Chapter 13
Opportunities for Coping with Climate Change and Variability Through Adoption of Soil and Water Conservation Technologies in Semi-arid Eastern Kenya

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Abstract Scenario analysis using data generated from APSIM model was conducted to investigate the effect of soil and water conservation practices (tied ridges and mulching) on grain yield of improved maize varieties (Katumani and Makueni) generated with and without N fertilizers under below normal (<250 mm), normal (≥250 < 350 mm) and above normal seasons (≥350 mm) in two sites, Katumani and Makindu in Machakos and Makueni counties Eastern Kenya. Results indicate that the yields were significant (<0.01) under the different seasons and treatments with the magnitude of the yields response varied. Highest yields in Katumani (3,370 kg/ha) were obtained during below normal seasons and when both fertilizer and tied ridges were used. In Makindu, however, under all treatments, highest yields were obtained during above normal seasons with 3,708 kg/ha yield when 40 kg N/ha fertilizer was applied. Lowest yields on the other hand, were obtained during normal seasons in both sites with 507 kg/ha in Katumani and 552 kg/ha under tied ridges and mulching + fertilizers in Makindu. Compared with farmers practice (control), the yield increment obtained was 4 kg/ha (0.6 %) and 5 kg/ha (0.7 %) in Katumani; 32 kg/ha (4.6 %) and 33 kg/ha (4.7 %) in Makindu under mulching and tied ridges respectively during below normal seasons otherwise the yield decreased during normal and above normal seasons with up to 19 % in Makindu when tied ridges was practised. Fertilization increased the yields of maize by as high as 2,552 kg/ha (433 %) and 2,319 kg/ha (166 %) in Katumani and Makindu respectively during above normal seasons. However, during normal seasons, there was yield decrease in Makindu by 42 %.

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W. Leal Filho et al. (eds.), *Adapting African Agriculture to Climate Change*, Climate Change Management, DOI 10.1007/978-3-319-13000-2_13

When both fertilization and soil and water conservation practices was done, yield increase was 2,335 kg/ha (456 %) and 2,382 kg/ha (465 %) in Katumani during normal seasons under mulching +40 kg N/ha and tied ridges +40 kg N/ha respectively. In Makindu, yields declined during normal seasons, however, increase was by 2,229 kg/ha (160 %) and 2,108 kg/ha (152 %) during above normal seasons under mulching +40 kg N/ha and tied ridges +40 kg N/ha respectively. The results indicate that the use of fertilizers and soil and water conservation are indispensable for ensuring food security in semi-arids where rainfall is very variable.

Keywords Tied ridges · Mulching · N fertilizer · Seasons · Katumani · Makindu

Introduction

The agriculture sector is the mainstay of the economies of most of the developing countries, employing about 60 percent of the workforce and contributing an average of 30 % gross domestic product (GDP) in sub-Saharan Africa (World Bank 2011). Kenya in particular, agriculture as the single most important sector in the economy contributed 21.4 and 24 % of the country's GDP in 2010 and 2011 respectively (KPMG Kenya 2012 in Kalungu et al. 2013). Additionally, smallholder farmers provide 75 % of the labour force and 75 % of the market output produce (Alila and Atieno 2006). However, about 82 % of the Kenya's agricultural lands (where 80 % of the smallholder farmers reside and derive their livelihoods, directly or indirectly from agriculture) are marginal with fragile ecosystems receiving variable, irregular and low amounts of rainfall (Mwakubo 2002). The variability in the amount and distribution of rainfall both during and across the seasons, that these areas experience not only makes the availability of water for crop production erratic, but farming, a risky undertaking. Variability in rainfall, the uncertainty that it creates and the general risk averse nature of smallholder farmers acts as a major deterrent to investing on productivity enhancing technologies in the semi-arid regions leading to low yields, worsening food shortages and economic situation of the farmers (Rao and Okwach 2005; Rao 2011). In addition, the low input management practices usually adopted contribute to severe physical, chemical and biological degradation leading to very serious problems of land degradation in the form of soil loss and nutrient depletion posing a threat to food security and sustainability of agricultural production in these areas (Juma 2010). Climate change is expected to further exacerbate this uncertainty and contribute to increased food insecurity in the smallholder farming sector. Small holder farmers, the elderly, women, children, and women and child-headed households will be the most vulnerable because they have limited adaptive capacity (Nyamadzawo et al. 2013). Current projections of future climatic conditions, though not accurate, indicate that there is a high likelihood for an increase in temperature and variability associated with rainfall as well as increased incidence of extreme events (IPCC 2007). Though there are uncertainties over the exact magnitude of these changes, there is a high probability for temperatures to increase by up to 3 °C by end of this century. One of the ways that warmer temperatures are going to manifest is through an increase in crop water requirements due to increased demand for evapotranspiration. Research on how to mitigate these impacts of climate change and variability to agricultural productivity is still very limited. In Kenya, studies have shown that awareness of climate change and variability is still low and farmers have been found to have a problem in differentiating between impacts arising from climate change and problems caused by environmental degradation. This lack of farmer awareness influences negatively on their adoption of appropriate adaptive technologies yet one approach of alleviating the impacts of climate change and variability is through the adoption of appropriate agricultural practices such as soil and water management technologies (Kalungu et al. 2013). These practices are mainly used by farmers with the aim of improving their agricultural production through reducing risks associated with farming. However, some of the agricultural practices continue to reduce the natural protection provided by vegetation cover hence subjecting land to severe soil erosive losses (Khisa et al. 2002). Thus, adopting soil and water management practices influences the agricultural production (Branca et al. 2012). The Government of Kenya is, however, promoting several farming improvement programmes such as the soil and water management project with the aim of increasing soil fertility and crop production (Nyangena 2007). In general, technologies that increase agricultural production and reduce production risk tend to support climate change adaptation as they increase agricultural resilience and reduce yield variability under climate variability and extreme weather events, which might intensify with climate change (Cooper et al. 2008). In Eastern Africa, where annual average precipitation and temperatures are expected to increase with climate change, the greatest impacts on agricultural production are expected from changes in rainfall variability, such as prolonged periods of drought and changes in the seasonal pattern of rainfall (IPCC 2007). Therefore, adaptation strategies that reduce yield variability during extreme events, such as droughts, erratic or changing patterns of rainfall will provide the greatest benefit to farmers and enhance their ability to adapt to current variability and future changes in climate which this study sought to find in semi-arid Eastern Kenya.

Materials and Methods

Study Sites

The study was carried out in two sites in Eastern Kenya; Katumani and Makindu in Machakos and Makueni counties respectively. Katumani falls around KARI Katumani research station at a latitude of 1°34′60S and longitude of 37°15′0E within agro ecological zone (AEZ) IV, which is described as medium to marginal for crop production (Jaetzold and Schmidt 1983). Annual rainfall varies between 500 and 800 mm, with a mean of about 700 mm. The average seasonal rainfall is between 300 and 400 mm for March–May and 310 and 370 mm for October–December while the mean maximum and minimum temperatures are 24.7 °C and 13.7 °C, respectively. However, like other areas of semi-arid eastern Kenya, rainfall in Machakos occurs in events of unpredictable intensity, with coefficients of variation in seasonal rainfall often exceeding 50 % (Keating et al. 1992). Both, the timing and relative lengths of each growing period vary substantially. Makindu lies at latitude of 2°11′38S and a longitude of 37°44′04E within agro ecological zone (AEZ) V. It receives an annual mean rainfall of 614 mm of which 337 mm is received during the short rain season and 195 mm during long rain season. The average annual maximum and minimum temperatures are 28.7 and 17.1 °C respectively. The terrain is flat and 970 m above the mean sea level, the temperature regime at this location is warmer. Both locations experience a semi-arid tropical climate, with a bimodal pattern of rainfall. The long rains come in March to May, with the peak in April followed by an extended dry period which lasts until mid-October when the short rains commence. The short rains peak in November and begin to taper off towards mid-December. They receive low and erratic rainfall with a poor temporal and spatial distribution. Temperature and evapo-transpiration rates are generally high going up to 8.2 mm day^{-1}.

Crop Simulations Using APSIM Model and the Inputs

Long-term yields of maize were simulated using the simulation model APSIM with the weather data available for the two sites, Katumani in Machakos and Kiboko in Makindu. Management practices evaluated were tied ridges, mulching with and without 40 kg N kg/ha of fertilizers under below normal, normal and above normal seasons. In both sites, short rain season (Oct–Dec) was simulated and maize was planted at 4.4 plants per square meter and the sowing window was from mid October to end November each year. A soil profile from Katumani (Chromic Luvisol, Katumani Research Station PAWC = 164 mm) and Kiboko (1,700 mm) was used to simulate soil water and N supply to crops at the two sites respectively. The maize yields simulated were subjected to analysis of variance (ANOVA) and the treatment means separated in linear model using R statistical software.

Results and Discussion

Maize Yields with and Without Fertilizers and Soil and Water Management Practice

The average grain yield of maize obtained with and without fertilizers and soil and water management practices under the different seasons are shown in Table 13.1. The mean grain yield was significantly different under the different treatments, sites

Table 13.1 Simulated mean maize yields (kg) under different fertilizer, soil and water management and seasons at Katumani and Makindu in Eastern Kenya

Site	Katumani			Makindu		
Treatment/Season	<250 (mm)	250–350 (mm)	>350 (mm)	<250 (mm)	250–350 (mm)	>350 (mm)
Farmers' practice	679.4	512.6	588.3	684.2	1,148.2	1,389.4
40 kg N	3,059.6**	2,502.3**	3,140.5**	979.4	656.3	3,708.1**
Mulch	683.5	507.4	562.8	715.8	1,095.5	1,215.7
Tied ridges	683.9	506.9	543.3	717.0	1,093.7	1,114.2
40 kg N-Mulch	3,332.6**	2,848.2**	3,158.9**	1,041.7**	552.5**	3,618.7**
40 kg N-Tied ridges	3,370.0**	2,895.5**	3,123.9**	1,056.4**	527.9**	3,497.2**

Significant at 0.05 '**'

and seasons as shown in Tables 13.2 and 13.3. Among the treatments studied, use of 40 kg N + tied ridges produced the highest maize yields (3,370 kg/ha) followed by 40 kg N/ha + Mulch (3,332.6 kg/ha) during the below normal seasons in Katumani. The lowest grain yields (506 kg/ha) were obtained during normal seasons when tied ridges were used. However, yields obtained with mulching (507.4 kg/ha), farmers' practice (512.6 kg/ha) during normal seasons and tied ridges (543.3 kg/ha), mulching (562.8 kg/ha) and farmers' practice (588.3 kg/ha) during above normal seasons did not differ statistically. Higher maize yields were simulated when soil and water conservation practices along with fertilizer is applied. Significant higher yields are attributed to the higher water harvesting (tied ridges) and retaining capacities giving water more time to penetrate and infiltrate and at the same time nutrients dissolution. Water that could have been lost through runoff and evapotranspiration is utilized by the plants. Makindu on the other hand, highest yields (3,708.1 kg/ha) were obtained during the above normal seasons when 40 kg N was applied followed by (3,618.7 kg/ha) when 40 kg N/ha + Mulch was used. Lowest yields (527.9 kg/ha) were produced when 40 kg N/ha + tied ridges was applied during the normal seasons.

Maize Yields (kg/ha) with Farmers' Practice and Soil and Water Management Practice

In both sites, the yields obtained when farmers' practice and soil and water management practise were applied were not statistically different under the different seasons (Table 13.1). In Katumani, highest yields (683.9 kg/ha) were obtained when tied ridges were applied during below normal seasons. The difference in mean yields obtained when tied ridges, mulch or farmers' practice were applied was very minimal in all the seasons studied. Farmers' practise gave slightly higher yields during normal and above normal seasons compared to mulch and tied ridges. The results suggest that soil and water management does not have beneficial effects on maize during normal or above normal seasons. In Makindu, there is yield incremental trend from below normal seasons to above normal seasons. This indicates the effects of water in this area where rainfall is more variable compared to Katumani. Highest yields (1,389.4 kg/ha) were obtained under farmers' practice. Application of mulch and tied ridges gave the same trend as in Katumani during below normal and normal seasons although the yields were much higher. This implies that whenever fertilizers are not applied, soil and water management may not be worthwhile.

Application of Fertilizers and Use of Soil and Water Management Practices

The mean yields of maize produced with the application of 40 kg N/ha fertilizer and as influenced by soil and water management practices varied from 527.9 to 3,370 kg/ha in both study sites (Table 13.1). The mean yields were significantly different ($P \leq 0.05$) as shown in Table 13.2. In Katumani, interaction of fertilizers and soil and water management practices gave the highest yields during below normal seasons. In Makindu, however, highest yields were obtained during above normal seasons with significantly low yield during normal seasons. The increment in yields 2,382 and 2,229 kg in Katumani and Makindu respectively indicates that integrating fertilizers and soil and water management practices is more effective in achieving higher yields. This was significant as shown in Table 13.3. Additionally,

Table 13.2 Analysis of variance of simulated maize yields (kg) under different fertilizer, soil and water management and seasons at Katumani and Makindu in Eastern Kenya

Source of Error	DF	SS	MS	F value	Pr(>F)
Treatment	5	22,800,265	4,560,053	13.244	$8.97e^{-06}$***
Season	2	5,459,538	2,729,769	7.928	0.00292**
Site	1	1,728,206	1,728,206	5.019	0.03658*
Season*site	2	4,735,601	2,367,800	6.877	0.00533**
Treatment*site	5	6,936,352	1,387,270	4.029	0.01084*

Significance level 0 '***' 0.001 '**' 0.01 '*'

Table 13.3 Analysis of variance of interactions between the treatments, site and seasons under different fertilizer, soil and water management and seasons at Katumani and Makindu in Eastern Kenya

Source of Error	Estimate	Std. Error	*t* value	Pr(>|t|)
40 kg N	2,307.385	479.113	4.816	0.000105***
40 kg N-Mulch	2,519.824	479.113	5.259	$3.80e^{-05}$***
40 kg N-tied ridges	2,536.385	479.113	5.294	$3.51e^{-05}$***
Mulch	−8.873	479.113	−0.019	0.985408
Tied ridges	−15.388	479.113	−0.032	0.974696
250–350 mm	−339.345	338.784	−1.002	0.328475
>350 mm	115.221	338.784	−0.34	0.737326
Makindu	−183.683	553.232	−0.332	0.74333
250–350 mm	319.296	479.113	0.666	0.512751
>350 mm	1,673.364	479.113	3.493	0.002294**
40 kg N	−1,600.08	677.568	−2.362	0.028458*
40 kg N-Mulch	−1,856.16	677.568	−2.739	0.012636*
40 kg N-tied ridges	−1,916.51	677.568	−2.829	0.010380*
Mulch	−56.049	677.568	−0.083	0.934895
Tied ridges	−83.643	677.568	−0.123	0.902986

Significance level 0 '***' 0.001 '**' 0.01 '*' it should be expected that the benefits obtained from water conservation and fertilization will be much higher in areas and crop seasons with erratic and low total rainfall and with varieties that are more sensitive to soil moisture deficit which is reflected in Katumani. This is because lands in Katumani have been in use for longer period compared to the newly opened lands in Makindu which are more fertile. Highest yield obtained during above normal seasons in Makindu indicates the effectiveness in the use of the fertilizers and conserved water in this area which is slightly drier compared to Katumani.

Conclusion

In general, from the mean maize grain yield data produced both under unfertilized and fertilized conditions of the soil, it could be realized that considerably high yield and monetary benefits would be accrued due to soil and water management practices. This is to be expected from the fact that the water harvested and retained by tied ridges and evapotranspiration minimized through mulching enhances water availability during water deficit periods. In Katumani, results indicate that either the use of fertilizers or soil and water management would be beneficial when done during below and above normal seasons. In Makindu, results have shown that maize requires more available soil water and at the same time tolerates excessive soil water more when grown with fertilizers than without fertilizer applications. Moreover, the substantial yield response of the crop to tied ridging and mulching on both the fertilized and unfertilized simulations indicated that in regions with poor rainfall distributions, soil and water conservation is a necessary agricultural practice in seasons and/or regions receiving variable rainfall.

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