Soil & Tillage Research 124 (2012) 83–94

Contents lists available at SciVerse ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

To tie or not to tie ridges for water conservation in Rift Valley drylands of Ethiopia

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ARTICLE INFO

Article history:
Received 5 December 2011
Received in revised form 22 March 2012
Accepted 14 May 2012

Keywords:
Tied-ridges
Rainwater harvesting
Manure
AquaCrop
Maize

ABSTRACT

The Rift Valley drylands of Ethiopia are characterized by sandy loam soils that have poor fertility and unreliable rainfall conditions. The aim of this study was to examine the potential benefit of rainwater harvesting by tied-ridges and improved soil fertility on maize productivity through field experimentation and simulation with the FAO's AquaCrop model. The effect of tied-ridges with and without manure on maize yield at smallholder farms was studied during the years 2009 (very dry, 96% probability of exceedance) and 2010 (normal year, 46% probability of exceedance). During a normal rainfall, the mean yield of maize grain was 4.0 Mg ha^{-1} when tied-ridges were applied in combination with manure (at 4.5 Mg ha^{-1} rate); 3.4 Mg ha^{-1} when tied-ridges were applied without manure; 3.5 Mg ha^{-1} when traditional tillage was applied in combination with manure; and 2.7 Mg ha^{-1} when traditional tillage was applied without manure. Long-term simulations with the FAO's AquaCrop showed that the root zone soil water may exceed field capacity for consecutive days during above average rainfall seasons in the shallow sandy loams. The question thus is when to tie or not to tie ridges. Therefore, upon proper calibration of the FAO's AquaCrop model, the effect of tied-ridges and improved soil fertility was simulated in response to different amounts of seasonal rainfall, number of rainfall days and sowing times. Simulations revealed that, during below average rainfall seasons (280–330 mm), tied-ridges are more effective at improving crop yields than enhancing the fertility level of the soil. But during above average rainfall seasons, the rainwater that is held in tied-ridges can be more effectively utilised when the current fertility level of the soil is improved. The simulated rainwater use efficiency of maize was 6.1–6.5 kg ha^{-1} mm^{-1} for traditional tillage without any fertiliser, 6.8–7.3 kg ha^{-1} mm^{-1} for tied-ridges without any fertiliser and 11.0–12.9 kg ha^{-1} mm^{-1} for tied-ridges with optimum fertiliser (96% soil fertility level). It is, therefore, concluded that combined use of tied-ridges and farmyard manure can enhance maize yield under wide range of rainfall conditions (annual rainfall ranging from 280 mm to 680 mm). The Maresha-modified ridger used in this study can be popularized among Ethiopian farmers due to its simplicity and effectiveness.

1. Introduction

Out of the 13.6 million ha of cultivated land in Ethiopia, close to 97% is rainfed implying that the nation's annual harvests depend heavily on the patterns of the seasonal rains (Awulachew et al., 2005; FAO, 2005). Given that Ethiopia's national GDP is mainly based on agriculture, the annual GDP growth during 1983–2000 showed strong correlation with rainfall variation (WWAP, 2009). Seasonal rainfalls are highly unpredictable and variable in Ethiopia (Gissila et al., 2004) contributing to higher risk of production in arid and semi-arid regions due to less crop water availability during the growing seasons (Araya and Stroosnijder, 2011; Tesfaye and Walker, 2004). Hence, smallholder-based agricultural production varies noticeably from year-to-year.

Maize (*Zea mays* L.) is critical to smallholder livelihoods in Ethiopia and has the largest smallholder coverage at 8 million holders, compared to 5.8 million for teff (*Eragratis teff*) and 4.2 million for wheat (CSA, 2010; IFPRI, 2011). It is also the largest crop nationwide by volume at 3.9 million tons (2.2 Mg ha^{-1} on average) in 2009/2010, compared to teff at 3.1 million tons (1.2 Mg ha^{-1}) and wheat at 3.0 million tons (1.8 Mg ha^{-1}) (CSA, 2010). Maize is the staple food particularly in dryland regions while teff is more important in highland regions. Maize production in Ethiopia is significantly limited due to low soil fertility and agricultural water scarcity during critical growth stages (Debelle et al., 2001; Demeke et al., 1997; Senay and Verdin, 2003).

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0167-1987/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.still.2012.05.006

The arid, semi-arid and dry sub-humid parts of Ethiopia cover about 65% (close to 700,000 km^2) of the total land mass of the country (EPA, 1998), and 46% of the total arable land (Yonas, 2001). The Ethiopian Rift Valley, which covers the major portion of the vast dryland areas, is undergoing increasing land-use conversion from pastoral to mixed crop-livestock systems (Dessie and Kleman, 2007; Garedew et al., 2009; Tsegaye et al., 2010). Not only the year to year rainfall variability (Tilahun, 2006), but also the non-productive loss of rainfall through soil evaporation and surface runoff limit rainfed agriculture. Up to 40% of the seasonal rainfall may be lost in the form of surface runoff in the Rift Valley drylands of Ethiopia (Welderufael et al., 2008).

Ridging, which creates furrows by opening the soil in between, is widely applied in different areas (Jones and Stewart, 1990; Lal, 1990, 1991). In areas of low and erratic rainfall, the furrows created by ridging can be left open, or closed at regular intervals for holding water and facilitating infiltration. When the ridges or furrows are blocked with earth ties with intervals, they are known as 'tied-ridges' or furrow diking. In tied-ridges, the earth ties are spaced at fixed distances to form a series of micro-catchment basins in the field (Lal, 1990; Nyamudeza and Jones, 1994; Wiyo et al., 1999). There has been a long experience of ridge tillage in Eastern Africa (Dagg and MacCartney, 1968; Gebreegziabher et al., 2009; Pereira et al., 1958, 1967). A tied-ridge system of hand cultivation has been practised successfully in parts of Tanzania for many years and later equipment was devised to mechanize this system and for use in areas of marginal rainfall where water conservation was essential (Dagg and MacCartney, 1968). In Kenya, the importance of tied ridges in controlling erosion and runoff was proved many years ago (Pereira et al., 1967). In the teff production areas of the Tigray region of Ethiopia, farmers traditionally make contour ridges, locally called *terwah*, at 2–4 m wide intervals to trap water for later crop use (Gebreegziabher et al., 2009). In the central Rift Valley areas of Ethiopia, the traditional *shilshalo* ridging practice is done 4–6 weeks after sowing of maize as a means of breaking the surface crusts and enhancing infiltration (Biazin et al., 2011a).

The significant role of tied-ridges in improving water and crop productivity in arid and semi-arid regions has been reported (Araya and Stroosnijder, 2010; Biamah et al., 1993; Jensen et al., 2003; McHugh et al., 2007; Motsi et al., 2004). However, depending on the pattern of the seasonal rainfall, tied-ridges may also cause waterlogging which can negatively affect crop yields (Jensen et al., 2003; Olufayo et al., 1994). The question thus is when to tie or not to tie ridges in response to different patterns of rainfall in the Rift Valley drylands of Ethiopia.

Given the poor soil fertility level of the Rift Valley drylands in Ethiopia (Biazin et al., 2011b; Itanna, 2005), a single intervention through rainwater harvesting techniques may not bring about substantial impact on crop productivity. Studies in arid and semi-arid regions of sub-Saharan Africa revealed that single interventions through water conservation could improve crop yields by up to 50% (Araya and Stroosnijder, 2010; Hensley et al., 2000; Walker et al., 2005) while the combined use of tied-ridges and nutrient inputs has resulted in two-fold to six-fold crop yields as compared to traditional farming practices without fertiliser use (Jensen et al., 2003; Zougmore et al., 2003). Other studies have shown that soil improvements through the use of farmyard manure and composting combined with in situ rainwater harvesting techniques has been beneficial for rainfed agricultural systems in arid and semi-arid regions (Fatondji et al., 2006; Gicheru et al., 2004; Reij et al., 2009; WOCAT, 2007). In the Rift Valley drylands of Ethiopia, there is ample opportunity to use animal manure for soil fertility improvements.

Simulations can be a substitute for expensive and long-term field studies to evaluate effects of tied-ridging in response to different seasonal rainfall patterns and fertility levels. Krishna (1989) tried to simulate the effect of conserving runoff by furrow diking on crop yields in Texas, USA. However, his deterministic models require detailed crop and soil data inputs. Wiyo et al. (1999) used a simple field capacity-based water balance model (TIEWBM) to simulate the effect of tied-ridges on water balance components under different soils and rainfall regimes in Malawi. However, both of the aforementioned models could not be used to simulate the effect of tied-ridges on crop yields in response to different levels of soil fertility. Relative to other simulation models, such as models used by Krishna (1989) and many others, the FAO's AquaCrop model requires a smaller number of parameters and input data to simulate the yield response to water for most of the major field crops cultivated worldwide (Steduto et al., 2009). Therefore, AquaCrop was used in this study to conduct long-term simulations of the effect of tied-ridges in response to different amounts of seasonal rainfall, sowing time and fertility levels. The outcome of the long-term simulation can be used to understand the scenario of combining tied-ridges and soil fertility improvements in response to different amounts of seasonal rainfall and time of sowing.

2. Materials and methods

2.1. Site characteristics and measured data

The field experiment site is located in the Central Rift Valley (CRV) of Ethiopia around Langano (38°40′ E, 7°33′ N), which is situated about 190 km south of the capital, Addis Ababa. It lies at about 1600 m above sea level and has a slope of 2–3%. With an aridity index of 0.37 (the ratio of precipitation to reference evapotranspiration), the study area is a semi-arid dryland according to the UNCCD classification of drylands (UNCCD, 2000; MEA, 2005). The annual rainfall varies between 270 mm and 960 mm (CV = 30%) with a mean of 650 mm for the past 30 years. Although the area was previously covered by dense acacia woodlands, which had been used by pastoral Oromo people coming from the nearby highland areas, a significant proportion of the area has become subjected to cultivation and grazing over the last five decades (Eshete, 1999). Major crops are maize (*Zea mays* L.) and haricot bean (*Phaseolus vulgaris* L.). Livestock consists mainly of goats and cattle. Following crop harvests, livestock freely graze on the crop residues. Although cattle manure is abundant around homesteads where households corral their livestock, most of the local households do not put any manure on the cultivated fields.

The geological and geomorphologic features of the region are the result of volcano-tectonic and sedimentation processes (Ayenew, 2007). The volcanic products were derived from tuff, ignimbrite and volcanic ash. The soil is classified as Haplic solonetz with a texture ranging from loamy sand to sandy loam (Biazin et al., 2011b; Itanna, 2005). The soil is poor in fertility (less than 50% fertility level) and shallow with an impermeable calcite layer between 0.55 m and 0.70 m as determined by field measurement. It readily compacts and is liable to crusting and drought. Soil physical characteristics such as bulk density, field capacity, permanent wilting point and water content at saturation were determined in the laboratory (Table 1).

During the 2009 and 2010 growing seasons, field experimentation was undertaken to examine the potential benefit of rainwater harvesting using tied-ridges in combination with application of farmyard manure. Split-plot designs were used. The tied-ridges and the traditional *Dirdaro* tillage (mentioned as traditional tillage hereafter) were considered as the main plots and presence or absence of farmyard manure as the sub-plots. Main plot areas were 30 m × 15 m and sub-plots were 15 m × 15 m. The treatments were replicated in four farmers' fields thereby making a total of 16