Effect of Moisture Conservation Practices and Soil Fertility Management on Yield of Sorghum (*Sorghum bicolor L. Moench*) in the Moisture Deficit Areas of Tigray, Northern Ethiopia

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Abstract

Study to investigate agronomic and economic effect of planting basins was conducted at Raya Alamata districts of Tigray, northern Ethiopia in 2016 and 2017 cropping season. Included treatments were; planting basin with fertilizer, planting basin without fertilizer, planting basin with farmyard manure, planting basin with fertilizer and farmyard manure, planting basin with fertilizer and cowpea intercropping , planting basin without fertilizer under cowpea intercropping , conventional/farmers practice planted sole sorghum and cowpea laid down in a randomized complete block design with three replications. Analysis of variance for grain yield showed significantly (P<0.05) more variation among the farming practices considered in the study. Higher grain yield of 4.61 and 4.0 tha^{-1} with more optimum economic returns were obtained from planting basin moisture conservation practice with fertilizer and planting basin with farmyard manure, respectively. While the lowest mean Sorghum grain yield of 2.86 t ha^{-1} was recorded in the conventional planting. The farmers have select planting basins with fertilizer, planting basin with farmyard manure and planting basin with farmyard and fertilizer 1st, 2nd and 3rd respectively based on over all crop performance. Planting basin practices outperforms their conventional farming counterparts. Consequently, planting basin moisture conservation practices can enhance Sorghum yield by increasing soil moisture holding in the crop growth period. Therefore, planting basin is recommended for sorghum production in the study areas even though its efficiency should be validated through different agro ecologies, soil types and climatic conditions for a comprehensive recommendation.

Keywords: Moisture, Sorghum, basin, fertilizer, yield

Introduction

Agriculture in Ethiopia contributes about 45% of the GDP and employs 80% of the population and 90% of the foreign exchange and 70% of the country's raw materials for industries (AEO, 2011; Tesfahunegn, 2016). Much of Ethiopia's agriculture is rainfed and food deficit and famines frequently occur because of erratic rainfall and associated droughts (Woldeamlak, 2009, Pankhurst and Johnson, 1988). About 80% of

Ethiopia's population is involved in rainfed agriculture and about 60% of the Ethiopian farming land is in the arid and semi-arid region, which indicates that rainfed agriculture is the main source of crop production for the increasing human populations in the country. However, rainfed agriculture without moisture conservation practice and efficient nutrient application is not coping for unreliable rainfall and recurrent droughts that leads to subsequent production failures. 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 coupled with complete removal of crop residues at harvest for fuel and livestock feed, and aftermath over grazing and little adoption of moisture conservation practices are the contributors for soil degradation and decline of productivity and production in the semi-arid Ethiopia (Girma, 2001; Bezuayehu *et al*., 2002 Temesgen *et al*., 2008 ;Araya *et al*., 2012). These areas have been also suffering with moisture stress and unreliable rainfall (Temesgen *et al*., 2007; Rockstrom, 1999) that also contributes highly to failure of crops and land degradation. Rainfall variability has caused significant problems on the economy and food production (Bewket and Conway, 2007).

Addressing the aforementioned challenges and issues is a pre-requisite to adapt the changing climate and ensure food security in dry lands as a whole. Moisture conservation techniques like basin and tie ridging supported with fertilizer application gave promising results in both crop production and soil fertility enhancement (Assefa *et al*., 2015). Planting basins help to concentrate rainfall in the field at the root zone and decrease runoff and soil loss. Planting basin practices provide encouraging results when combined with fertility improvements, such as microdosing with N from organic and/or inorganic sources or with mulching.

Developing of sustainable sorghum-legume cropping system supported with moisture conservation techniques like planting basin can be promoted at small-scale farm level. The system integrated, minimize mono cropping, reduce long period and frequent plowing and encourage efficient crop, reduces soil fertility degradation and moisture stress. The system also breaks disease and pest cycles. Likewise, the introduction of improved varieties of legume crops may also have an impact on the existing crop biodiversity and human nutrition, as farmers may only opt for limited improved varieties of crops. Therefore, the impact of introduction of improved varieties on crop biodiversity should also be given due emphasis (Meles *et al*., 2009). Adoption of the culture of sorghum – legume cropping integration would also enable farmers benefit from improved crop yields and other associated economic gains and contribute for the sustainable management of natural resources. Therefore, the adoption of planting basin as moisture conservation farming practices integrated with fertilizer management practices in the dry land areas of Tigray mainly aims increase soil fertility, crop and water productivity.

Hence, the aim of this research was to investigate agronomic and economic effect of planting basin moisture conservation technologies and fertilizer managements on sorghum yields in Raya Alamata districts of south Tigray, Ethiopia.

Materials and Methods

Description of the study area

The study was conducted in low rainfall areas of Raya Alamata, Tao district (which is located on 39° 38' 52" E longitude and 12°30'01"N latitude and having an elevation ranges from 1560 to 1615 m.a.s.l.) districts of southern Tigray, northern Ethiopia from 2016-2017 main cropping season. A semi-arid type of climate characterizes the study area receiving highly variable rainfall. Rain-fed farming is the dominant in the study area even though; spate irrigation is commonly practices when available. The rainfall characteristic in the study area is bimodal, with a short rainy season from February-March (locally known as ‘belg’) and the main rainy season from June-September known as locally known ‘kiremt’) , but potential evapotranspiration is high and exceeds rainfall amount most of the year. The study area receives annual long-term (1997-2017) mean annual rainfall of 684 mm. The study area has also received annual rainfall of 299.4 and 537.2 mm in 2016 and 2017. The mean minimum and maximum annual temperatures of the study area are 17 °C and 26 °C, respectively. The major crops grown under a rainfed conditions are Sorghum (*Sorghum bicolor*), Maize (*Zea mays* L.) and Tef (*Eragrostis tef* Zucca).

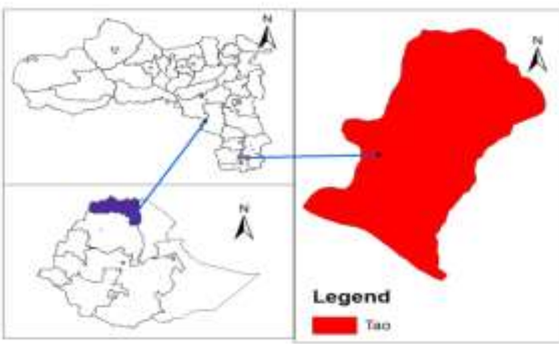

Figure 1 : Geographic map of the study area

Soil sampling and analysis

Five composite disturbed soil samples were collected randomly at the 0–20 cm soil depth from the entire experimental site before imposing any treatment at the beginning of the research period in 2016. The disturbed soil samples were pooled and mixed thoroughly in a basket and a subsample of 500 g was taken for analysis following a standard procedure for soil sampling and sample preparation (Andreas & Berndt-Micheal 2005*)*. The samples were air-dried, passed through 2mm sieve and analyzed for texture, organic matter, cation exchange capacity, pH, total nitrogen and available phosphorus using standard methods of physico-chemical analysis. Soil texture was analyzed using the hydrometer method (Bouyoucos, 1951). Soil organic matter content was determined by oxidation of organic carbon with acidic potassium di-chromate by the Walkley and Black method (Jacson, 1967). Total nitrogen was analyzed by Micro-Kjeldhal method (Bremner, *et al.,* 1982). Soil pH was determined in 1:2.5 (weight/volume) soils to water dilution ratio using pH meter (Jackson, 1967). CEC was measured after saturating the soil with 1N ammonium acetate (NH_4OAC) and displacing it with 1N NaOAC (Chapman, 1965) whereas Av.p was determined using Olsen method (Olsen *et al*., 1982).

Experimental design, treatments and procedure

The treatments were laid out in a randomized complete block design (replicated three times). The plot sizes for each treatment were 10m x 10m. Planting basins are small pits in the ground used for planting many types of crops used to reserve moisture. The planting basins with dimensions of 0.75 m (length) x 0.20 m (width) x 0.25 m (depth) were dug using hand hoes at an inter row spacing of 0.75 m and intra-row spacing of 0.1m.

For the farmers practice/conventional plots, plowing was done as per the farmers practice by farmers' equipment locally known 'Maresha' with no moisture conservation practice.

The seed of sorghum was planted at 3-5 cm depth and 15cm plant spacing and then five plants were maintained per basin after thinning. Fertilizer was applied according to the requirements of each test crop in each respective site as micro dosing. NPS (19%N +38% P_2O_5 + 7% S) and urea (46%N) fertilizers were applied at a rate of 5.62 g basin^{-1}. Well-decomposed farmyard manure was applied at a rate of 450g basin^{-1}. The full dose of NPS fertilizer and farmyard manure 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} cowpea were used at spacing of 15cm between plants. The seeding rate for sorghum was 12 kg ha^{-1}. All of sorghum plant population and 50% of the legume plant population was used for intercropping treatments.

Table 1: Treatments used in the experimentation

Farming system	Fertilizer rate
Planting basin with fertilizer	5.62 g NPS/basin
Planting basin with fertilizer and farmyard manure	5.62 g NPS + 450g FYM / basin
Planting basin with farmyard manure	450 g FYM/basin
Plating basin with fertilizer and cowpea intercropping	5.62 g NPS/ha
Planting basin without fertilizer with cowpea intercropping	
Planting basin without fertilizer	
Conventional (sorghum)	100 NPS+100 kg urea /ha
Conventional (cowpea)	50kg NPS kg /ha

Key: FYM is farmyard manure

Data collection

Grain yield, percent deviation, farmers perception were determined. For determination of grain yield (g $plot^{-1}$) was taken from each plot by excluding the border rows, adjusted to 12.5% moisture level, and then converted to hectare basis.

Partial budget analysis

Grain and biomass yield data for the organic and inorganic fertilizers effects, costs for basin preparation and costs for fertilizer application were subjected to economic analysis, using the CIMMYT (1988) partial budget techniques to evaluate the economic profitability of planting basins and fertilizer management's practices.

Total revenue was calculated based on grain yield and biomass yield and grain and biomass prices obtained from the local market. Local market grain and straw yield prices for Sorghum were 15.41 and 2.9 ETB kg^{-1}, respectively. Local market grain and straw yield prices for Cowpea were 21.22 and 2.7 ETB kg^{-1}, respectively. Total variable cost was estimated from labor and input cost. Labor cost was estimated from labor incurred for seedbed preparation, planting, fertilization, mulching, weeding, harvesting and threshing. Input cost was determined from the cost of fertilizers (NPS, manure and urea) and seeds (sorghum and cowpea). Local market NPS and urea prices per kilogram were 1.05 and 0.95 ETB respectively. Labor cost (for fertilization application and basin making) was estimated at 80 ETB/person/day was recorded.

Statistical analysis

The analysis of variance on the agronomic traits was computed using the GLM procedure of SAS (SAS, 2008) software following the standard procedures of ANOVA for randomized complete block design (Montgomery, 1991). The differences among treatments were considered significant if the P-values were at ≤ 0.05 probability level and leas significance difference was used to for mean comparisons.

Result and Discussion

Soil physical and chemical properties of the study site

Soils in the study area are dominantly clay loam in texture and slightly alkaline (pH=7.73), low in soil organic matter (1.83%), low in total nitrogen content (0.13%) and low in phosphorus content (25mg/kg of soil). 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. It has been reported that soil total nitrogen content (%) > 0.3, 0.226-0.3, 0.126-0.225, 0.050-0.125 and < 0.05 are characterized as very high, high, medium, low and very low, respectively, and total organic carbon (%) > 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 and available phosphorus (mg kg^{-1}) >4.6, 4.1-4.6, 2-4.1, 1.5-2 and <1.5% , respectively as very high, high, sub-optimal, low and very low as per the classification of EthioSIS (2014).

Table 2: Soil physical and chemical properties the study site

Soil physical and chemical properties	Values
pH(1:2.5 H2O)	7.39
Available P (mg /kg soil)	25.06
Total N (%)	0.13
Soil organic carbon (%)	1.83
Electrical conductivity(ds/m)	0.19
CEC (cmol(+)/kg of soil)	47.5
Exch k^+(cmol(+)/kg of soil)	0.59
Exch Na^+(cmol(+)/kg of soil)	0.13
Exch Ca^{2+}(cmol(+)/kg of soil)	4.40
Exch Mg^{+2}(cmol(+)/kg of soil)	2.60
Textural class	Clay loam

Effect planting basin moisture conservation farming practice on Sorghum grain yield

Table 4 represents the effects of planting basin and conservation farming technologies on grain yield of the test crops grown in 2016 and 2017 at Raya Alamata. In 2016 and 2017, the use of planting basin associated with fertilizer (either organic, inorganic or both organic and inorganic) significantly (P<0.05) increase sorghum yield.

Direct planting of sorghum seeds at planting basin supported with micro dosing of chemical fertilizer and farmyard manure gave mean grain yield of 4.61 (61.4% over the conventional) and 4.1 t ha^{-1} (43.7% over the conventional), respectively. These treatments gave consistence grain yield over the variable two cropping seasons. Planting basin in the sorghum/cowpea intercropping supported by fertilizer micro dosing also gave mean sorghum and cowpea grain yield of 3.78 and 1.09 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 from Ethiopian drylands 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). This research result is in agreement with the previous findings of Tekle and Wedajo (2015) which indicate that Sorghum grain and biomass yield advantages of 55.72% and 38.55%, respectively were obtained from tied ridge moisture conservation over the farmers' practice at southern Ethiopia.

The lowest grain yield (2.86 t ha^{-1}) was obtained from farmers practice (4 times tillage, fertilizer broadcasting, no moisture harvesting and fertilizer broad casting) method, which indicates that, the importance of fertilizer managements and moisture harvesting system for boosting agricultural production in the marginal areas of Tigray, Ethiopia.

The moisture conservation practice in the semi-arid regions of Ethiopia includes dry-season land preparation like hand hoe basins, precision input application and rotations/intercropping nitrogen-fixing crop. 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 grain yields (+34% over the farmers practice) in Argentina. The major reasons for maize yields increments were better moisture availability and improved soil fertility (Belay, 1998, Lal, 2000, Temesgen *et al*., 2008). Similar findings on sub-soiling/rippering 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). This result is in agreement with the earlier research results of Heluf and Yohannes (2002), reported that tied ridge moisture conservation, has resulted yield increments of 15 to 50% on maize and they also stated that yield increment of 15 to 38% was recorded for sorghum on different soil types of eastern Ethiopia. In areas where soil moisture is a major constraint on yields, conservation agriculture can have immediate yield benefits (Giller *et al*. 2009). Planting basin offers the promise of a locally adapted, low-external-input agricultural strategy that can be adopted by resource-constrained farming communities and female farmers.

Table 3: Effect of planting basin conservation farming on grain yield of sorghum and cowpea

Treatment	Grain yield (t ha^{-1})		
	2016	2017	Mean
Planting basin with fertilizer	4.68	4.54	4.61
Planting basin with farmyard manure	4.08	4.13	4.11
Planting basin with fertilizer and farmyard manure	3.94	3.84	3.89
Planting basin with fertilizer and cowpea intercropping	3.72 (1.09)	3.84 (1.1)	3.78 (1.07)
Planting basin with cowpea intercropping without fertilizer	3.60 (0.98)	3.47 (1.0)	3.53 (0.99)
Planting basin without fertilizer	3.55	3.44	3.50
Conventional (sole Sorghum)	2.81	2.90	2.86
Conventional (sole cowpea)	0.94	3.05	2.00
CV (%)	5.4	6.6	6.0
LSD (5%)	0.36	0.45	0.26

Key: figures in parenthesis are the grain yields for cowpea

In addition to the sorghum grain yields, 1.09 t ha^{-1} cowpea grain yields was attained from the intercropping, in addition to long term enhancement soil organic matter and nitrogen content, and protect soil form exposing to sun light role of the legume. Legumes have great role in enhancing inputs of nitrogen through nitrogen-fixing plants is key in maximizing production and ensuring long-term sustainability of agricultural systems (Fageria, 2007). Inter cropping of maize with haricot bean followed by application of NPS significantly increased biomass, grain yield and kernel weight of maize (Erkossa *et al*, 2018).

Local farmers' insight

As part of participatory study of planting basin moisture conservation practices, different group discussions were also held at different plant growth stages. The participant farmers and experts were then given chance to evaluate the basin technologies based on their own selection criteria, hence all the respondents indicated that planting basin moisture conservation practices (supported with organic or inorganic fertilizer, intercropping), can increase biomass yield, grain yield, soil moisture and reduce soil erosion than the farmers practices /conventional method of tillage. In terms of weed control, the farmers stated that more labor is required in planting basin preparation, however in conventional method of tillage as there is frequent plowing and inter-row cultivation ('Shelshalo') weed control is easier (Table 5). Based on the overall performance of the test crop, farmers select basin + fertilizer; basin + farmyard manure and basin +fertilizer + farmyard manure as first, second and third respectively, while the conventional method of tillage was least scored from all the treatments (Table 4). 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.

Table 4: Panelist (n=49) ranking of the treatments

Treatment	Total score	Preference rank
Planting basin with fertilizer	7	1
Planting basin with farmyard manure	6	2
Planting basin with fertilizer and farmyard manure	5	3
Planting basin with fertilizer & cowpea intercropping	4	4
Planting basin with cowpea intercropping without fertilizer	3	5
Planting basin without fertilizer	2	6
Conventional tillage	1	7

Where: In the preference rank, 1 is the highest score and 7, the lowest score

Table 5: Farmers comparative evaluation planting basin & conventional tillage

Contribution of planting basin	Farmers response (n=49)	
	Agree (%)	Dis agree (%)
Enhance soil fertility and soil health	75	25
Conserve soil moisture	100	0
Reduce soil erosion	100	0
Save labor cost	30	70
Decrease weed problem	0	100
Increase yield and biomass	100	0

Partial budget analysis

The costs of fertilizers (organic or inorganic) and costs for preparation of basin were considered for this analysis (Table 7). The results of the partial budget analysis showed maximum net benefit of 79413.64 ETB ha^{-1} (with MRR=38.5) was recorded from direct planting on basin supported with and fertilizer micro dosing.

Table 6: Partial budget analysis

Treatment	TVC	GY	Ad GY	SY	TGR	NR	MRR (%)
Conventional (sole cow pea)	5010	2.00	1.8	9.07	62540.5	57530.5	
Planting basin without fertilizer	5800	3.50	3.2	10.28	78276.7	72476.7	1891.9
Planting basin + intercropping without fertilizer	6215	3.53	3.2	11.39	84667.0	78452.0	1439.8
Planting basin with farmyard manure	6660	4.11	3.7	9.77	79106.3	72446.3	D
Conventional (sole sorghum)	7660	2.86	2.6	10.19	73983.2	66323.2	D
Planting basin with fertilizer	8000	4.61	4.1	10.72	87413.6	79413.6	3850.1
Planting basin with fertilizer & intercropping	8494	3.78	3.4	9.00	72843.3	64349.3	D
Planting basin with farmyard manure & fertilizer	8710	3.89	3.5	9.49	76223.6	67513.6	1465.0

Keys: ETB is Ethiopian birr, TVC= Total variable costs (ETB ha^{-1}), GY=grain yield t ha^{-1}), Ad. GY= Adjusted grain yield, SY=Straw yield t ha^{-1}, TGR=Total gross return (ETB ha^{-1}), NR =net return (ETB ha^{-1}) and MRR=marginal rate of return, D=dominance

Conclusions and Recommendations

From the present study, the results of analysis of variance showed planting basin with fertilizer had brought a significant yield enhanced over the other practices in overall and the famers' practice/conventional in specific. Higher Sorghum grain yield of 4.61 t ha^{-1}) with more economic return (79,413.6 ETB ha^{-1}) was obtained from planting basin moisture conservation with fertilizer. The farmers have select planting basins with fertilizer, planting basin with farmyard manure and planting basin with farmyard and fertilizer 1st, 2nd and 3rd respectively based on over all crop performance. Planting basins technologies integrated with fertilizer and or farmyard manure micro dosing/localized fertilizer application are recommended for the moisture deficit areas of Tigray and other similar location of the Ethiopia.

Hence it is believed that the two year research result on evaluating planting basin moisture conservation and fertilizer management practices has contribute lots and continue to influence the policy towards the moisture conservation best results in the regional strategy. However further detailed study on different agro-ecology, soil and climate conditions is essential to obtain all-inclusive view of the moisture conservation and fertilizer management practices.

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