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} y ^{o} y ^{o} y ^{o}y 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).

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

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.

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

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).

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

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

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.

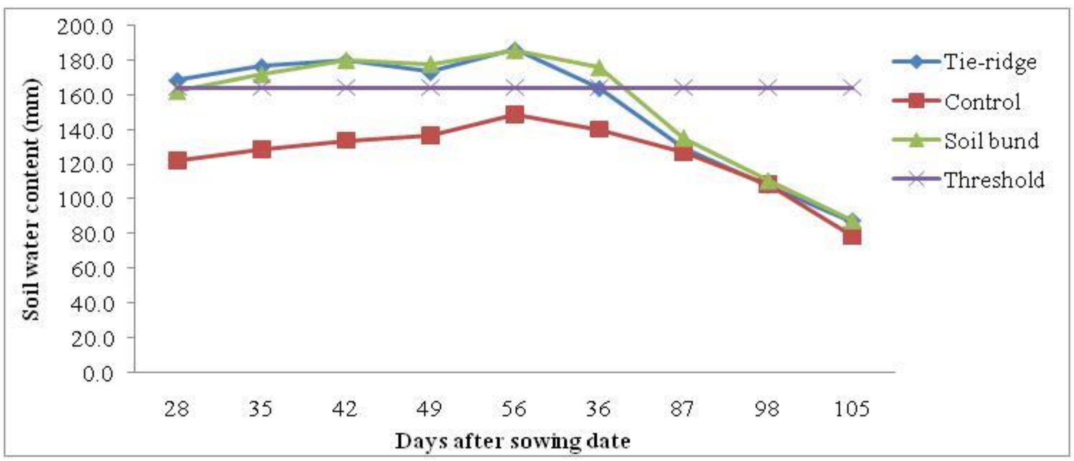

Figure1. Average soil moisture content at Maichew sites

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.

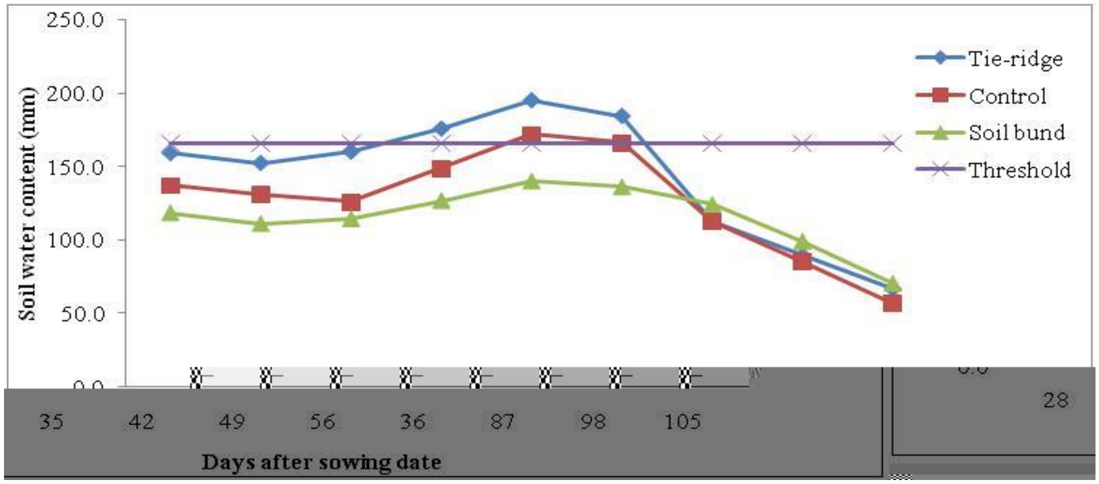

Figure2. Average soil moisture content at Mekelle sites

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 (3.76kg $ha^{-1}mm^{-1}$) compared to the control (3.19kg $ha^{-1}mm^{-1}$) (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 (4th July) and NSD (12th July) showed significantly high difference over the LSD (22nd 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.

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References

Araya, A., Solomon H., Kiros, M.H., Afewerk, K., Tadesse, D., 2010a. Test of Aqua-Crop model in simulating biomass and yield of water deficient and irrigated barley (*hordeum vulgare).* Agricultural Water Management. 97, 1838-1846.

Araya, A., and Stroosnijder, L., 2010. Effect of tied ridges and much on barley (*Hordeum Vulgare)* rainwater use efficiency and production in northern Ethiopia. Agricultural water management 97. 841-847.

Araya, A., Keesstra, S.D. and Stroosnijder, L., 2010b. A new agro-climatic classification for crop suitability zoning in northern semi-arid Ethiopia. Agric. Forest Meteorol., doi: 10.1016/J.agroformet. 2010.04.003

Araya, A., Solomon Habtu, Mitiku Haile, F. Sisay and Tadesse Dejene 2011. Determination of local barley (*Hordeum vulgare*) crop coefficient and comparative assessment of water productivity for crops grown under the present pond water in Tigray, Northern Ethiopia. Momena J. Sci. in press.

Barron, J., Rockstrom, J., Gichuki, F., Hatibu, N., 2003. Dry spell analysis and maize yield for semi-arid locations in east Africa. Agriculture and Forest Metrology117, 23-37.

McHugh, O.V., Steenhuise, T.S., Berihun Abebe, Fernandes, E.C.M., 2007. Performance of in- situ rainwater conservation tillage techniques on dry spell mitigation and erosion control in the drought-prone north wello zone of the Ethiopia highlands. Soil and tillage research 97. 19-36

Mugalavai, E.M., Emmanuel C. Kipkoror, E.C., Reas, D., and Rao, M.S., 2008. Analysis of rainfall onset, cessation and length of growing season for western Kenya. Agric. Forest Meteorol. 148, 1123-1135.

National Biogas Program, 2008. Program Implementation Document on Biogas for Better Life. Published by: Ethiopian Rural Energy Development and Promotion Center (EREDPC)

Nuti, R.C., Lamb, M.C., Sorensen, R.B., Turman, C.C., 2009. Agronomic and economic response to furrow diking tillage in irrigated and non-irrigated cotton (Gossypium hirsutum L.) Agric. Water Manage. 96, 1078-1084.

Raes D., 2001. Water balance of cropped soil. Katholieke Universitiet Leuven. Belgium

Raes D., Sithole A., Makarau A., Milford J., 2004. Evaluation of First Planting Dates Recommended by Criteria Currently Used in Zimbabwe. Agricultural and Forest Meteorology 125. 177-185.

Sivakumar, M.V.K., 1992. Empirical analysis of dry-spells for agricultural application in West Africa. Journal of climate 5, 532-539.

Stern R.D., Dennett, M.D., Garbutt, D.J.,1981. The start of rains in West Africa. Journal of Climatol. 1, 59-65.

Temesgen, M., 2000. Animal-drawn implements for improved cultivation in Ethiopia: participatory development and testing. In: Kaumbutho, P.G.,pearsons, R.A.,Simalwenga. T.E., (Eds.), Empowering farmers with animal Traction. Proceeding of the workshop of animal traction network for Eastern and Southern Africa (ATNESA), Mpumalanga, South Africa,20-24September 1999, pp. 70-74.

Temesgen, M., Hoogmoed, W.B., Rockstrom, J., Savenije, H.H.G., 2009. Conservation tillage implements and systems for smallholder farmers in semi- arid Ethiopia. Soil tillage reaserch 104, 185-191.

Tesfay, K., and Walker, S., 2004. Matching of crop and environment for optimal water use: the case of Ethiopia. Physics and chem. Of the Earth 29, 1061-1067.

Wiyo, K.A., Kasomekera, Z.M., Feyen, J., 2000. Effect of tie-ridging on soil water status of maize crop under Malawi condition. Agriculture and Water management. 45, 101-112.