Micro-basin technology in Ethiopia – is it worth the effort?

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Abstract
Micro-basin technologies such as tied-ridge tillage have been proposed as a means to lessen effects of high rainfall variability on crop yields. Relationships between three seasonal climate variables and maize/sorghum yields and two tillage systems were examined for a semi-arid environment in the Central Rift Valley of Ethiopia. The average yield (pooled data) was significantly higher with tied-ridge tillage compared to traditional tillage (3099 vs. 2669 kg/ha). The number of dry spells was the most important predictor for crop yield in either tillage system while total seasonal rainfall was the weakest predictor. The linear yield response to the climate variables was the same in either tillage system: yields increased by 1.85 kg/ha per mm rainfall, and decreased by 81 kg/ha for each dry spell and by 216 kg/ha for each additional dry spell event ≥ 7 days. Thus, there was no differential performance of tillage systems depending on seasonal conditions. Overall, tied-ridge tillage could be a means to improve productivity in the study environment if management-related system constraints (e.g. nutrient supply, residue management) are adequately addressed.

Key Words
Tied-ridge tillage, rainfall variability, maize, sorghum.

Introduction
Dryland agriculture in Ethiopia is highly affected by production risks associated with variable rainfall. Most of the land in small-holder farming systems is devoted to cereals, primarily sorghum and maize. Intense rainfall events before and after planting often result in high runoff from the field. Reducing such unproductive water-losses can be an important step for increasing crop yields and hence agricultural productivity. A relatively easy and cheap way for small-holder farmers is the use of *in-situ* water-harvesting techniques such as tied-ridge tillage to conserve rainfall.

Tied-ridge tillage is a form of micro-basin technology that has been also called boxed-ridging, furrow-diking, and basin listing (Jones & Clark 1987; Krishna 1989; Jones & Stewart 1990). By creating micro-basins, the aim is to reduce runoff and store the rainfall in the soil for crop-use later in the season. Tied-ridge tillage consists of ridging the soil typically to heights of 20-30 cm, and establishing about 10-20 cm high cross-ties at intervals of 2 m or more depending on the slope of the land, water infiltration rate, and the expected rainfall intensity (Gusha, 2002; Brhane et al., 2006).

The technique of tied-ridge tillage has received considerable attention in the sub-humid to semi-arid tropics and sub-tropics of Africa. However, both positive and negative effects on crop productivity have been reported for various locations in Africa including in the Central Rift Valley of Ethiopia (Hulugalle, 1987; Hulugalle, 1990; Vogel, 1993; Teshome et al., 1995; Wiyo & Feyen, 1999; Gusha, 2002; Brhane et al., 2006; Mchugh et al., 2007; Mesfin et al., 2009; Mesfin et al., 2010). In addition to the mixed performance of tied-ridge tillage, higher labor cost compared to traditional tillage has discouraged farmers from adopting the practice (Wiyo & Feyen, 1999; Mmbaga & Lyamchai, 2001; Mchugh et al., 2007) although some benefits for soil conservation have been shown (Mchugh et al., 2007).

Field experiments have generally focused on the impact of tied-ridge tillage on crop yields. It has been also suggested that the efficacy of the method depends on environmental factors such as soil type and slope, and differences in the total amount and distribution of seasonal rainfall (Hulugalle, 1990; McFarland et al., 1991; Wright , 1991; Vogel, 1993; Brhane et al., 2006). Therefore, better understanding of the conditions under which tied-ridge tillage enhances crop yields is required for implementation to be successful. The objectives of this study were to evaluate effects of seasonal climate variables (total rainfall, number of dry days, and number of dry spells ≥ 7 days) on crop yields in tied-ridge and traditional tillage systems, and to assess whether there is a yield advantage with tied-ridge over traditional tillage under specific seasonal conditions as described by the climate variables.

Methods

Maize and sorghum experiments were carried out between 1983 and 2010 (Table 1) at the Melkassa Research Centre (8.43^o N, 39.31^o E; 1550 m altitude) in the Central Rift Valley of Ethiopia. The climate in the area is semi-arid and characterized by highly variable rainfall. The average growing season rainfall (June to October) is 572 mm (1977-2010) with a standard deviation of 130 mm. The rainfall distribution is mono-modal with July and August being the wettest months. The mean monthly temperature is 21^{o}C. Experiments were conducted on moderately sloping land (2-4%) with silt loam and clay loam soil types classified as Typic Haplustand (Mesfin et al., 2010). Soils are well-drained and calcareous with organic matter contents of 1-1.3%. The major soil constraint is the formation of crusts due to weak soil structure.

Analyses included 11 years of maize and seven years of sorghum yield data, and daily rainfall data of the experimental seasons (Table 1). In the traditional tillage system (TRAD), the land was plowed 2-3 times using a tractor drawn disc plow before the onset of the rainy season. With tied-ridge tillage (TR), the soil was firstly plowed and subsequently parallel ridges were formed (20-30 cm deep and 75 cm apart) by hand-hoe. Finally, the micro-basins (5-6 m length) were constructed by forming earth ties between ridge furrows. Ridges were reshaped about 2-3 times per season as required (i.e. after manual weed control, incorporation of urea, and heavy rainfall events). Fertilizer-N and -P were applied at rates of 40 kgN/ha and 20 kgP/ha, which are the standard rates recommended to farmers by extension. Residues were removed from the experimental plots after the harvest of the previous crop.

Daily rainfall data from Melkassa was used to calculate three climate variables: total seasonal rainfall (June to October), number of dry days in a season, and the number of dry spell events (Table 1). A dry day was defined as having less than two mm rainfall, and a dry spell as seven or more consecutive days with rainfall of less than two mm (Sun et al., 2007).

The statistical computations were performed in GENSTAT14. Because maize and sorghum yields were similar ($p>0.05$), the yield data were pooled. The yield data were modeled against 'tillage system' (factor levels: TRAD and TR) using the three climate variables as co-variates in an ANOVA. Relationships between yield and the climate variables were further explored in a Multiple Linear Regression (model: yield = constant + seasonal rainfall + no. dry days + no. dry spell events ≥ 7 days + tillage system).

Table 1. Climatic conditions during experimental seasons at Melkassa, and maize and sorghum yields observed under traditional (TRAD) and tied-ridge (TR) tillage (data sources: Reddy & Giorgis, 1993; Teshome et al., 1995; Mesfin et al., 2009; Mesfin et al., 2010).

Year	Jun-Oct rainfall (mm)	No. of dry days	No. of dry spell events	Maize yield (kg/ha)		Sorghum yield (kg/ha)	
				TRAD	TR	TRAD	TR
1983	462	68	5	3155	3310	-	-
1984	434	85	5	565	2160	850	2860
1985	652	80	3	3174	2660	-	-
1989	539	80	4	-	-	2950	3000
1992	592	81	3	1946	2175	-	-
1993	497	85	5	1396	1401	-	-
2001	505	79	4	2713	3229	-	-
2003	586	77	1	2653	3275	3722	3869
2005	548	79	2	-	-	3440	3130
2006	656	69	3	3589	4765	3180	2970
2007	701	74	3	3444	4695	2834	3295
2008	855	70	3	2780	4160	-	-
2010	725	85	3	3497	2748	2150	2085
Mean	596	78	3.4	2628	3143	2732	3030
Median	586	79	3	2780	3229	2950	3000
				TRAD	TR		
Pooled maize and sorghum yield (kg/ha)				2669	3099		

Results and Discussion

The average pooled maize and sorghum yield (Table 1) was significantly higher with TR compared to TRAD (3099 vs. 2669 kg/ha; LSD 397 kg/ha), and there were significant linear effects of the co-variates (i.e. the three climate variables) on yield ($p<0.001$) as revealed in the ANOVA. The Regression Analysis showed that crop yields increased by 1.85 kg/ha per mm rainfall ($p=0.058$), and decreased by 81 kg/ha for each dry day ($p<0.001$) and by 216 kg/ha for each additional dry spell event ≥ 7 days ($p=0.019$). The factor tillage system was significant at $p=0.035$ in the regression. Overall, the regression model explained 59.8% of the variance in the yield data, i.e. about 40% remained unaccounted.

Interestingly, the number of dry days/spells explained more of the yield variability than total seasonal rainfall. Growth conditions in the semi-arid environment of Melkassa are often water-limited, and the regression analysis showed that the absence of water rather than its presence had a high explanatory power for crop yield. A reason for the weak relationship of yield with 'total seasonal rainfall' is that only a portion of the rainfall is actually plant available due to asynchrony between the timing of rainfall and the crop's growth cycle, the water-holding capacity of the soil, or nutrient deficiencies – to name just a few factors.

The slopes of the linear yield response to the climate variables were somewhat, but not significantly, different between tillage systems (Fig. 1 and 2). Differences between slopes would suggest a specific advantage of one tillage system over the other depending on the rainfall characteristics prevailing at the study site (an example would be a greater yield response per mm rainfall with TR compared to TRAD). However, this could not be confirmed in this study. That is, there was only a general, additive benefit of TR for yield. Among the reasons for this could be the high unexplained variability in the yield data.

While our results showed that TR was overall a more productive system than TRAD, reasons for the mixed performance of TR could not be established using the climate variables selected for the statistical analyses presented here. Causes for this may be related to differences in the length of the growing seasons (e.g. sowing date effects), unaccounted biotic stresses, and non-adapted nutrient management. Jensen et al. (2003) found a negative yield response in maize to TR during wet seasons in cases where the fertilizer-N supplied did not meet crop demand. This might have been the case in our study where the fertilizer rate was the same irrespective of season. Other experimental limitations may have been that the location of the experiments shifted each year and that above-ground residues from previous crops were removed. Thus, any management effects on the soil which manifest themselves only after longer periods remained unaccounted for. Reddy and Giorgis (1993) showed that residue retention is an important aspect in improving soil fertility and yield in the study environment. Thus, the integration of both TR and residue retention could create synergies for soil moisture retention while improving soil biological and physical quality.

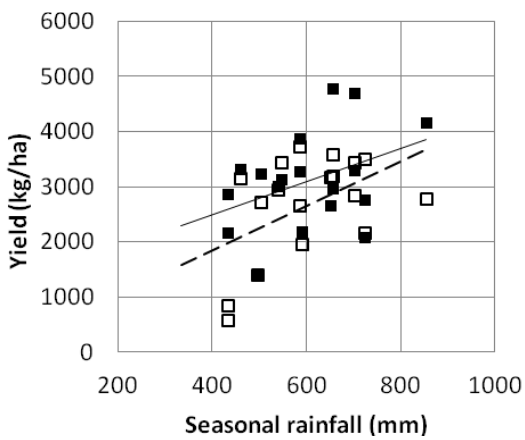

Figure 1. Relationship between yield and total seasonal rainfall for tied-ridge tillage (■, solid line) and traditional tillage (□, dashed line) at Melkassa.

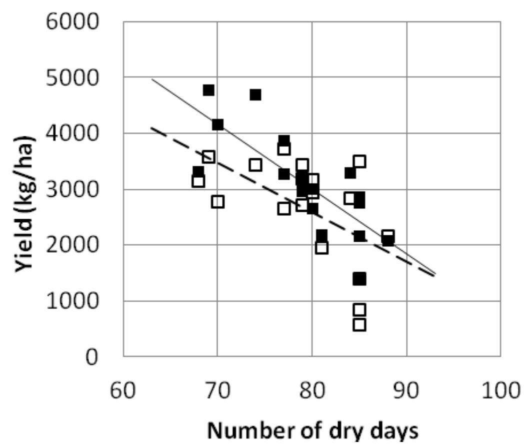

Figure 2. Relationship between yield and the number of dry days for tied-ridge tillage (■, solid line) and traditional tillage (□, dashed line) at Melkassa.

Conclusion

Tied-ridge tillage performed on average better than traditional tillage in terms of crop productivity, and this may be related to greater crop water availability with tied-ridge tillage in some seasons. However, our analyses did not establish causes for reduced crop yields as observed in some seasons with tied-ridge tillage. The yield data did not reveal any differential performance of tillage systems depending on seasonal conditions (i.e. presence of interactions), which may be due to large unexplained variability (e.g. unaccounted nutrient deficiencies). Most of the yield variability was explained by the absence (dry days/spells) rather than the presence of water (total rainfall) in the semi-arid study environment. Overall, tied-ridge tillage could be a means to improve productivity in the semi-arid environments of Ethiopia if other system constraints such as nutrients are adequately managed.

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