Chapter 13
Effect of In Situ Soil Water Harvesting Techniques and Local Plant Nutrient Sources on Grain Yield of Drought-Resistant Sorghum Varieties in Semi-arid Zone, Tanzania

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Abstract Aridity is becoming a key threat to more than 500 million people who depend on agriculture for their livelihood in semi-arid areas worldwide. Climate change represents a significant threat to current agricultural production, and consequently to farmers' livelihoods in sub-Saharan Africa. The compounded effects of climate change, population pressure and change in dietary demands will further threaten fragile natural resources and accelerate land degradation processes. Poverty and hunger are still characteristics of sub-Saharan African countries in specific areas frequently hit by drought including the central zone of Tanzania. Typical characteristics of these areas are periodic to frequent dry spells that lead to crop failure, food shortage and lasting poverty. In Tanzania, the central regions of Dodoma and Singida are frequently threatened by drought that causes crop failure. In Dodoma, Singida and Tabora, 45–55 % of the households are food insecure. The purpose of this work was to investigate the effect of combining selected soil water harvesting techniques and locally available plant nutrient sources (FYM and urea-treated local phosphate rock, *Minjingu Mazao*) on the grain yield of early maturing and drought-resistant sorghum varieties (*Wahi* and *Hakika*). The trials were conducted at Mbande village, Kongwa

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District and Ikhanoda village, Singida Rural District in Tanzania. A split-split plot design setup was used in this study. The main plots were tillage methods, which were infiltration pit (PI), tied-ridging (TR) and flat cultivation (FC). The sub-plots were the fertilizers, which were farmyard manure and *Minjingu Mazao*, and the sub-sub plots were the two sorghum (*Sorghum bicolor* L. Moench) varieties: *Wahi* and *Hakika*. Data were subjected to one-way analysis of variance. Treatment differences were separated using least significant differences (LSD) at $p < 0.05$, $p < 0.01$ and $p < 0.001$. At the Ikhanoda study site, when *Minjingu Mazao* was applied, the *Wahi* grain yield was significantly ($p < 0.05$) higher in PI (2,414 kg ha^{-1}) and FC (1,126 kg ha^{-1}) than in TR treatment (648 kg ha^{-1}). In contrast, with *Hakika*, TR significantly ($p < 0.05$) outperformed other water harvesting methods with the highest grain yield (3,199 kg ha^{-1}). The PI treatment recorded the highest grain yield (2,789 kg ha^{-1} under *Wahi* and 3,223 kg ha^{-1} under *Hakika*) when FYM was applied at 5 t ha^{-1}. The grain yield of both varieties under FYM and all water harvesting techniques, including FC, did not differ significantly ($p > 0.05$). However, *Hakika* under PI had the best yield (3,223 kg ha^{-1}) while *Wahi* under FC registered the lowest yield (2,573 kg ha^{-1}). In the absence of FYM or *Minjingu Mazao*, the grain yield showed the following trend: FC (1,660 kg ha^{-1}, 1,863 kg ha^{-1}) > PI (1,234 kg ha^{-1}, 1,387 kg ha^{-1}) > TR (875 kg ha^{-1}, 930 kg ha^{-1}) for *Wahi* and *Hakika*, respectively. At the Mbande site, the *Wahi* variety had a significantly higher grain yield ($p < 0.05$) in the FC treatment (1058.6 kg ha^{-1}) than TR (543 kg ha^{-1}) and PI (320.3 kg ha^{-1}) when FYM was applied. With the application of 5 tons ha^{-1} FYM, the *Wahi* variety gave a significantly ($p < 0.05$) higher grain yield (1320.2 kg ha^{-1}) in the TR treatment but the lowest in the FC treatment (476.6 kg ha^{-1}). With the *Hakika* variety, the grain yield was higher (1773.4 kg ha^{-1}) in TR and FC than in PI (890.6 kg ha^{-1}). The superiority of the FC treatment in the absence of external nutrient input is attributed to topsoil that is slightly richer in nutrients compared to the rest of the treatments in which the poorer subsoil is part of the root zone. External nutrient input might have compensated for nutrient deficiencies and thus attenuated the treatment differences. This study demonstrated that in the absence of external sources of plant nutrients such as FYM and *Minjingu Mazao*, FC performed better than PI and TR. With external nutrient input, the grain yield varied due to water harvesting practice and site. At Ikhanoda, PI was superior to the other treatments while at Mbande, TR outperformed the other treatments. The outcome of the use of rainwater harvesting technologies ought to be applied in well-characterized fields in terms of physical and bio-chemical soil characteristics for better results.

Keywords Wahi • Hakika • Sorghum varieties • In situ rainwater harvesting • Farmyard manure • *Minjingu Mazao* fertilizer • Central semi-arid Tanzania

13.1 Introduction

Arid and semi-arid areas are defined as areas that fall within the rainfall zones of 0–300 mm and 300–600 mm, respectively (Food and Agriculture Organization [FAO] 1987). Because of the short growing periods (1–74 and 75–119 growing days, respectively), these areas are either not suitable or are only marginally suitable for cultivation. Rainfall patterns are unpredictable and are subject to great fluctuations. Inter-annual fluctuations range from 50 to 100 % in the arid zones to 20–50 % in the semi-arid zones (IISD 2006; Sutherland et al. 1991).

Worldwide, 868 million people continue to suffer from undernourishment, and the negative health consequences of micronutrient deficiencies continue to affect around two billion people (FAO et al. 2012). Further, more than 100 million children under the age of five are underweight, and therefore unable to realize their full socio-economic and human potential. Children malnutrition is the cause of death for more than 2.5 million children every year (FAO et al. 2012). Hunger and malnutrition can be a significant obstacle to economic growth (FAO 2010). In the Dodoma, Singida and Tabora regions in Tanzania, 45–55 % of the households are food (Sidahmed, 2000) insecure (World Food Programme [WFP] 2007).

In sub-Saharan Africa, agricultural production improved slightly, stagnated or has been declining for the last 50 years. This has caused a lot of food insecurity in the region as shown in Table 13.1. Problems associated with food insecurity are more pronounced in arid and semi-arid zones where the consequences of climate change are most severe (Salas et al. 2009). In sub-Saharan Africa, the majority of the countries are faced with a high level of malnutrition, frequently exceeding a quarter of the population; only a few countries have reversed the trend over the last two decades (Table 13.1). Countries dominated by arid and semi-arid subsistence agriculture are more vulnerable than those with better climatic conditions. Apart from the aridity, agriculture in these areas faces many challenges, including vulnerability to soil erosion, low soil fertility and reduced rainfall infiltration rate (Maestre et al. 2000), water-induced soil erosion (D'Odorico and Porporato 2006), scarce moisture reserves and low organic matter content (IISD 2006).

Better and efficient use of water resources is needed and soil fertility must be restored in arid and semi-arid zones through the application of affordable plant nutrient carriers and optimization of scarce rainfall through water harvesting. These actions would bring sustainable benefits to the target communities if appropriate crop varieties adapted to local conditions are considered.

Sorghum, millet and maize are the staple foods in Dodoma and Singida. However, most resource-poor farmers grow cereal crops that are not adapted to drought (Monyo et al. 2004). The *Striga* species (witchweed) is another limitation to food production in the marginal lands of the semi-arid zone of Tanzania (Monyo et al. 2004). *Striga* reduces up to 40 % of the sorghum yield in Tanzania (Ejeta et al. 1991). Recently, early maturing, drought and *Striga*-resistant sorghum varieties known as *Hakika* and *Wahi* were successfully introduced in Tanzania under the National Sorghum and Millet Improvement Program. However, farmers in Dodoma and Singida, and similar areas in Sub-Saharan Africa still depend on local landraces, though they are characterized low grain yield and are more prone to *Striga* (Dicko et al. 2006). The trend is attributed to many factors such as taste and preferences (Monyo et al. 2004), low ability of input markets to respond to farmers demands (Ahmed et al. 2000) and biotic and abiotic stresses to introduced varies in certain agro-ecological zones.

Table 13.1 Prevalence of undernourishment in selected sub-Saharan Africa countries

	Number of people undernourished (10^6)						Proportion of undernourished in total population (%)					
	1990–1992	1999–2001	2004–2006	2007–2009	2010–2012	Change so far	1990–1992	1999–2001	2004–2006	2007–2009	2010–2012	Change so far
Angola	7	7	6	6	5	−21.0	63.9	47.5	35.1	30.7	27.4	−57.1
Benin	1	1	1	1	1	−33.7	22.4	16.4	13.1	10.8	8.1	−63.8
Botswana	<0.5	1	1	1	1	45.3	27.4	34.5	32.9	31.9	27.9	1.8
Burkina Faso	2	3	4	4	4	99.9	22.9	26.4	25.8	24.4	25.9	13.1
Burundi	3	4	5	6	6	124.4	49.0	63.0	67.9	72.4	73.4	49.8
Cameroon	5	5	3	3	3	−35.2	38.7	29.1	19.5	15.6	15.7	−59.4
Central Africa Rep.	1	2	2	1	1	−9.8	49.5	45.1	40.6	32.6	30.0	−39.4
Chad	4	3	4	4	4	1.7	61.1	41.0	37.3	36.4	33.4	−45.3
Congo	1	1	1	1	2	47.1	42.8	30.1	32.9	34.6	37.4	−12.6
Cote d'Ivoire	2	3	4	4	4	143.4	13.7	19.9	19.6	19.3	21.4	56.2
Eritrea	2	3	3	3	4	54.3	72.4	76.2	74.8	69.1	65.4	−9.7
Ethiopia	34	36	35	35	34	0.1	68.0	55.3	47.7	43.8	40.2	−40.9
Ghana	6	3	2	1	1	−87.0	40.5	16.6	9.5	5.8	<5	na
SSA	**170**	**200**	**205**	**216**	**234**	**37.8**	**32.8**	**30.0**	**27.2**	**26.5**	**26.8**	**−18.3**

Modified from FAO et al. (2012)

Integrated water management solutions in rain-fed agriculture can result in significant yield improvements (Hatibu et al. 2006). Research has shown that there are no agro-hydrological limitations to doubling or tripling on-farm stable food yields in rain-fed agriculture in a drought-prone environment. Different management techniques can contribute to improved water productivity, i.e., "more crop per drop" of rain. In arid and semi-arid regions, a large part of the rainfall is lost as unproductive evaporation and runoff. Approximately, 70–85 % of the rainfall depending on land management conditions) from farmers' fields (Dile et al. 2013). Thus, less than 15–30 % of rainfall is used for plant growth. Managing water and soil appropriately results in improved rainfall use efficiency and bridges intra-seasonal rainfall variability to double or even triple agricultural yield levels (Dile et al. 2013).

In Tanzania, the central regions of Dodoma and Singida and neighboring areas are semi-arid; moisture availability is the most limiting crop production factor (Hatibu et al. 2006). About 30–35 % of storm rainfall is lost as runoff (Hoogmodel et al. 1984). Rwehumbiza (1987) showed that the recharged root zone over-performed moisture-stressed treatments in terms of dry matter yield, maize kernel weight and total water use efficiency for dry matter and grain yield.

Water harvesting can play a larger role in achieving water productivity. Water harvesting practices are classified into three categories: macro-catchment systems, micro-catchments and in situ systems (Dile et al. 2013). Macro-catchment water harvesting systems are also called external water harvesting systems or ex situ. These systems collect water from a large area and have water collection catchment, conveyance and storage structures. Micro-catchment water harvesting systems collect water from a relatively small catchment area. The catchment and crop area are distinct but adjacent. In situ water harvesting systems are used where rainfall water is captured and stored where it falls. These techniques improve soil moisture by enhancing infiltration and reducing runoff and evaporation (Hatibu et al. 2006; Vohland and Barry 2009).

Field studies in Northern Ethiopia on in situ water harvesting systems such as tied-ridging, open ridging and sub-soiling improved the soil water content in the root zone during the cropping period compared to traditional tillage by 24 %, 15 % and 3 %, respectively (McHugh et al. 2007). Similarly, in the semi-arid region of Northern Ethiopia, tied-ridges improved the barley yield by 44 % compared to traditional tillage (Araya and Stroosnijder 2010).

Several in situ water harvesting techniques have proven effective in soil moisture conservation in semi-arid areas. Mwaliko (2001) noted a twice as large sorghum grain yield with the residual tied-ridge treatment compared to the no-till treatment. Working at Hombolo in Dodoma, Swai (1999) noted an increase in sorghum grain yield of 480–640 % and 79–320 % under annually made and residual tied-ridges over the no-till treatment when 30 t ha^{-1} of FYM was applied.

Numerous studies show that high soil fertility methods such as the use of farmyard manure and enhanced soil moisture status reduce the adverse effects of *Striga* (Oswald 2005). The traditional tillage method (slash and burn) locally called *kuberega* dominates the sorghum-growing areas of the Dodoma and Singida regions. Studies conducted in the central zone of Tanzania showed that tied-ridging in combination with farmyard manure using *Striga*-resistant varieties *Hakika* and

Wahi gave higher grain yields compared to traditional tillage and research station trials.

However, recently a study on similar agro-ecological conditions revealed that in situ rainwater harvesting that involved ripping and deep ploughing techniques markedly increased sorghum productivity compared to tied-ridging (Swai 1999). Therefore, from these findings, integrating *Striga*-resistant varieties notably *Wahi* and *Hakika* and promising soil and water management technologies (tied-ridges, infiltration pit and ripping) are likely to significantly enhance sorghum grain yield in the drought-prone areas of Kongwa District, Dodoma Region and Singida Rural District, Singida Region, Tanzania. It is therefore assumed that combining these technologies will enhance sorghum grain yield and hence contribute to sustained household food security and poverty alleviation. That notwithstanding, there is ample evidence of existence of large gaps between on station crop yields and those actually attained at farmers' fields (van Ittersum et al. 2013; Lobell et al. 2009). This study was designed to minimize such discrepancies by making it on-farm and participatory.

The overall objective of this study was to investigate effect of combining selected soil water harvesting techniques and locally available plant nutrient sources, FYM and urea-treated local phosphate rock, *Minjingu Mazao*, on the grain yield of early maturing and drought-resistant sorghum varieties (*Wahi* and *Hakika*). The specific objective was to quantify the effects of tillage methods, tied-ridges and pit infiltration pits, compared with traditional flat cultivation on the grain yield of the *Wahi* and *Hakika* sorghum varieties.

13.2 Materials and Methods

13.2.1 Study Site

A participatory study was conducted at Mbande village in Kongwa District and Ikhanoda village in Singida Rural District, Tanzania, during the 2010–2011 cropping season. Mbande and Ikhanoda are located at 6° 6′ 8″ S and 36° 19′ 25″ E, 941.3 m.a.s.l., and 6° 38′ 7″ S and 34° 59′ 2″ E, 1,600 m.a.s.l., respectively.

13.2.2 Rainfall Characteristics of the Study Sites

Mbande and Ikhanoda are characterized by one rainy season that extends from November/December to April/May with an annual mean rainfall of 438.9 and 542.6 mm per annum, respectively. The areas are also characterized by wide inter-annual rainfall variation. For instance, data from the Kongwa Pasture Institute for a period of 24 years (1970–1993) show a range of 222.0–923.9 mm.

13.2.3 Soil Characteristics of the Study Sites

At each site, sampling was sampled from a soil profile that was dug close to the experimental trial area. Soil characteristics were determined for air-dried fine earth soil samples. Particle size distribution was estimated with Gee and Bauder's (1986) method. The pH (H_2O) was measured following the procedure after Mclean (1982). Organic carbon was determined using the Black and Walkley wet combustion method (Nelson and Sommers 1982). Total nitrogen was determined with Bremner and Mulvaney's (1982) method. Extractable phosphorus was measured using Olsen and Sommers' (1982) procedure. CEC was determined using Thomas's (1982) method. The soil characteristics of the sites are shown in Table 13.2. Based on morphological and laboratory data, the soils were classified in accordance with the classification system developed by the Soil Survey Staff (2006) as Aridic Haplusteps at Kongwa and Dystric Haplustepts at Ikhanoda.

13.2.4 Experimental Design and Treatments

A split-split plot design experiment was laid down with three tillage treatments: traditional tillage or flat cultivation (FC), tied-ridges (TR) and infiltration pits (PI) as the main plots. The fertilizer types were no fertilizer (control), farmyard manure at 5 tons per ha and *Minjingu Mazao* at 30 kg per ha the subplots. In addition, two sorghum varieties, *Wahi* and *Hakika*, served as the sub-sub plots. The treatments were randomly replicated three times. Treatments were randomly allocated to a plot 10 m by 8 m (80 m^2). Plant spacing of 0.8 m between rows and 0.3 m within rows with two plants per hill/hole was used. The seeds were top-dressed against head smut disease with a copper-based fungicide. Standard agronomic practices were applied that included two weedings at 3 and 6 weeks after germination.

13.2.5 Data Collection and Statistical Analysis

The weight of the grain yield of individual plots was obtained from mature plants in the inner three rows, shelled and dried to 14 % moisture content. The latter was converted to kg per hectare.

Data were analyzed with GenStat ($p \leq 0.05$); trial data were subjected to analysis of variance appropriate for the experimental design. Treatment differences were separated using least significant differences (LSD) at $p < 0.05$; $p < 0.01$ and $p < 0.001$. The data were run using GenStatF stat (Wim et al. 2007) version 4.

The general statistical model is given by: $Y_{ijk} = F + A_i + B_j + (AB)_{ij} + e_{ijk}$

Table 13.2 Selected soil characteristics of the Mbande and Ikhanoda sites

Site	Soil horizon	Soil texture	pH (H_2O)	SOC (%)	Total N (%)	Extractable P (mg/kg)	CEC (cmol/kg soil)
Mbande	Ap	Loamy sand	6.1	0.6	0.06	2.5	21.8
	AB	Loamy sand	6.9	0.1	0.05	0.8	18
	BA	Loamy sand	6.6	0.4	0.04	0.6	22.6
	B	Loamy sand	7.8	0.4	0.03	0.8	10.8
	Mean ± stdev		6.9 ± 0.7	0.4 ± 0.2	0.05 ± 0.01	1.2 ± 0.9	18.3 ± 5.4
Ikhanoda	Ap	Sandy loam	5.7	0.3	0.05	9.9	13.8
	AB	Sandy loam	6.3	0.2	0.04	8.3	13.6
	BA	Sandy clay loam	5.8	0.3	0.02	0.6	13.2
	B	Sandy clay loam	6.6	0.2	0.03	0.2	13.6
	Mean ± stdev		6.1 ± 0.4	0.3 ± 0.1	0.04 ± 0.01	6.3 ± 5.0	13.6 ± 0.3

Where:

Y_{ijk} = general mean common to all observations; A_i = effect of ith level of tillage methods; B_j = effects of varieties to be tested; $[(AB)_{ij}]$ = interaction effects of three tillage methods and two varieties; and ε_{ijk} = random error effect. One-way analysis of variance (one-way ANOVA) to evaluate productivity of two varieties (*Wahi* and *Hakika*) and three tillage methods (flat cultivation, infiltration pit and tied-ridges) were conducted.

In the second year of the study, the experiment was up-scaled by 10 farmers at Mbande and 25 farmers at Ikhanoda out of the 30 and 45 farmers, respectively, who were supplied with *Wahi* and *Hakika* seeds for the same purpose. The latter were randomly selected from the two villages from more than 100 farmers who took participated in the project initiation workshop held before the study started. The farmers invited to up-scale were those who had received training during the first year of the study and who were willing to raise the crop using their own resources and have their yield data recorded and be used by the project. Four farmers were randomly selected among the adopters at Ikhanoda to demonstrate crop performance under farmer management (Table 13.4).

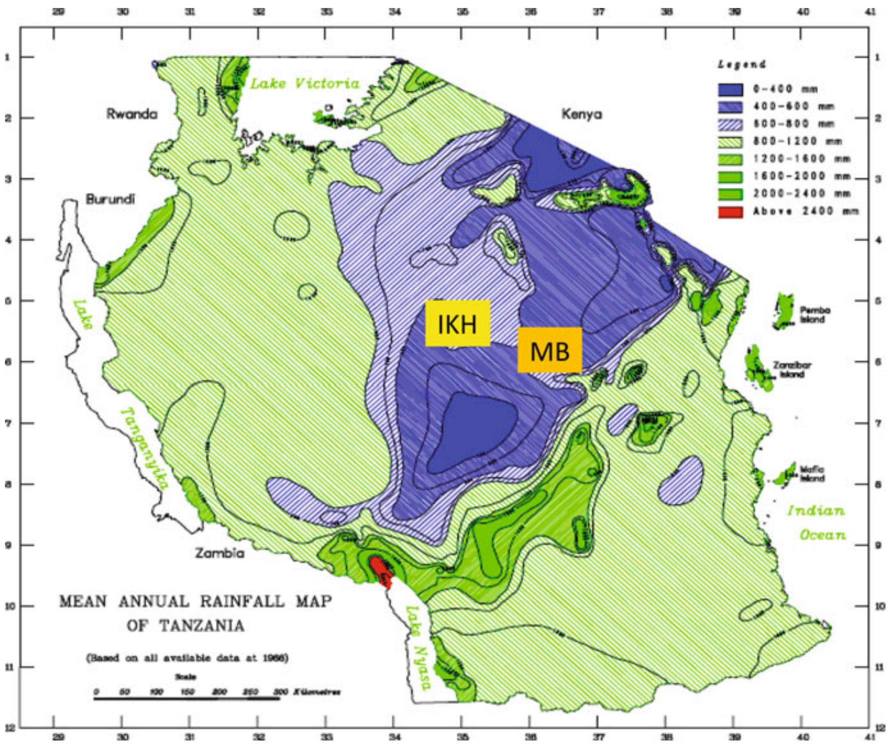

Fig. 13.1 Map showing rainfall zones of Tanzania and the location of the study sites Key: *IKH* Ikhanoda village, Singida Rural District, Singida Region. *MB* Mbande village, Kongwa District, Dodoma Region

13.3 Results and Discussion

13.3.1 Rainfall Distribution

The monthly rainfall for the 2010–2011 crop season is shown in Fig. 13.2. The rainy period started in November and ended in May 2011. However, good rainfall distribution was observed between December and March and then tapered in April and May 2011. The total precipitation for that year was typical for the arid regions of central Tanzania; the total rainfall was 542.6 mm and 434.9 mm for Ikhanoda (Singida Rural District) and Mbande (Kongwa District) villages, respectively. The annual rainfall data for the past 24 years from the Kongwa Pasture Research Centre agrees with the rainfall data for this crop year; the mean total annual rainfall data was 458.7 mm, with a maximum of 924.9 mm and a minimum of 222.0 mm (Figs. 13.3, 13.4, and 13.5).

13.3.2 Effect of Rainwater Harvesting on Grain Yield

At the Ikhanoda study site, when *Minjingu Mazao* was applied, the grain yield of *Wahi* was significantly ($p < 0.05$) higher in PI (2,414 kg ha^{-1}) and FC (1,126 kg ha^{-1}) than in the TR treatment (648 kg ha^{-1}). In contrast, with *Hakika*, TR significantly ($p < 0.05$) outperformed other water harvesting methods with the highest grain yield (3,199 kg ha^{-1}). The PI treatment recorded the highest grain yield (2,789 kg ha^{-1}) under *Wahi* and 3,223 kg ha^{-1} under *Hakika*) when FYM was

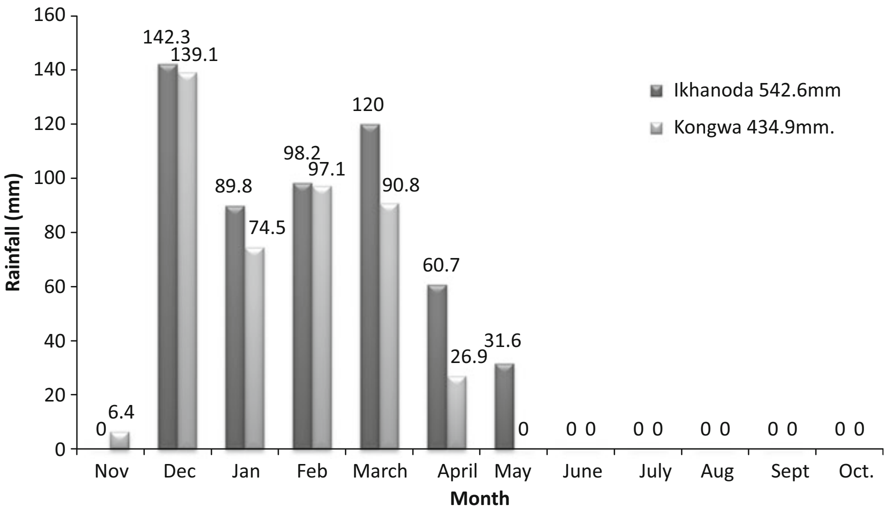

Fig. 13.2 Mean monthly rainfall at Ikhanoda and Mbande for 2010–2011 cropping season

Fig. 13.3 Land preparation at Ikhanoda village trial site, Singida Rural District

Fig. 13.4 Preparation of tie ridges (**a**) and application of FYM (**b**)

applied at 5 t ha^{-1}. The grain yield of both varieties under FYM all water harvesting techniques including FC, did not differ significantly ($p > 0.05$) (Table 13.3).

Hakika under PI out-yielded the rest (3,223 kg ha^{-1}) while *Wahi* under FC registered the lowest yield (2,573 kg ha^{-1}). In the absence of FYM or *Minjingu Mazao*, the grain yield showed the following trend: FC (1,660 kg ha^{-1}, 1,863 kg ha^{-1}) > PI (1,234 kg ha^{-1}, 1,387 kg ha^{-1}) > TR (875 kg ha^{-1}, 930 kg ha^{-1}) for *Wahi* and *Hakika*, respectively (Table 13.3).

At the Mbande site, the *Wahi* variety had a significantly higher yield (<0.05) in the FC treatment (1058.6 kg ha^{-1}) than TR (543 kg ha^{-1}) and PI (320.3 kg ha^{-1}) when FYM was applied. With the application of 5 t ha^{-1} FYM, the *Wahi* variety

Fig. 13.5 Wahi on tied ridges with FMY at Fatuma F. Tenanzo's farm, Ikhanoda village

gave a significantly ($p<0.05$) higher grain yield (1320.2 kg ha^{-1}) in the TR treatment but lowest in the FC treatment (476.6 kg ha^{-1}). With the *Hakika* variety, the grain yield was higher (1773.4 kg ha^{-1}) in TR and FC than in PI (890.6 kg ha^{-1}) (Tables 13.4 and 13.5).

13.4 Discussion and Conclusion

The superiority of the FC treatment in the absence of external nutrient input is presumably attributed to the topsoil that was slightly richer in nutrients that were easily accessed by plant roots through scavenging as opposed to TR and PI, in which the root biomass are exposed to the poorer subsoil. If there is no possibility of improving the soil with external nutrients, then farmers at the two sites and other places with similar soil and climatic conditions are advised to use FC. External nutrient input might have compensated for nutrient deficiencies and thus attenuated treatment differences.

In a similar observation to this study, Mwaliko (2001) observed a twice as large sorghum grain yield for residual tied-ridge treatment over the no-till treatment. In addition, working at Hombolo in Dodoma, Swai (1999) noted an increase in

Table 13.3 Effect of in situ rainwater harvesting (tillage practices) and type of plant nutrient source on the grain yield of *Wahi* and *Hakika* sorghum varieties at the Ikhanoda village site

Treatments		Grain yield (kg ha^{-1})			
Variety	Tillage	No fertilizer	FYM	Minjingu Mazao	
Wahi	PI	1,234ab	2,789a	2,414b	**2,414b**
	TR	875a	2,605a	648a	**648a**
	FC	1,660ab	2,573a	1,126a	**1,126a**
Hakika	PI	1,387ab	3,223a	2,616b	**2,616b**
	TR	930a	2,836a	3,199b	**3,199b**
	FC	1,863b	2,859a	2,496b	**2,496b**
	SE±		422.9	642.8	**641.2**
	CV (%)		31.9	22.8	**30.8**
	$LSD_{0.05}$	Variety	368.0	559.3	**641.2**
		Tillage	450.7	685.1	**683.3**
		Interaction	637.4	968.8	**966.4**
	F Stat	Variety	N.S.	N.S.	***
		Tillage	N.S.	N.S.	**N.S.**
		Interaction	**	N.S.	**

Means with a column followed by the same superscript are not significantly different according to LSD at a probability level of 0.05

PI Infiltration Pit, *TR* Tied-Ridging, *F* Flat cultivation

Key: Significant levels: N.S. = $p > 0.05$; *; $p \leq 0.01$; **; $p \leq 0.01$; ***; $p \leq 0.001$

Table 13.4 Effect of in situ rainwater harvesting (tillage practices) and type of plant nutrient source on the grain yield of *Wahi* and *Hakika* sorghum varieties at the Mbande village site

Treatments		Grain yield (kg ha^{-1})	
Variety	Tillage	No fertilizer	Farm yard manure (FYM)
Wahi	PI	320.3a	523.4ab
	TR	543ab	1,320.3c
	FC	1,058.6c	476.6a
Hakika	PI	312.5a	890.6abc
	TR	335.9a	1,773.4d
	FC	617.2b	1,773.4d
	SE±	97.2	164.8
	CV (%)	18.3	16.7
$LSD_{0.5\%}$	Variety	144.3	244.6
	Tillage	176.8	299.6
	Interaction	250	423.7
F. Stat	Variety	*	N.S
	Tillage	**	***
	Interaction	N.S	N.S

Means with a column followed by the same superscript are not significantly different according to LSD at a probability level of 0.05

PI Infiltration Pit, *TR* Tied-Ridging, *FC* Flat Cultivation

Key: Significant levels: N.S. $p > 0.05$; *; $p \leq 0.05$; **; $p \leq 0.01$; ***; $p \leq 0.001$

Table 13.5 Grain yield data for selected farmer fields at Ikhanoda village

S. no	Farmer's name	Variety	Practice adopted by the farmer	Yield (kg/ha)
1	Fatuma F. Tenanzo	Wahi	TR and FYM	7,777.8
2	Hawa O. Ramadhani	Wahi	TR and FYM	3,777.8
3	Halima Athumani	Wahi	TR	750.0
4	Salum Iddi	Wahi	TR and FYM	1,777.8

sorghum grain yield of 480–640 % and 79–320 % under annually made and residual tied-ridges over the no-till treatment when 30 t ha^{-1} of FYM was applied. In the semi-arid area of Abergelle, Northern Ethiopia, the tillage main treatment effects, tied-ridging, increased grain yield by 5–10 % and up to 28 % for the stover yield of the sorghum variety compared to its effect on the *Woitozira* variety (Tesfahunegn 2012). Field studies from Northern Ethiopia on in situ water harvesting systems such as tied-ridging, open ridging and sub-soiling improved soil water content in the root zone during the cropping period compared to traditional tillage systems by 25 %, 15 % and 3 %, respectively (McHugh et al. 2007).

A study conducted by Karrar et al. (2012) revealed that ridge tillage is very effective in conserving water in the root zone in semi-arid to sub-humid regions, particularly when the ridges have cross ties in the furrows. The ridges referred to included tied-ridging, furrow blocking or basin tillage. In addition, Botha et al. (2003) found that plant growth conditions were hampered by climatic factors such as low and erratic rainfall, low humidity levels and high temperature during the growing season, which is envisaged in arid and semi-arid regions. Karrar et al.'s (2012) findings suggest that the in situ water harvesting techniques improved the soil moisture stored within the root zone compared to conventional harrowing that uses a wide-level disc, resulting in increased sorghum dry matter and grain yield. Mmbaga and Lyamchai (2001) found a low yield in the bottom seed placement as a strategy for using water efficiently in the arid and semi-arid zones of Tanzania. Their results were related to the water logging in tied-ridging and by removing nutrients in the open ridges.

In another study, applying manure and compost on a half-moon soil and water conservation practice in a field trial in semi-arid Burkina Faso provided yields from 900 to 1,600 kg ha^{-1} of sorghum grain, that is, 20–39 % of the yield obtained in the half moon treatment without added nutrients (Zougmoré et al. 2006). Appropriate water and soil management results in improved rainfall use efficiency and bridges intra-seasonal rainfall variability to double or even triple agricultural yield levels (Dile et al. 2013).

The higher grain yield obtained under the flat cultivation treatment compared to the other treatments contradicts many findings that indicate tied-ridging or infiltration pits increase crop yield (Swai 1999; Zougmoré et al. 2006). These results cannot be explained by the data collected. Mixing of the poorer subsoil in the PI and TR treatments might have created a condition with less to the root zone compared to the flat cultivation treatment. This may be explained as the decrease in evaporation by conservation tillage is not possible in dry land environments because of poor ground cover by the crop especially during the early stage (Cooper et al. 1987). The other explanation could be that the ridges might be too high for water at the bottom of the ridges to reach root zones, especially during the early stages of plant growth coupled with the effect of evaporation on uncovered soils. More work, particularly detailed characterization of the topsoil and sub-soil of the studied sites, may provide a better understanding of these results.

The wider grain yield range observed among the farmers who up-scaled may be partly explained by farmer and land characteristics. Farmers differed in their ability and commitment to their experimental plots. The hard-working farmers got better yields than the rest. These farmers had better maintained fields. Nearly all higher-yielding fields were located close to the lower slope of the terrain or at the valley bottom with soils rich in the capacity to retain moisture. The farmers' fields on degraded land surfaces, which characteristically were located on upper slopes, gave poorer grain yields. The on-farm sorghum grain yields recorded in this study contrast with the average 0.8 t ha^{-1} values obtained in Sub Sahara Africa (FAO 1998). The results show the potential of the tested water harvesting technologies, even on soils with modest soil fertility, to change the food production status in the region and similar areas within and outside Tanzania. They provide the opportunity and means to fight hunger in the sub-Sahara region. In addition, the grain yield of the best farmers is close to the 5,000–6,000 kg ha^{-1} range, which has been reported in tropical regions with reliable rainfall and sufficient nutrient application under commercial agriculture (Dile et al. 2013). Therefore, with farmer education and sanitization, soil ripping, in situ water harvesting, the use of farmyard manure, proper plant spacing, timely thinning and weeding, the use of early maturing, drought- and *Striga*-resistant *Wahi* and *Hakika* varieties can contribute significantly in eradicating hunger in the climatically disadvantaged semi-arid areas in sub-Saharan Africa.

This research played a role in demonstrating that appropriate tillage with even modest nutrient input levels can result in high crop yields under good crop management. Even in less well-managed plots, infiltration pits or tied-ridges with low levels of FYM or *Minjingu Mazao* can double the sorghum grain yield.

In semi-arid zones similar to that of central Tanzania, the use of appropriate rainwater harvesting technologies, such as TR and PI, combined with external nutrient sources such as FYM and *Minjingu Mazao* is important to significantly increase sorghum (*Wahi* and *Hakika*) grain yield per hectare as observed in this study.

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