher in early sowing date compared to normal sowing date and late sowing date on both experimental sites. Therefore, normal sowing date with tied ridging technique can be used as an option to obtain higher barley grain yield.

Key words: In-situ moisture conservation, barley, soil moisture content, yield, weed.

Introduction

Agriculture is the backbone of the Ethiopian economy. It is responsible for approximately 54% of the GDP, 90% of foreign exchange earnings, and 80% of the livelihoods of the population (NBP, 2008). Barley is the major staple food crop in the northern Ethiopia. It is well adapted to the altitude ranges from 1800-3000 masl (Araya and Stroosnijder, 2010). The crop is used for preparing food types like *Enjera, Tela, Genfo, Kita, Kolo, and* making beer. Its straw is used for animal feed. Despite the importance of the crop for human and livestock use, its yield has been severely limited mainly by water shortage.

Soil moisture is the major limiting factor for crop production in the semi-arid environments of Africa (Barron et al., 2003; Araya et al; 2010a). In northern Ethiopia, particularly the smallholder farmers have faced many challenges especially the lack of secured rainwater for rainfed agriculture. In addition to the unsecured and uneven distribution of the rainfall within the rainy season, the onset and cessation of rain varies from year to year. This variation has generated irregularities in date of sowing which has a direct impact on the length of growing period and crop production.

In northern Ethiopia regardless of its severe drought risks, technologies that effectively use rainwater are limited. In addition, to what extent the climatic stress that resulted from climate change could be reduced by improving rainwater use efficiency is not known. Therefore, understanding rainfall and other associated factors that affect soil moisture variability during the crop growing period is crucial.

Sowing date technique is used to optimize the rainwater use in the growing season (Tesfay and Walker, 2004). Knowledge of the most optimal sowing date will enable to improve rainwater use and reduce false start risk and to obtain better crop yield (Stern et al., 1981; Sivakumar et al., 1992; Reas et al., 2004; Mugalava et al., 2008). However, most farmers in northern Ethiopia are interested to sow barley on dry soil (after few showers of rain) for the following reasons: *to prolong the growing period of the crop, to reduce work burden and to rent their oxen and labor power*. Late sowing is practiced in the *absence of oxen and* *labor and/or due to late start of the rain*. Hence, identifying the best sowing date for barley in the growing period could have paramount importance in reducing crop failure. However, information on optimal sowing date in the northern Ethiopia is not available.

In-situ rainwater conservation measures can enhance the water availability in the crop root in order to improve the yield and water use efficiency of barley during below average rainfall condition (Araya and Stroosnijder, 2010). However, some farmers in northern Ethiopia indicated that in-situ rainwater conservation structures enhance the dominance of weed over their crops and increase the possibility of weed infestation. Report on the effect of in-situ water conservation on prevalence of weeds however is not available. Therefore, there is need to assess the effect of in-situ conservation measures on the extent of infestation of weeds. In addition, the interaction effect of in-situ rainwater conservation practices and sowing date on grain yield has not been fully understood.

In this study, an attempt was made to evaluate the effect of sowing dates and in-situ water conservation techniques in reducing vulnerability of barley crop to soil moisture shortage and weed infestation through the evaluation of In-situ soil water conservation techniques and sowing dates: a) on soil moisture status, b) on total biomass yield of barley and, c) on weed infestation.

Materials and Methods

Description of the Study Area

The study areas are located at Maichew and Mekelle found in the northern part of Ethiopia, at 13^o 3’N and 12^{o}47’N latitude and 39^o 6’E and 39^{o}32’E longitude with an elevation of 2210 and 2400 masl, respectively. The climate of the study areas is tepid semi-arid with mean annual rainfall of about 600 mm for Mekelle site (Araya et al., 2010b) and 600-800 mm for Maichew site. The mean minimum and maximum seasonal temperature values are 9^{o}c and 22^{o}c for Maichew and 9^{o}c and 28^{o}c for Mekelle, respectively. The soils type at Mekelle and Maichew were Cambisols and Vertisols, and the corresponding textural classes of the surface soils (top 0.2 m) were silt loam and clay loam, respectively. The soil depth at both sites was approximately 1m.

Experimental Design and Crop Management

The sowing dates were adopted from the farmers practice and from the analysis based on the long-term climate data (Araya *et al*., 2010b). Early sowing date (*ESD*) is the period corresponds to July 1-8. Normal sowing date (*NSD*) occurs in period July 9-19. Whereas late sowing date (*LSD*) is corresponds to the period July 19-27. The tie-ridges were 0.15m high and 0.25m wide and spaced at 0.8-1.0m apart and ridges were tied at intervals of 2.0m, and 0.1-0.12m high. The practice was similar to the introduced oxen drawn rigger presented in Temesgen (2000) and McHugh *et al*. (2007). The soil bunds were basin like structures with a height of 0.15-0.20m soil. The conventional (control) plots were without soil and water conservation structures but with all other management practices similar to those of the in-situ water conservation treatments. The experimental design was RCB with three replications. The plot size was 6m by 6m with 1.0m and 2.0m spacing between plots and blocks, respectively.

The amount of seed and fertilizer applied was following the blanket recommendation. i.e. 120 kg ha^{-1} of barley seed and 100 kg ha^{-1} each DAP and UREA were applied by broadcasting. The phosphorus was applied at planting and half of the nitrogen fertilizer was applied at planting and the other half at four weeks after planting. Weed count was carried out within $1m^2$ quadrant in each plot 28 days after sowing and average number of weeds per treatment was computed and weeds were removed, and the total biomass was harvested from the central $4m^2$ of each plot and dried by sunlight. The dry grain yield and aboveground dry matter at maturity were used to evaluate the impact of different in-situ rainwater management and sowing date practices.

Soil Moisture

The soil moisture was measured using Time Domain Reflectometery (TDR) and gravimetric methods in both experimental sites. The glass fiber access tubes were installed in each plot and the data were taken using TDR at an interval of 0.2m to a depth of 0.6m of the rooting depth of the barley. The soil moisture analysis was made based on the average of the observed TDR (soil moisture in vol. % or $m^3\ m^{-3}$) and gravimetric value (kg kg^{-1}) of soil moisture of each treatment. Based on Eq. 1 the gravimetric soil moisture (kg kg^{-1}) was converted to its corresponding volumetric value by multiplying its bulk density (Wiyo *et al.*, 2000) and the soil moisture obtained in volumetric water content (m^3m^{-3}) was converted into equivalent depth per unit soil depth (mm) by multiplying 1000 kg m^{-3} of density of soil moisture content and its soil moisture depth (Raes, 2001).

$$Soil\ water\ content = \left(\frac{\text{Bulk density}}{\text{Density of soil watr solution}}\right)\text{mass of water content} \qquad (1)$$

Threshold soil moisture (*mm*) of the remaining soil moisture amount after the Readily Available Moisture *RAM* (mm) is depleted (w*here depletion factor of barley (p) is 0.55),* and computed using Eq.2.

$$Threshold\ (mm) = (1 - p) * RAM + PWP \qquad (2)$$

The rainwater use efficiency (*RWUE* in kg ha^{-1} mm^{-1}) and harvest index (*HI*) was of different crops can be determined using Eq.3 and Eq.4, respectively (Araya and Stroosnijder, 2010).

$$RWUE = \frac{\text{GY}}{\text{R}} \qquad (3)$$

$$HI = \frac{\text{GY}}{\text{DM}} \qquad (4)$$

Data Analysis

SAS statistical software package was used to compute the effect of treatments, on grain yield, dry matter, harvesting index and rain water use efficiency of the barley and on weed infestation. Mean separation of significant difference was done by Duncan Multiple range.

Results and discussions

Soil Moisture Status

Water plays important role for crop growth in realizing i) photosynthesis ii) Translocation of plant synthesis from leaf to other part of the plant, and iii) Transportation of mineral nutrients. Thus, the presence of adequate water in the root zone improves the aforementioned roles of water. Effective in-situ conservation measures capture rainwater in the soil during rainy periods for continued plant uptake at moisture sensitive crop growth stage.

The average soil moisture content within the barley root zone at Maichew sites for each sowing date treatments and in-situ rainwater conservation measures are shown in Fig.1. The available soil moisture content values at FC and PWP were 214mm and 124mm, respectively. The total available moisture (TAM) content was 90mm and the readily available moisture (RAM) content was estimated to be 49.5mm. Moisture stress began when it reaches below threshold (164.5mm) as indicated by the threshold line in Fig.1.

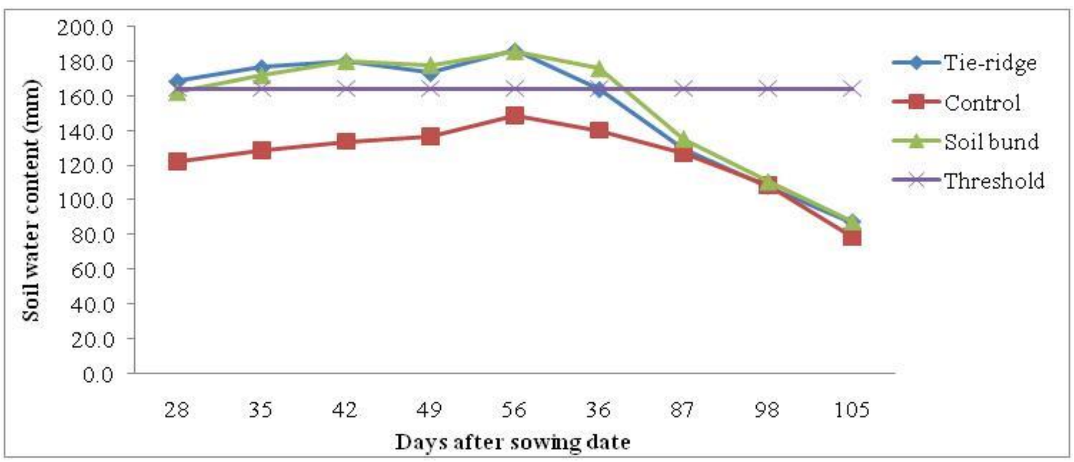

Figure1. Average soil moisture content at Maichew sites

Similarly, at Mekelle site, the available soil moisture content values at FC and at PWP were 244mm and 102mm, respectively. The total available moisture (TAM) content was 142mm and the readily available moisture (RAM) content was 78mm. Moisture stress began when it reached below threshold (166 mm) as indicated by threshold line in Fig.2.

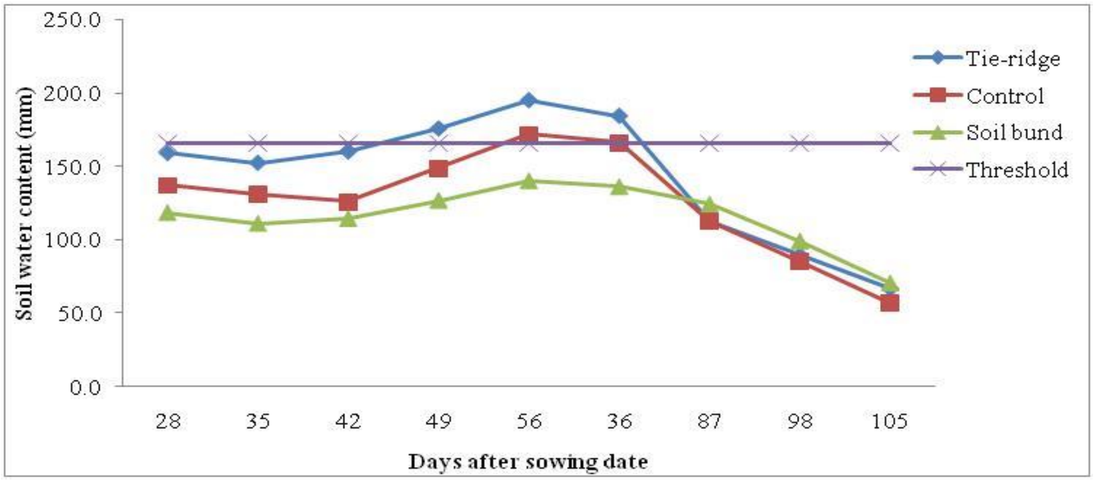

Figure2. Average soil moisture content at Mekelle sites

As shown in Fig.1, the soil moisture content per unit soil depth for both tie-ridge and soil bunds were 23% higher than that of the control. Similarly, as shown in Fig.2, tied ridge improved the soil moisture in the root zone by 14% compared to the control. McHugh *et al*., (2007) found tied ridge improved the soil moisture storage by 9% - 24% compared to the control. Also, Araya and Stroosnijder (2010) obtained 13% - 27% increment in soil moisture content with tie-ridge compared to the control. Many authors reported that tie-ridge enhances positive partitioning of rainwater for better utilization of the soil moisture in the root zone (McHugh et al., 2007; Nuti et al., 2009; Temesgen et al., 2009). Although, tie-ridge increased the soil moisture in the root zone, there was no significant difference in soil moisture availability between tie-ridge and soil bund at both sites. Furthermore, in spite of the more available water in the tie-ridge, there was small difference in lengthening (prolonging) the moisture availability period in the season (Fig.1 and Fig.2). Araya and Stroosnijder (2010) recommended tied ridge for below average rainfall season. In below average rainfall seasons, barley grown without soil water conservation is likely to be exposed to late water stress earlier than barley grown with in-situ conservation measures.

Effect of In-Situ Rainwater Conservation Practices

The tie-ridge improved the GY and RWUE significantly ($p<0.05$) over the control at Maichew and no significant difference was observed in dry matter (DM) yield and HI compared to the control (Table1). Whereas at Mekelle site, none of the in-situ rainwater conservation measures had significant difference on GY, DM, HI and RWUE compared to the control (Table1).

Table1. Effect of in-situ rainwater conservation practices on barley yield and yield parameters at Maichew and Mekelle sites

Treatments	Maichew				Mekelle			
	GY	DM	HI	RWUE	GY	DM	HI	RWUE
Tie ridge	2181a	7678a	28.6a	3.76a	1535a	6882a	22.1a	2.67a
Soil bund	2044ab	7742a	26.5a	3.52ab	1459a	6598a	21.9a	2.54a
Control	1848b	6997a	26.3a	3.19b	1474a	6921a	21.4a	2.57a
P<0.05	**	ns	ns	**	ns	ns	ns	ns

***Significant at 0.01; ns, non-significant; where; GY: (kg ha^{-1}); DM: (kg ha^{-1}); HI: (%); and RWUE: (kg ha^{-1} mm^{-1}); Different letters in a column showed significant difference.*

At Maichew there was 18% increment in GY with tie-ridge and 10% increment with Soil bund compared to the control. At Mekelle site tie-ridge improved the GY by 4% over the control whereas the GY obtained in the soil bund was lower than the control. The reason was not fully understood, but it could be due to excess rain water during sensitive stage as barley is sensitive to aeration stress (Araya *et al*., 2010b). The potential water requirement of barley varied from 340 to 375mm (Araya *et al*., 2011). However, the study site received rainfall of 580mm for short period of time (mid-July to mid-August), and hence, the crop with treatment soil bund might have suffered aeration stress due to water logging.

According to McHugh (2007), tied ridge improved the grain yield by 73% in sorghum field. Araya and Stroosnijder (2010) also reported that tie-ridging improved the grain yield by 60% in barley field. As shown in Table1, tie-ridge and soil bund improved the dry matter by 10% compared to the control at Maichew. However, lower dry-matter was found at Mekelle site in tie-ridge and soil bund as compared to the control. In-situ rainwater conservation may not significantly improve the dry matter during above average rainfall at barley sensitive stage (Araya *et al*., 2010b). However, in-situ rainwater conservation measures have benefits such as reducing runoff, increasing ground water recharge, and improving the nutrient status (Nuti *et al*., 2009).

Slightly higher HI was observed with tie-ridge treatment and followed by soil bund. Araya and Stroosnijder (2010a) reported that harvest index was slightly higher in treatment with tie-ridge compared to the control. At Maichew site, tie-ridging showed significantly ($p<0.05$) higher RWUE ($3.76 kg\ ha^{-1}mm^{-1}$) compared to the control ($3.19 kg\ ha^{-1}mm^{-1}$) (Table 1). The result indicated that in-situ rainwater conservation measures especially tie-ridge was effective in conserving rainwater. Tie-ridge reduced not only runoff, but also soil and nutrient loss and improves water availability in the root zone for the crop growth as compared to the control. McHugh *et al*. (2007) concluded that conservation tillage can be beneficial for improving soil moisture and reducing runoff and soil loss. Overall, tie-ridge was most effective at improving rainfall partitioning (i.e. less runoff loss from field) for dry spell mitigation.

Effect of Sowing Date

Sowing date techniques are known to optimize the crop RWUE and allow fit the majority of sensitive crop growth period with the peak rainy season (Tesfay and Walker, 2004). At Maichew experimental site, ESD (4^{th} July) and NSD (12^{th} July) showed significantly high difference over the LSD (22^{nd} July) ($P<0.05$) in GY, HI and RWUE. NSD significantly improved the GY, HI and RWUE over ESD at Mekelle. Although, there was no significant difference ($p<0.05$) in dry-matter (DM) due to sowing date at both experimental sites, there was relative increment in DM with NSD when compared to LSD and ESD at Maichew (Table2).

Table2. Effect of sowing date on barley yield and yield parameters at Maichew and Mekelle

Treatment	Maichew				Mekelle			
	GY	DM	HI	RWUE	GY	DM	HI	RWUE
ESD	2180a	7167a	30.5a	3.37a	1358b	6446a	20.8b	2.36b
NSD	2296a	7947a	28.9a	3.96a	1673a	6663a	25.1a	2.92a
LSD	1596b	7303a	22.1b	2.75b	1437ab	7293a	19.6b	2.5ab
P<0.05	**	ns	**	**	**	ns	**	**

***Significant at 0.01; ns, non-significant; where; GY: (kg ha^{-1}); DM: (kg ha^{-1}); HI: (%); and RWUE: (kg ha^{-1} mm^{-1}); Different letters in a column showed significant difference.*

NSD increased the *GY* by 44% and 13% over LSD at Maichew and Mekelle respectively (Table 2). ESD increased the *GY* over LSD by 37% at Maichew site (Table 2). The increment in *GY* was due to better use of rainwater by the crop during the growing season. Unlike NSD and ESD, LSD exposed to later seasonal drought because the late season sowing received short rainy period compared to ESD and NSD. Knowledge of optimal growing season is very important to set the type of crop to be cultivated and planning of sowing date (Mugalavai *et al*., 2008). Crops sown early have got the greater opportunity in receiving rainwater for an extended period than that of the late sowing. NSD improved the HI by 28% and 31% over LSD at Mekelle and Maichew, respectively (Table 2). The result showed that, sowing date optimizes RWUE (Table 2). The NSD improved the RWUE by 44% and 16% over LSD and ESD at Maichew. Similarly, NSD improved the RWUE by 17% and 23% over LSD and ESD at Mekelle, respectively (Table 2). This indicates that normal sowing escapes from early and late season dry-spells and hence, minimizes crop failure.

Interaction Effect of In-Situ Rainwater Conservation and Sowing Date

The combined treatment effect of sowing date and in-situ rainwater conservation practices on barley fields were significantly different (p<0.05) in GY, HI and RWUE at Maichew site while at Mekelle site significant difference was not observed (Table 3).

Table 3. Interaction effect of in-situ RWC and sowing date on yield and yield parameters

Interaction Effect	Maichew				Mekelle			
	GY	DM	HI	RWUE	GY	DM	HI	RWUE
ESD*Tr	2232.5ab	7358.3	30.6a	3.85ab	1540.0	7264.2	20.7	2.68
ESD*Sb	2336.7ab	7333.3	31.9a	4.03ab	1069.2	5560.8	19.3	1.86
ESD*C	1971.7bcd	6808.3	28.9ab	3.4bcd	1464.2	6513.3	22.3	2.55
NSD*Tr	2585.2a	8183.3	31.7a	4.46a	1828.3	6564.2	27.7	3.18
NSD*Sb	2216.7ab	7958.3	27.8ab	3.82ab	1614.2	6360.0	25.0	2.81
NSD*C	2088.3bc	7700	27.1ab	3.6bc	1576.7	7064.2	22.7	2.75
LSD*Tr	1725.0cde	7491.7	23.6bc	2.97cd	1236.7	6818.3	18.0	2.15
LSD*Sb	1579.2de	7933.3	19.7c	2.27de	1692.5	7872.5	21.3	2.95
LSD*C	1485e	6483.3	22.9bc	2.56e	1380.8	7186.7	19.3	2.40
SD* SWC	**	ns	**	**	ns	ns	ns	ns

*** Significant at 0.01; ns, non-significant; Tr: tie ridge; Sb: soil bund and C: control; SWC: soil water conservation, SD: sowing date; Different letters in a column showed significant difference.*

At Maichew, tie-ridging when combined with NSD improved the GY significantly compared to the LSD combined with tie-ridging. NSD combined with tie-ridge increased the GY by 48-50% and 16 -20% than combined with LSD and ESD, respectively (Table 3). However, there was no significant difference in DM at both sites. The result implies that if farmers practiced NSD in combination with tie-ridging they could obtain better quantity of GY.

Soil bund improved the GY by 48% when combined with ESD and by 40% when combined with NSD at Maichew site (Table 3). ESD when combined with tie-ridge and soil bund resulted in significantly higher HI when compared to LSD and NSD at Maichew site. However, at Mekelle site, only NSD combined with tie-ridging improved the HI significantly ($p<0.05$) compared to ESD and LSD (Table 3). Generally NSD improved the HI by 34% and 54% when combined with tie-ridge over LSD and by 4% and 34% over ESD at Maichew and Mekelle experimental sites respectively.

In both experimental sites the NSD when combined with tie-ridge treatments improved the RWUE significantly ($p<0.05$) over LSD (Table 3). The NSD when combined with tie-ridge improved RWUE by 16%-18% and 48%-50% than ESD and LSD combined with tie-ridge respectively. Generally, in NSD, RWUE was increased by 5% and 57% in Mekelle site and by 18% and 4% in Maichew site, compared to LSD and ESD when combined with in-situ conservation respectively. This demonstrates that farmers can collect rainwater by constructing tie-ridge and sow their crop during NSD to reduce water stress and crop failure.

Single effect of in-situ rainwater conservation practice and sowing date on weed infestation

There was no significant difference in weed infestation due to in-situ soil water conservation practices in barley fields at both sites (Table 4). However, weeds were more prevalent and significantly higher with ESD at Maichew and Mekelle experimental sites.

Table4. Effect of in-situ SWC and sowing date on weed infestations

Treatment	level	Number of weeds	
		Maichew	Mekelle
In-situ SWC practice	Tie-ridge	80a	187a
	Soil bund	79a	160a
	Control	78a	180a
	$p<0.05$	ns	ns
Sowing Date	ESD	94a	214a
	NSD	75b	169ab
	LSD	67b	142b
	$p<0.05$	**	**

*** Significant at 0.01; ns non-significant; Different letters in a column showed significant difference*

The result disproves the negative perception of some farmers that weed infestation increase in fields with in-situ conservation measures. Therefore, practicing in-situ rainwater conservation measures on cropped land does not enhance weed prevalence. However, the number of weeds in ESD was significantly higher from NSD and LSD. As shown in Table 4, ESD increased weed infestation by 25% and 40 to 50% over NSD and LSD respectively at both sites. The result indicated that, the numbers of weeds in NSD and LSD were minimized because more weeds were observed by the first rains and were removed by plowing during NSD and LSD. Barley sown on dry soils (ESD) has the chance to germinate with weeds just after few showers of rain are received. Hence more weed infestation is likely to occur in ESD. This may also have cost implications in weeding and may also significantly affect the crop yield due to weed competition.

Combined effect of In-situ RWC and sowing date on weed infestation

There was no significant difference due to combination of sowing date and in-situ rainwater conservation treatment at both sites. Generally, it was investigated that ESD when combined with both in-situ water conservation measures, increased the number of weeds by 10%-17% and 34%-56% over NSD and LSD respectively. From weed infestation point of view, practicing of ESD is not advisable unlike the case of NSD and LSD (Table 5).

Table5. Combined effects of In-situ SWC and sowing date on weed infestation

Site	In-situ RWC	Sowing Dates		
		ESD	NSD	LSD
Maichew	Tie-ridge	78	88ab	72
	Soil bund	104	68c	64
	Control	99	69bc	65
	P<0.05	ns	**	ns
Mekelle	Tie-ridge	222	187	150
	Soil bund	184	183	110
	Control	236	137	166
	P<0.05	ns	ns	ns

***Significant at p<0.05; ns: non-significant; Different letters in a column and row showed significant difference.*

Conclusions

Barley growth and development are affected by water stress. To avoid the negative effect of dry-spell on the barley growth and development, alternative water management practices are important towards better use of rainwater in semi-arid areas. Tie-ridge captured rainwater and improved soil moisture in the root zone and reduced loss of water due to runoff and consequently increased the GY compared to the farmers practice. This implies that tie-ridge improves RWUE. The increment in GY and RWUE in the case of soil bund was insignificant. Normal sowing date was found to be one of the methods to maximize the RWUE in barley field. Thus, NSD gave higher GY and RWUE compared to

LSD. However, there was no significant difference in DM due to different sowing dates. NSD has enabled barley to better use of rainwater during the season. Unlike NSD, LSD shortens the growing season and exposed the crop to latter season drought. Furthermore, the GY and RWUE significantly increased when tie-ridge combined with NSD. There was no significant difference in number of weeds due to in-situ rainwater conservation practices. Hence, the assumption of some farmers (increased weed infestation in farm lands with in-situ water conservation) was not supported by this study. Rather sowing date significantly favored weed infestation with higher rate in ESD.

Recommendations

- In-situ water conservation measures are recommended in order to capture the rainwater to mitigate dry-spells and to obtain higher *GY* and *DM*. However, it may not be recommended in barley in times of excess rainfall.
- NSD combined with tie-ridge is recommended for it gave higher GY and DM.
- Further study on the relationship of in-situ water harvesting and sowing date should done across different seasons, crops and their economic benefit is required.

Acknowledgement

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Water harvesting ponds for improved agricultural production and income generation at Meket DawaChefa

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Abstract

This survey was conducted to: (i) evaluate the socioeconomic and technical situation of water harvesting technologies on farmers condition (ii) assess farmers awareness and perception on the use of introduced household water harvesting systems and adoption rate. The survey was carried out in selected kebeles from the two districts. Three representative kebeles from each district were identified for the survey. Structured questionnaire and systematic random sampling were in the survey. Sample households interviewed from the two study districts were 90. Primary data was collected through in-depth interviews of households, key informants, conducting focus group discussions, and observation. The technical and socioeconomic problems observed in both districts were described for further solution. The economic analysis focused on cost and benefit relationship of rain water harvesting techniques. The cost benefit analysis depicts that in semiarid regions both cemented and plastic lined type of WHS should be used to collect rain water and had positive net present value. The internal rate of return (IRR) was 160 % and the return on investment values was 387%. However, the cheapest way of rain water harvesting is geo-membrane which has IRR of 315 % and 179% at Meket and Dawachefa respectively. Geo-membrane together with the adoption of further seepage control techniques and improved water management technologies like drip system and pedal pumps should be used to maximize the benefit of harvested rainwater. It is concluded that for rain water harvesting to contribute to improved incomes and food security, smallholder farmers should be assisted to change from subsistent to commercial objectives with market oriented production of high value crops.

Key words: Water harvesting structures, Irrigation, lining material, Geo-membrane, cropping scheme

Introduction

Agriculture occupies a key position in the Ethiopian economy and more than 90 percent of the agricultural productions are generated from agriculture. Agriculture provides livelihood to more than 85 percent of the population and more than 87 percent of the economically active labor force is engaged in it. Nearly, 90 percent of the export earnings and more than 41 percent of the country's GDP usually come from the agricultural sector (CSA, 2010).

Agricultural productivity is declining due to variable rainfall, frequent floods and recurrent droughts. The erratic nature and seasonal variability of rainfall constitute a major cause for frequent failures of crops and scarcity of livestock feed (Habtamu, 1999).

Water harvesting is usually employed as an umbrella term describing the whole ranges of methods of collecting and concentrating various forms of runoff (roof top runoff, overland flow, stream flow, etc.) from various sources (precipitation, dew, etc.) and for various purposes (agriculture, livestock, domestic consumption and other purposes) (Rejj *et al*., 1993). In the semi-arid areas, water harvesting is a direct productive form of soil and water conservation. Both yields and reliability of production can be significantly improved with this method (FAO, 1995).

Agricultural development based on water harvesting and irrigation is often considered a promising avenue for poverty alleviation in rural areas. The development of small-scale irrigation schemes through water harvesting techniques help to distribute runoff from time of excess rainfall to the shortfall season. Availability of water for a small garden usually managed by women can make a significant difference to a household's nutrition and thus contribute to improve food security. Low-cost irrigation technologies can help smallholders' move from subsistence farming into growing cash crops. Factors influencing technology uptake are: (i) the existence of a market-driven demand for agricultural produces; (ii) a well-designed technology that is both appropriate and affordable for the local farming and manufacturing systems; and (iii) existence of a local private sector capable of mass production of reliable equipment as well as existence of effective private sector distribution networks for agricultural inputs and equipment.

The government of Ethiopia has invested in the construction of various surface water harvesting schemes including micro-earth dams and diversion weirs, as a result of which, some positive benefits have been recorded. In Amhara region many farmers had constructed water harvesting structures from concretes and geo-membrane. Meanwhile, the successes are very limited because the needs and aspirations of the farmers were not well considered in the planning, designing and implementation processes. Lack of focus on the selection of appropriate water harvesting technologies that fit to the local situation and farmer's circumstances was another limiting factor. Moreover, the application of water harvesting techniques was new to most of the development workers and farmers. Meanwhile, evidences on the extent to which improved water harvesting and irrigation technologies/techniques are adopted by and disseminated to farmers are not adequately available.

This survey was, therefore, conducted to study farmers' adoption of improved water harvesting technologies and socioeconomic condition of those technologies in the study districts from 2003/04 to 2010.

Objectives

The overall objective of the survey was to assess the awareness, perception and use of water harvesting technologies by farmers in the selected districts. Specifically the survey tries to: (i) evaluate the socioeconomic and technical situation of water harvesting technologies at farmers' condition (ii) assess farmers' awareness and perception on the use of water harvesting structures and technology characteristics that influence adoption rate and (iii) recommend the most profitable WHS for further scale up.

Scope of the Survey

The survey was carried out in the selected kebeles from the two districts from each district, three kebeles representative to the districts were identified for the survey. Results of the survey in relation to household water harvesting systems is primarily based on data collected from randomly selected sample of 90 farm households from 6 kebeles in the two districts. However, recommendations drawn out from this survey could be used in other districts having similar conditions.

Significance of the Survey

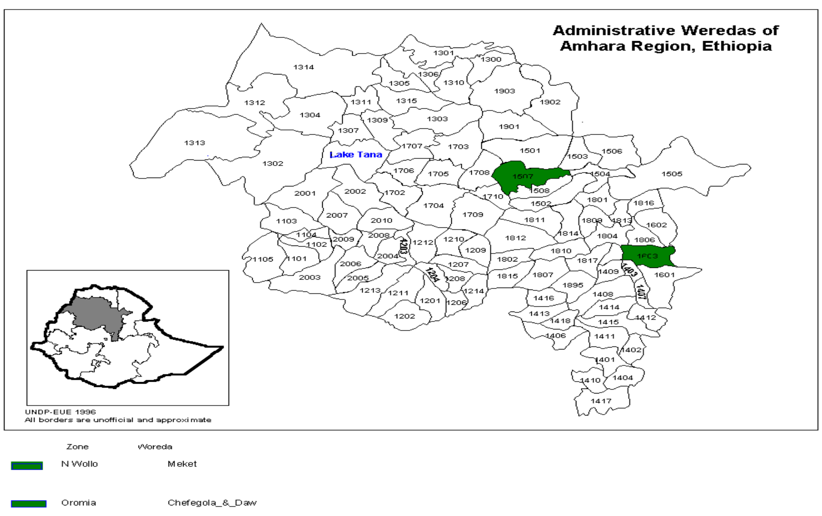
The findings of the study will serve to measure the current status of improved water harvesting and irrigation techniques in the selected districts. It will also be used as a basis for subsequent results-based monitoring and evaluation of the technologies. Causes of the successes or failures on improved water harvesting technologies were identified. Moreover socioeconomic and technical evaluations on water harvesting technologies were made.

Methodology

The study area

The study sites are located in the Amhara Region, North Wollo zone (Meket district) and Oromia Zone (DawaChefa district). In Dawachefa district the study was conducted in three peasant associations namely: Dodo, Riqqee and Chirt having an altitude ranging from 2000m to 2300m masl. While in Meket district the study was conducted in three peasant associations namely: Anjeb, Debrezebit and Timtemat having an altitude ranging from 2115m to 2900m masl (Fig.1).

Figure 1. Location of the study sites



The target districts were well-represented the agro-ecological zones (highland, midland and lowland) and relief features (plain & rugged topographies) of the region. The two districts in eastern Amhara (DawaChefa and Meket) receive bi-modal rainfall which is highly variable that necessitates the application of all possible options of irrigation so as to reduce crop failures.

Sampling Procedure, Data Collection and Analysis

Baseline data were collected from publications and records kept by the district, zonal and regional offices of agriculture. These data covered issues such as water harvesting, farming systems and socio-economic data. Also, supporting data were collected from the regional and district offices of Agriculture. Primary data was collected through conducting in depth interviews of individual households, key informants, focus group discussion and observation. Filed data were then collected through farm visits, and interviewing farmers using structured questionnaires. The structured questionnaire for household survey was reviewed and updated by group of researchers. Checklist to collect information from key informants and secondary sources, including topic guides to conduct focus group discussions with the beneficiaries were also developed. The key informants included in the survey were development agents, irrigation process owners, extension supervisors, and irrigation technicians. Information collected through key informants, focus group discussion, and observation was used to triangulate and further elaborate the findings from the analysis of interview.

A two stage stratified random sampling method was used to select farmers for the study. At the outset, the district was stratified into three categories, i.e., highland, midland and lowland. One Peasant Association (Kebele) from each stratum was selected. The second stage was selection of sample households from each sample kebele identified for the survey. For each technology 10 farmers were randomly selected for interviews. In total, 94 sample households out of which 64 and 30 farmers were interviewed for plastic lined and cemented type of WHS respectively. 4 questionnaires were discarded due to consistency problem. Data collected was processed using software-Statistical Package for Social Sciences (SPSS V16.0) and Excel. After employing data cleaning, coding, and encoding of both primary and secondary data descriptive statistics was applied for data analysis, and results of the analysis are presented in tables and diagrams.

Yield comparison was done based on gross margin analysis and investment analysis. Here cost and benefit relationship was used to identify the adoption of improved rain water harvesting techniques. Since decision to adopt is driven by profit motive, components of cost are investment cost, operating cost (land preparation, planting, weeding, thinning, harvesting and threshing costs), input cost (seed, chemical and fertilizer costs), maintenance cost, watering cost, cost of water and full contributions made by various partners to the development of RWH (the value of water considering alternative uses), cost of catchment area and treating the catchment and external cost (externalities, environmental destruction and health hazards, cost of de-silting etc). Components of benefit consist of direct and indirect benefits. Direct benefits are increased crop production and indirect benefits are support of appropriate infrastructures such as market, roads, transport and storage facilities.

The decision criteria (the costs of various alternatives) are compared and the cost effective alternative is selected. The cost alternative was compared with the benefits in a cost benefit analysis. Net Present Value (NPV) of the various costs and benefits is the decision criteria used to select the best alternative technology. The technology having the higher positive NPV or the lower cost benefit ratio (CBR) was selected. Then economic evaluation of rainwater harvesting was done based on two dynamic indices; financial net present value (NPV) and financial internal rate of return (IRR). Service life for WHS used for comparisons was 10 years. The discount rate used for calculations was 10% which is usual for economic calculations.

Gross benefit (GB) and Total cost (TC) can be computed using the formula:

$$GB = \sum_{t=1}^{n} \frac{Bt}{(1+i)^t} \qquad (1)$$

$$TC = C_1 + C_2 + \sum_{t=0}^{m} \frac{C3_t}{(1+i)^t} + \sum_{t=1}^{n} \frac{C_t}{(1+i)^t} \qquad (2)$$

Where:

B_t = Average gross benefit at the t^{th} year C_t = Average cost at the t^{th} year

i = discount rate

C_1 = Average investment on catchment areas

C_2 =Average investment on WHS (tanks and ponds)

C_3 = Average investment on irrigation equipment's of t th year

m = Average replacement time of irrigation equipment's of t th year

n = calculation period of years (effective time of life of structures)

Then, NPV = GB-TC (3)

If NPV > 0, the scenario is accepted if not the scenario is not viable. The duration of time when the net revenue compensates for the total investment is total recovery period. In order to calculate the internal rate of return the solution of IRR in the Eq. (4) must be found, that is

$$\sum_{t=1}^{n} \frac{\mathrm{Bt}}{(1+\mathrm{IRR})^{t}} - [\, C_1 + C_2 + \sum_{t=0}^{m} \frac{\mathrm{C3}_{t}}{(1+\mathrm{IRR})^{t}} + \sum_{t=1}^{n} \frac{\mathrm{C}_{t}}{(1+\mathrm{IRR})^{t}} \,] = 0 \qquad (4)$$

Where, IRR is the internal rate of return. The IRR is acceptable if it is greater than the minimum expected interest rate.

Results and Discussions

Improved irrigation technologies addressed in this survey include: household water harvesting systems (hand dug wells and water harvesting structures either cemented or plastic type; water lifting devices (motor pumps, treadle pumps, rope and bucket, and rope and washer pumps) and water application methods or devices (drip system and watering can). It also includes improved water application or irrigation techniques like furrow, border and basin.

The results of the survey on household water harvesting systems give detail information about: (i) household characteristics; (ii) perception of households on water harvesting; (iii) technology characteristics that affect rate of adoption of improved water harvesting technologies; and (iv) technical and socioeconomic evaluation of WHS under smallholder farmers condition.

Table 1. Household characteristics

Household characteristics	Groups	Percent	Range
Sex:	Male Female	100 0	
Marital status	Single Married	6.67 93.33	
Education	Illiterate Grade 1-8 Grade 9-10 College	56.7 35.5 6.7 1.1	
Age	<15 years 15-64ears >64 years	53.5 45 1.5	Dependency ratio of 122%, every productive person feeds himself and additional 1.22 persons
Age and farming experience	Average age Farming experience Irrigation experience	43.8 years 29 years 7 years	25-68 years 7-50 years 0-20 years
Land holding	Average land size Irrigated land size Land ownership	1.26 ha 0.153 ha (Dawa Chefa) 0.035 ha (Meket) 100 % own land 50% both own and rent land	0.04-4.25 ha 0.01-0.32 ha (Dawa Chefa) 0-0.1 ha (Meket)

Current farm landholding and size of irrigable land by WHS

The average size of land holding is 1.26 ha with the minimum and maximum being 0.04 and 4.25 hectares. The average size of irrigable land per household for Dawa-chefa was 0.153 ha with the minimum and maximum being 0.01 and 0.32 ha. While the average irrigable land for Meket was 0.035 ha with the minimum and maximum being 0 and 0.1 ha respectively. Analysis of land title (ownership) shows that 100% of the households have their own land and 50% have both own land and rented land.

Awareness of farmers about household level water harvesting structures

Analysis of households' awareness about water harvesting systems showed that about 77.78% were aware of different systems of water harvesting. As a result of farmer-to-farmer knowledge transfer and knowledge transfer through experts and development agents of the district office of agriculture, there was no considerable difference between kebeles in the percent of farmers who have awareness on water harvesting systems.

The main sources of information for those households are neighboring farmers and extension workers. Regular extension services delivered by extension workers and farmer-to-farmer knowledge transfer are the key sources of information that help most of the farmers to know about water harvesting. Most of the households (61.11%) have participated in community meetings that promote water harvesting. Only few farmers have participated in field days (7.78%), experience sharing visits (6.67%) and trainings (7.78%) related to water harvesting.

Perception of farmers about household level water harvesting

According to the result of the survey, most of the households (95.66%) think that household level water harvesting systems can improve their income and food security. Whereas very few (4.44%) thought the opposite because they believed that: (i) water harvesting structures cannot provide adequate water for crop production; and (ii) water harvesting structures usually fail to harvest runoff. When group discussion was held with farmers and experts, only 1% of the households have water harvesting structures and 25% of the HHs need to have WHS in the future. Reasons for not having Water Harvesting Structures (WHS), according to farmers' were labor cost for excavation especially for the female household heads, costs for cement and masonry, lack of material support from the government, lack of training on how to establish and use WHS, failure of the constructed water harvesting structures by some farmers and lack of appropriate site to construct water harvesting structures.

Rate of adoption of improved irrigation technologies and techniques

Type of water harvesting technologies and percent of farmers who have these water harvesting structures in each Woreda are depicted in Table 2. However, among the surveyed 90 households, 26% had hand dug wells, 57% had water harvesting structures which is lined with plastic geo-membrane, 4% had cemented water harvesting structures, and only 5% used small springs.

Table 2. Number and percent of HHs who have different types of WHS up to 2010

District	Hand dug well			Plastic type WHS			Cemented type WHS		
	No	Current Status		No	Current Status		No	Current status	
		Functional	Not functional		Functional	Not functional		Functional	Not functional
Dawachefa	2	1	1	155	135	20	3	0	3
Meket	455	257	198	1350	360	990	100	58	42
Overall	457	258	199	1505	495	1010	103	58	45

Source: District office of Agriculture (May, 2011)

The rate of adoption of water harvesting structures is almost at its early stage (Table 3). Based on Roger's adoption curve, adoption of improved technologies such as motor pumps is limited to the first category of adopters. The reason for the limited adoption of these technologies may be limited technical skill, lack of financial capacity and risk taking ability. As evidence, the reason for 65% non- adoption of the technology was lack of financial and material resources. Therefore, adoption of improved irrigation technologies was mostly limited to those farmers having better financial resource.

Table 3. Rate of adoption of improved irrigation technologies

Se. No	Type of technology	Rate of adoption
1	Water harvesting structures	39.16 %
2	Water lifting devices	8.75 %
3	Water application / irrigation techniques	4.25 %
4	Irrigation systems	31.14 %

Source: Household survey (May, 2011)

Technical and Socioeconomic evaluation of water harvesting structures

Technical aspects of water harvesting

Based on the lining materials used, the types of water harvesting structures addressed in the survey were plastic lined and cemented types. For these types of structures major technical problems related to the lining materials were: deformation of the structures, inappropriate site for runoff collection, lack of silt trap, and size and shape of the ponds do not fit with the lining materials. According to farmers saying and personal observation the most serious problems associated with the water storage structures were siltation, evaporation and seepage. These problems occurred due to the absence of silt traps in the WH system and no shade that protects the reservoir from wind and direct sunlight and tear of the lining materials were among others. Moreover, area allocated for irrigation was too much that do not fit with the collected volume of water by the WHS (Table 4).

Table 4. Type of problems encountered

Type of problems	Dawa-chefa		Meket	
	Yes	No	Yes	No
Siltation	24	6	52	8
Evaporation	28	2	56	4
Seepage	22	8	54	6

Source: Household survey (May, 2011)

Some of the limitations observed on WHS

- Poor extension services which leads to limited flow of information and technologies.
- Area irrigated by WHS is too much beyond storage capacity of WHS especially at Dawachefa.
- Weak policy enforcement mechanisms which was expressed in supplying lining materials without payment.
- No possibility of water distribution by gravity
- Promotion of the technologies without pilot testing and evaluation

- Takes more land for construction
- Not capable of providing water for the cropping season as a single source.
- Lack of adequate characterization of the rainfall, evapo-transpiration and soil properties that help for the design of WHS.
- Tear of the plastic material during loading and unloading, Sharp objects and stones underneath torn the lining material and wrong plastic lining at steep side slope and folds and wrinkles due to oversized.
- No silt traps constructed in most of the ponds

Social aspects of water harvesting

Components of the social aspects of rain water harvesting are policy and legal frameworks, local institutions and equity. Land tenure is one of the policy and legal frameworks since rain water harvesting involves long term investment, long term and secure tenure system is desirable. In this respect farmers have land occupation and use right so the policy supports the construction of WHS. When conflicts and disputes arise on water rights, land ownership and use, local institutions such as kebele administrators, community based organizations, NGO and district administrators etc should support the farmers in resolving the conflicts. Equity in using WHS refers to fairness especially in distribution of resources and benefits from economic activities.

Allocation of WHS should not create inequality in ownership between men and women, individuals in the society and between leaders and the rest of the society, correcting it on time if already exists. In both districts female household heads do not have their own WHS so this implies that construction of WHS and technology transfer did not consider the interests of all groups.

Social problems observed in the survey

- To adopt WHS, 55% of the respondents fail due to fear of theft and 45% due to labor shortage.
- Farmers were given lining material without agreement and incurring cost; this hinders future expansion and leads to inappropriate use of the materials for other

purpose. So there must be cost sharing or credit arrangement when households participate in the technology use.

- At the group discussion most farmers responded that they were discouraged to construct WHS due to failure of water harvesting structures constructed by their neighbors.
- Year after year technology users need subsidy for improved input supply like pedal pump, improved seeds and fertilizers.

Marketing practices of the farmers

In both cases of the households interviewed, farmers sell their agricultural produces at district markets and local markets. On average, they walk 2 to 3 hrs to reach district markets and 0.5-1 hour to reach local markets. Farmers sell their agricultural products mainly within three months of harvest. The main sources of information about market for the farmers were: (i) friends/neighbors /relatives and (ii) traders. Pack animals were the main means of transportation for marketing of agricultural products. The farmers store their products in traditional silos, made of mud, or in underground storages. During the focus group discussion with the beneficiaries of irrigation schemes it was learned that the producers were not accustomed to get into pre-harvest contract agreements with customers. They directly carry their products to the market and sell it to any consumer.

Despite the price fluctuations, local markets and district markets seem to absorb the supply of agricultural produces. Consumers' at the district towns were the major users, especially of the vegetables supplied by the farmers. So, it is wise to be pro-active and make farmers aware of the opportunities to improve marketing of their agricultural produces. As the price of agricultural products is one of the main factors that determine feasibility of improved irrigation technologies, it has a direct relation with the farmers' adoption of improved irrigation technologies. Hence, for further adoption and scale up of improved irrigation technologies needs to improve the existing marketing system.

Economic aspects of water harvesting

The financial net present values for the types of WHS in the two districts were calculated (Table 5). The NPV's of the plastic type at Meket was greater than that of the cemented or concrete type. When the plastic type was used, the capital recovery period of the structures was less than 3 years.

Table 5. The average costs incurred and revenues obtained using WHS and rain fed.

District	WHS Type	Revenue RF ETB/ha	Revenue WHS ETB/ha	Average Cost of material ETB/pcs	Total cost WHS	Cost for WHS ETB/pcs	Input cost	Incremental income due to WH
Dawa chefa	Geo-membrane	12,365.83	31,911.10	4500.00	8024.46	7355.79	668.67	12,852.90
Meket	Geo-membrane	10,237.50	34,636.03	4500.00	6822.85	6228.13	594.72	18,746.45
	Cemented	8,625.57	29,005.50	9000.00	13601.17	12724.5	876.67	8,641.55

Source: own calculation based on survey

Returns to investment

The financial analysis of storage ponds from agricultural enterprises is presented in Table 6 and 7 below. The parameters considered in these analyses were net present value (NPV) and financial internal rate of return (FIRR). Initial investment costs of WHS were 7629, 6415 and 12901 ETB/pond in Dawachefa geo-membrane, Meket geo-membrane and Meket cemented types respectively. Maintenance and production costs were 829, 732 and 1146 ETB/pond/yr in Dawachefa geo-membrane, Meket geo-membrane and Meket cemented respectively.

Gross incomes from crop production were 34,812, 37,782 and 31,642 ETB ha^{-1} in Dawachefa geo-membrane, Meket geo-membrane and Meket cemented respectively. However, this calculation didn't include the water used for livestock and household consumption. In general, the benefits of storage ponds with a discount rate of 10%, the average NPV of 10 years was on average 25,764 ETB indicating that the WH technologies are financially profitable. Furthermore, the FIRR was 160% (average of the two types of WHS) which is higher than the discounted factor 10% indicating its financial profitability.

Table 6: Discounted benefit and discounted costs

District	Discounted costs ETB WHS/ha	Discounted costs ETB RF/ha	Discounted Revenue ETB WHS/ha	Discounted Revenue ETB RF/ha	Net Revenue WHS	Net Revenue ETB RF/ha	Incremental due to WHS/ha
Dawachefa Geo-membrane	7,629.23	2,043.70	34,812	13,490.00	27,182.88	11,446.30	15,736.58
Meket Geo-membrane	6415.33	1,255.03	37,785	11,168.18	31,369.43	9,913.15	21,456.28
Meket Cemented	12901.16	2,081.02	31,642	9,409.71	18,741.20	7,328.69	11,412.51
Average	**8981.91**	**1793.25**	**34746.33**	**11356.00**	**25764.52**	**9562.67**	**16201.85**

Source: own calculation based on survey

Table 7: NPV, Financial internal rate of return and Return on investment of WHS

Performance Parameters	Dawa chefa geo-membrane	Meket geo-membrane	Meket cemented	Average
Discount Factor (%)	10	10	10	10
Discounted costs(ETB/ha)	7629	6415	12901	8982
Discounted Benefits(ETB/ha)	34812	37785	31642	34746
NPV (10)	27183	31369	18741	25764
ROI (%)	456	589	245	387
FIRR (%)	179	315	112	160

Source: own calculation based on survey

Conclusions

The result of the cost benefit analysis depicted that both cemented and plastic lined type of WHS should be used to collect rain water in semiarid regions. It had positive net present value and the internal rate of return of 160 % as well as 387% return on investment values. However, the cheapest way of rain water harvesting was geo-membrane which had IRR of 315 % and 179% at Meket and Dawachefa respectively (Table 7).

Geo-membrane together with the adoption of water conserving methods like seepage control, drip system and pedal pumps should be used to maximize the benefit of harvested rainwater in both Districts. To contribute for poverty reduction, rain water harvesting for crop production should be integrated with improved irrigation management options like drip irrigation, improved agronomic practices and crop selection. Improved management implies selection of crops which have high value in the market (like garlic, onion, khat, fruits) and appropriate cultural practices (management of soil fertility), supply of improved varieties and timely socioeconomic interventions, and marketing strategy will help to achieve the objective of improving water productivity.

Recommendations

- Community based management, farmer participation in planning and cost sharing may help to manage these reservoirs and to overcome the problem of theft and sell of lining materials. Use of the technology in cluster may be the better solution for proper implementation of WHS and protect theft.
- Market improvement begins from production. Supports should be given to the farmers in the selection of marketable crops (high value crops), and improving the quality of products. In this regard, developing reliable improved seed and fertilizer supply systems and building the capacity of farmers are vital.
- Though technologies for various conditions are available many of them are not widely adopted. This can be attributed to technical, socioeconomic and policy factors, but most importantly the lack of community participation in the development and implementation of these technologies. So water harvesting techniques should be selected according to the biophysical and resource availability and must be implemented accordingly without enforcing technologies which are not appropriate to the locations.
- Training should be given to some volunteer and knowledgeable farmers on maintenance of WHS from each district. Then the trained farmers can give services to other farmers with reasonable cost.
- Developing a regulatory system on utilization of geo-membrane is also very important to mitigate the problems related to geo-membrane misuse by the farmers. For example,

signing agreement with the farmers during distribution (not to use it for other purposes) may reduce the problem.

- Future research is needed on cropping schemes in order to select the most suitable crops for water harvesting and supplemental irrigation farming systems; moreover, marketing issues of crops produced with WHS should be addressed.

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ANNEX

Table 8. Net incomes from major crops at Dawachefa and Meket

Crops/systems	Mean gross value (ETB/ha)	Costs of inputs (ETB/ha)	Net income (ETB/ha)
Teff rainfed both locations (ETB/ha)	10234	2873	7361
Wheat rainfed Meket (ETB/ha)	8619	1717	6902
Sorghum rainfed Dawachefa (ETB/ha)	12359	2516	9843
Average rainfed Meket (ETB/ha)	10285	2295	7990
Average rainfed Dawachefa (ETB/ha)	13481	2686	10795
Onion seedling with WH (ETB/100m^2)	2737	884	1853
Chat and onion rainfed Dawachefa plastic (ETB/ha)	31909	6613	25296
Onion , vegetables and fruit rainfed Meket plastic (ETB/ha)	34629	7565	27064
Onion , vegetables and fruit rainfed Meket Cemented (ETB/ha)	31807	5865	25942
Incremental income due to WH (ETB/ha)	35513	8075	27438

Table 9. Average total family labor inputs (man-day) and gross return to family labor (ETB/man-day)

Crops/systems	Total family labour	Return to family labor (ETB/man-day)
Teff rainfed	130 (man-day/ha)	76.5
Wheat rainfed	90 (man-day/ha)	92
Sorghum rainfed	100 (man-day/ha)	99
Seedling production with WHS	15 (man-day/100m^2)	138
Onion and chat WHS	180 (man-day/ha)	160
Onion, vegetables and fruit WHS	175 (man-day/ha)	180163
Onion, vegetables and fruit WHS	180(man-day/ha)	161
Incremental labor due to WHS	193(man-day/yr)	