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Research Article

Integrated Cropping and Moisture Harvesting Systems for Sustainable Crop, Water and Soil Productivity in The Dryland Areas of Northern Ethiopia

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ABSTRACT

The yield of sorghum (Sorghum bicolor L. Moench) and other crops is often constrained by soil water deficits in semiarid areas of Ethiopia. Study on integrated cropping and moisture-harvesting system was investigated at Raya Azobo (Genete and Tsgea) and Raya Alamata (Tao and Garjale) districts of Tigray, Ethiopia in 2016 and 2017 cropping season both on station and on farmers field in conservation farming field experiments. Included treatments were; Sole Sorghum with and without fertilizer on conventional tillage, Basin with and without fertilizer, Basin + farmyard manure, Basin + fertilizer + farmyard manure, Basin + cowpea intercropping with and without fertilizer and, Sole cow pea on conventional plot. Significantly Higher grain yield of 4.61 t ha^{-1} (+61.4% over the conventional) with optimum economic gain and 4.01 t ha^{-1} (+43.7 % over the conventional) were obtained from planting basin with fertilizer and planting basin with farmyard manure respectively in the researcher managed plots at Raya Alamata. Mean grain yield of 3.57 t ha^{-1} were also obtained from basin conservation tillage supported with fertilizer from the farmers managed plots, while the lowest mean grain yield of 2.98 t ha^{-1} was obtained from the conventional plots. The respondents of participating and non-participating farmers have also selected planting with fertilizer, farmyard manure or integrated of farmyard and fertilizer 1st, 2nd and 3rd respectively.

Key words: Conservation farming, Sorghum, Planting basin, Mulch

INTRODUCTION

Increasing food security and reducing risk are recurring themes in the agricultural development. As climate is undeniably changing, and Ethiopia is facing challenging climatic conditions, small scale farmers face the loss and degradation of natural resources (Yumbya *et al.*, 2011). Improving cropland management is a key to increase crop productivity without further degrading of soil and water resources (Branca *et al.*, 2011). At the same time, sustainable agriculture has the potential to deliver co benefits in the form of reduced greenhouse gases emissions while increasing carbon sequestration, that contribute to climate change mitigation and adaptation (FAO 2010c, Branca *et al., 2011*).

Agriculture in Ethiopia contributes about 55 % of the GDP and employs 80% of the population and 90% of the export (Befekadu and Birahnu, 2000). Much of Ethiopia's agriculture is rain fed and food deficit and famines frequently occur because of erratic rainfall and drought (Woldeamlak, 2009). Rain fed agriculture accounts for more than 95% of farmed land in sub-Saharan Africa (https://en.wikipedia.org/wiki/Rainfed_agriculture) about 41% of the Sub-Saharan Africa farming land is in the semi-arid region, which indicates that rain fed agriculture is the main source of crop production for the increasing populations in this region. However, rainfall is poorly distributed and high losses occur due to high surface runoff, poor crop rooting conditions, past and present soil erosion and evaporation losses from soil and crop canopy (Rockström, 2003).

Integrated soil, water and crop management practices should be addressed simultaneously in order to reduce runoff and soil erosion associated nutrient losses, increase water infiltration, and nutrient availability for crop production in this marginal regions.

Repeated tillage accelerates SOM decomposition (Doran and Smith,1987) and water runoff and soil erosion (Derpsch *et al.*, 1991), and other manifestations of physical, chemical and biological soil degradation (Kerte *et al.*, 2008), and it has been reported to be the main cause of land degradation in Ethiopia (Tefera, 2002).

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Dry land areas in Ethiopia have been also suffering with moisture stress and erratic rainfall (Temesgen *et al*., 2009, Rockstrom, 1999) that also contributes highly to failure of crops and land degradation. These all practices and challenges over time, cause a decline in soil fertility and overall productivity resulting from deterioration of soils' physical, chemical, and biological properties and there is a considerable risk of crop failure. Many research works indicate that repeated ploughing of layers accelerates organic matter decomposition and nutrient leaching and therefore it become difficult to conserve soil fertility.

The challenges posed by climate change to agriculture and food security require a holistic and strategic approach to linking knowledge with action. Among the solutions, being floated to mitigate the impact of climate change is adapting to droughts through sustainable farming methods. Conservation farming CF practices hold the promise of providing both a strategy for mitigating climate change and working as an adaptive mechanism to cope with climate change. CF is being promoted as a panacea to the production challenges, confronting rural smallholder families particularly in Sub-Saharan Africa.As an important technology, conservation farming (CF) is mainly to keep the soil covered (>30% residue), to have minimal soil disturbance (reduction in tillage) and to mix and rotate crops as well as local in-situ soil and water conservation practices (Bradford and Peterson, 2000; Verhulst*et al*., 2010; Rockstrom *et al*., 2003).

It maintains a cover of vegetation or mulch on the surface, raises the organic matter content of the soil, improving fertility (Desale, 2014),reducing the amount of CO_2 that is produced and protects the soil from erosion and leads to positive changes in the physical, chemical and biological properties of a soil (Bescanca *et al*., 2006). In CF, crops are grown using conservation tillage and legumes are included in rotation/intercropping with other crops which help to fix nitrogen, improve fertility of the soil, increase crop yields and provide protein intake for the family. Conservation farming practices emphasize maximum use of available water resources through early and timely planting, soil protection through organically fertilizing ground-cover plants (Simbarashe, *et al*., 2010). This reduces long-term dependency on external inputs, enhances environmental management, and improves water quality and water use efficienc. Reduced tillage leads to lessened human inputs, in both time and effort (Dumansky *et al*, 2006), Thus, to attain an integrated cropping systems for sustainable crop, water and soil productivity and then improve natural resource management and climate change adaptation in drylands of Tigray region, application of holistic approach is paramount important.

Therefore, the adoption of sorghum-legume cropping integration associated with water harvesting techniques as conservation farming practices in the dry land areas of Tigray mainly aims Increase soil fertility productivity and ensured food security.

MATERIALS AND METHODS

The study area

The study was conducted at Raya Azobo (Genetie and Tsigea districts) & Raya Alamata (Tao and Garjalle districts) woredas Tigray, Ethiopia (Table 1).

A semi-arid type of climate characterizes the study districts receiving highly variable rainfall. The study areas receive annual average rainfall between 250 and 700 mm. In the study areas, land preparation is done using traditional oxen drawn implement 'Maresha'. The major crops grown in the area are Sorghum (*Sorghum bicolor L.*), Maize (*Zea mays* L.) and Teff (*Eragrostistef*).

Soil sampling and analysis

Soil samples were taken before planting and analyzed for texture, organic carbon, cation exchange capacity (CEC), pH, total nitrogen and available phosphorus using standard methods of physico-chemical analysis.

Experimental design and procedure

The study was conducted both on station (with full set of treatment) and on farmers (selected treatments) field. For each test crop in each location, a set of treatments (a single replication of the treatments) planted on an individual farmer's plot where farmers considered as a replication. Farmer planted a full set of experiment, replicated three times, at Tao FTC (on-station) serve as a researcher managed trial for comparison against the experimentation.

The plot sizes were $100m^2$ for both on station and on farm trials. The varieties used for on farm experiment were long maturing local cultivar (180-210 days) 'Abaere' ,Medium Maturing local cultivar 'Kodem' which were planted at April, and early maturing improved Grana-1 variety (100-120 day) which were planted at July.

For the control plots tillage was done as per the farmers practice by farmers' equipment 'Maresha' with no mulching and moisture conservation practice while the conservation plots (basins) were mulched with locally available weeds and 30% residue left after harvest.

Sorghum seeds were planted at 15cm plant spacing and then five plants were maintained per basin after thinning. NPS and urea fertilizers were applied at a rate of 100 kg ha^{-1} and 50 kg ha^{-1}, respectively. The full dose of NPS was applied at the time of planting while urea was applied in splits, 33 kg ha^{-1} at planting and 67 kg ha^{-1} at knee height stage of growth of the plant. Seed rates of 30 kg ha^{-1} legumes were used at spacing of 15cm between plants. The seeding rate for sorghum was 12 kg ha^{-1}. 100% of sorghum plant population and 50% of the legume plant population was used for intercropping.

Table 1 : Geographical location of the study sites

Location (District)	Latitude (N)	Longitude (E)	Altitude *m.a.s.l.*
Raya Alamata (Tao)	12º30'01"	39º38'52"	1560-1615
Raya Alamata (Garjalle)	12° 23' 03"	39° 34' 01"	1585-1600
Raya Azobo (Genetie)	12° 46' 36"	39° 37' 31"	1567-1595
Raya Azobo (Tsigea)	12° 47'59"	39° 38' 38"	1574-1640

Table 2: Treatments used in the experimentation

S/N	Farming system
1	Plating basin with fertilizer
2	Planting basin with fertilizer and farmyard manure
3	Planting basin with farmyard manure
4	Planting basin+ cow pea intercropping with fertilizer
5	Planting basin+ cow pea intercropping without fertilizer
6	Planting basin without fertilizer
7	Conventional (sorghum)
8	Conventional (cow pea)

Variety: Sorghum (Grana 1) and cow pea (black eye).

Data collection and statistical analysis

The Analysis of variance on the agronomic traits was computed using the GLM procedure of SAS version 9.2 (SAS, 2000) software following the standard procedures of ANOVA for randomized complete block design (Montgomery, 1991) for the full set of treatments. The differences among farming practices were considered significant if the P-values were ≤ 0.05 and Leas Significance Difference (LSD) was used to compare among farming systems. For the demonstration trials, analysis was done using descriptive analysis.

RESULTS AND DISCUSSION

On station trial

Soil pysico-chemical properties

Soils in the study area are dominantly clay loam in texture and vary from neutral to slightly basic (pH=6.5-7.73). The soil organic carbon contents, phosphorus and total nitrogen was low, indicating the low fertility status of the soil aggravated by continuous cereal based cultivation, lack of incorporation of organic materials in to the soils through mulching or crop residues and frequent tillage.

The Total Nitrogen content in the areas ranges from 0.064 to 0.4 %. It has been reported that soil total N (%) > 0.300, 0.226-0.300, 0.126-0.225, 0.050-0.125 and < 0.050 are characterized as very high, high, medium, low and very low, respectively, and total C (%) of greater than 3.50, 2.51-3.5, 1.26-2.50, 0.60-1.25 and < 0.60 as very high, high, medium, low and very low, respectively as per the classification of and Tekalign *et al*. (1991).

Effect of integrated cropping and moisture harvesting practice grain yield of sorghum

Planting of sorghum seedling at basin supported with fertilizer and farmyard manure gave mean grain yield of 4.6 (+61.4% than conventional) and 4.1 t ha-1 (43.7% than conventional) respectively on the researcher managed onsation trial and 3.57 t ha^{-1} (+19.79% than conventional tillage method) on the farmers managed plot. These treatments gave consistence grain yield over the variable two cropping seasons (table 4).

Sorghum/cow pea intercropping in basin tillage in the sorghum/cow pea intercropping supported by fertilizer gave mean sorghum and cowpea grain yield of 3.8 and 1.1 t ha^{-1} respectively. The intercropped cowpea have great role in soil nutrient replacement and source of protein in the low land south Tigray. Research findings Ethiopian dry lands showed that conservation farming can reduce soil erosion and runoff (Oicha *et al*., 2010), increase crop yields (Mesfin *et al*., 2005; Burayu *et al*., 2006; Temesgen *et al*., 2009), soil organic matter, and mineral nutrients (Burayu *et al*., 2006). The lowest grain yield (2.86 t ha^{-1}) was obtained from conventional tillage (four times tillage, no moisture harvesting, no mulching and drilling fertilizer application) method ,which indicate that the importance of integrated cropping and moisture harvesting system for boosting agricultural production in the marginal areas of Tigray, Ethiopia. The overall crop performance was generally worst for conventional tillage this might be due to no organic matter residue incorporation, frequent tillage practice that also facilitates soil erosion and nutrient depletion and soil moisture loss. Reduced tillage in integrated with mulching in fact increase water availability to plants improving the capacity of the soil surface to intercept rainfall, reducing direct evaporation and increasing water storage (Scopel *et al*. 2001).

The conservation farming package components includes dry-season land preparation using minimum tillage methods (basins), crop residue retention, and nitrogen-fixing intercropping. These practices aim to improve soil structure and water retention and reduce the need for chemical fertilizers while at the same time increasing crop yield. In line to this study Hine and Pretty (2008) reported that increased in maize yields (+34%) and soya (+11%) in Argentina. other research result indicated that the major reasons for the increase in yields were better moisture availability, improved soil fertility and better root growth as a result of conservation tillage application (Belay, 1998, Lal, 2000, Temesgen*et al*., 2008). Similar findings on deep ripping and sub-soiling techniques also resulted in 60% yield increments (Temesgen*et al*., 2009). In drier environments, practices that allow plants to make better use of the limited amount of water available result to be most productive. The increased crop yield in conservation plots is primarily due to rainwater harvested in planting basins. Proper water management can help capture more rainfall (Vohland & Barry 2009), making more water available to crops, and using water more efficiently (Rockstrom& Barron 2007),which are crucially important for increased agricultural production (Rockstrom *et al*. 2010). In line with this study, Giller *et al*. 2009 presents that in areas where soil moisture is a key constraint on yields, conservation agriculture can have immediate yield benefits. Conservation farming technologies are relevant, especially with the consensus on increasing year-to year variability in precipitation, due to the effects of Elli-No and climate change, which will lead to an increase in both inter- and intra-seasonal drought events and high uncertainty about the onset of the rainy seasons. Mostly crops use only 36–64% of the seasonal rainfall on average (Barron *et al*. 2003), so there is a large proportion (50%) of non-productive water flow (Nyamadzawo *et al*. 2012), wich is relevant for stable plant growth if properly managed by CF techniques.

Local farmers insight

Different, field days and group discussion were also held at different plant growth stages. The participants were then given chance to evaluate the integrated cropping and moisture harvesting system technologies hence all the respondents including non-participating farmers indicated that planting basin with conservation farming practices (supported mulching, fertilizer micro dosing, seed hydro priming, intercropping), can increase biomass yield, grain yield, soil moisture and reduce soil erosion than the conventional method of tillage. In terms of weed control, the farmers stated that more labor is required in conservation farming specially, however in conventional method of tillage as there is frequent plowing and inter-row cultivation (‘Shelshalo’) weed control is easier. Farmer’s select basin + fertilizer, basin + FYM and basin +fertilizer +FYM - first, second and third respectively, while the conventional method of tillage was least scored from all the treatments (table 6). The perception of farmers are usually very influential in policy directions and recommendations for technologies as extension officers, experts from non-governmental organizations and administrator bodies including policy makers from district, zone and region were also participating in each events, concussions and evaluation of the technologies.

Partial Budget Analysis

The costs of fertilizers, costs for preparation of basin, plowing of conventional plots, harvesting costs, weeding and costs of seeds were considered for this analysis (Table 5). The results of the partial budget analysis showed maximum net benefit of 79413.64 birr/ha (with MRR=144%) was recorded from direct planting on basin supported with mulching and fertilizer micro dosing followed by basin intercropping without fertilizer with net 78452.05birr/ha (with MRR=189%). But, the profitability and feasibility of integrated cropping and moisture harvesting under conservation farming cannot determined by its ultimate economic return per hectare with this two year period as the mulching, nodules from intercropped legumes and crop residues left had beneficial residual effects not only on crop yield but also on soil nutrient build up that can gradually reduce the use of chemical fertilizer and adapt the changing climate.

Even if the lobar demand for preparation of planting basin and weeding of CF plots were generally higher than conventional plots, preparation of planting basin using hand hoe and 3 times hand weeding in CF gave higher yield with economically optimum return. However in order for planting basin with CF to be practiced on a large area by smallholder farmers, there is also need for research on the economic feasibility of using herbicides for early season weed control.

Table 3: Soil physico-chemical properties the study districts

Nutrients	Testing sites				Critical Level
	Tao	Garjalle	Genetie	Tsigea	
Total N (%)	0.13	0.064-0.19	0.09-0.4	0.11-0.161	0.15-0.25
Av.P (Mg kg^{-1})	25.06	10.5-20.9	15.4-19.6	7.0-25.4	10–17
OM (%)	1.83	1.15-2.10	2.2-3.39	1.68-3.03	1.70–3.00
EC (ms/cm)	0.19	0.08-0.20	0.12-0.28	0.05-0.24	<2 non saline
CEC (cmol kg^{-1})	47.50	39.8-45.12	7.4-23.4	7.0-25.4	12-25
Ph (H_20)	7.39	6.9-7.73	6.8-7.5	6.5-7.55	
Na (cmol kg^{-1})	0.13	0.11-0.16	0.12-0.17	0.12-0.14	0.3–0.7
Mg (cmol kg^{-1})	2.60	4.6-4.9	2.6-5.2	1.60-2.80	1–3
Ca (cmol kg^{-1})	4.40	4.0.8-5.8	4.2-5.8	3.40-5.20	5–10
K (cmol kg^{-1})	0.59	0.52-0.61	0.65-0.73	0.61-0.72	0.3–0.7

Source for critical level: Metson (1961). & Tekalign (1991).

Table 4 : Effect of Integrated cropping and moisture harvesting system (ICMHS) on grain yield (t ha-1) of sorghum and cow pea

S/N	Treatment	Grain yield (t ha-1)		
		2016	2017	Mean
1	Basin with fertilizer	4.68	4.54	4.61
2	Basin with farmyard manure	4.08	4.13	4.105
3	Basin+ fertilizer + farmyard manure	3.94	3.84	3.89
4	Basin+ cow pea intercropping with fertilizer	3.72	3.84	3.78
5	Basin+ cow pea intercropping without fertilizer	3.60	3.47	3.53
6	Basin without fertilizer	3.55	3.44	3.495
7	Conventional (sole Sorghum)	2.81	2.90	2.855
8	Conventional (sole cow pea)	0.94	3.05	1.995
	CV (%)	23.1	19.2	
	LSD (5%)	1.3	1.23	

Table 5: Partial budget analysis.

Tillage practice	TVC (ETB/ha)	GY (t ha-1)	GBGY (ETB/ha)	BY (t/a)	GBBY (ETB/ha)	TGB (ETB/ha)	NB (ETB/ha)	MRR (ratio)
Sole cow pea	5010	1.995	23072	9.07	39468	62540.5	57530.53	
Basin without fertilizer	5800	3.495	40420	10.28	37857	78276.7	72476.69	18.9
Basin+IC without fertilizer	6215	3.53	40824	11.39	43843	84667.1	78452.05	14.4
Basin +FYM	6660	4.105	47474	9.77	31632	79106.3	72446.28	D
Conventional	7660	2.855	33018	10.19	40965	73983.2	66323.25	D
Basin with fertilizer	8000	4.61	53315	10.72	34099	87413.6	79413.64	38.5
Basinr+IC with fertilizer	8494	3.78	43716	9.00	29128	72843.3	64349.3	D
Basin +FYM +fertilizer	8710	3.89	44988	9.49	31236	76223.6	67513.6	14.6

Where: TVC= Total variable costs (tillage, seed, fertilizer, weeding and harvesting), ETB is Ethiopian birr (1USD=27ETB), GY=grain yield, BY=biomass yield, GBGY =gross benefit from grain yield , GBBY= gross benefit from biomass yield, TGB=total gross benefit, NB =net benefit and MRR=Marginal rate of return, D=dominance, labor cost (80 birr/day/man), plowing cost (300 birr/day), seed rate (sorghum =12 kgha^{-1} and cow pea =30kg ha^{-1}).

Table 6 : Panelist (n=49) ranking of the treatments

S/N	Treatment	Preference rank
1	Basin with fertilizer	1
2	Basin with farmyard manure	2
3	Basin+ fertilizer + farmyard manure	3
4	Basin+ cow pea intercropping with fertilizer	4
5	Basin+ cow pea intercropping without fertilizer	6
6	Basin without fertilizer	5
7	Conventional (Sorghum)	7
8	Conventional (cow pea)	

On farm trial

On farm demonstration of selected integrated cropping and moisture, harvesting practices were conducted on 35 farmers' field at Raya Alamata (Garjalle and Tao districts) and Raya Azobo (Genetie, Tsigea, and districts) areas in 2016-2017 cropping seasons.

Basin gave more grain yield of 5.6 and 3.9 t ha^{-1} for late maturing 'Abaere' and Medium maturing 'Kodem' land races (table 7). While using early maturing variety Grana1 in basin conservation tillage it gave 2.5 t/ha. Rain fed smallholder agriculture in low rainfall area is subject to numerous constraints including low rainfall with high spatial and temporal variability, and significant loss of soil water through evaporation and erosions have limited crop production.

Conclusions and recommendations

Basin under CF component packages can further help mitigate the effects of frequent dry spells and helps to concentrate rainfall in the field at the root zone and decrease runoff and soil loss in the dry land of Tigray. Therefore, from the study the basin combined with CF packages (like, mulching, seed hydro priming, fertilizer and or FYM micro dosing, seed hydro priming, intercropping with legumes) components are recommended for the dry land areas of Tigray and other similar location of the country.

However; application of integrated cropping and moisture harvesting system in conservation farms where free grazing is highly practiced, and fire wood demand of sorghum stalk, maintaining 30 -50 % crop residue left was found difficult and treat in Tigray to scale up and disseminate good practices of conservation farming.

Therefore, pilot scaling of integrated cropping and moisture harvesting system in watershed level can mitigate the treat, however for sustainable use of integrated cropping and moisture harvesting system combined with conservation technologies, changing the mindsets of farming communities who have been farming using conventional agriculture (especially free grazing, frequent tillage, and residue managements) for many years need to be addressed to further increase the sustainable uptake of conservation tillage and consequently its impact on food security and climate. Hence, it is believed that the two year research project on integrated cropping and moisture harvesting system has contribute a lot and continue to influence the policy towards including the integrated cropping and moisture harvesting system best results in the regional strategy, working manuals as well as working towards the free grazing issues, but further detailed study and dissemination period is required for transformation from locally to climate smart technologies.

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