Adapting agriculture to climate change - An evaluation of yield potential of maize, sorghum, common bean and pigeon pea varieties in a very cool-wet region of Nayandarua County

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Abstract

Soil and water conservation, use of more adaptive crop genotypes and crop diversification are widely accepted as some of the management practices that can help reduce agriculture vulnerability to impacts of climate change. A study was conducted to evaluate the yield potential of maize, sorghum, common bean and pigeon pea varieties under different water management, plant densities and fertility levels in Nyahururu, Central Kenya. The study involved three experiments. The first experiment evaluated the growth and performance of three varieties (early maturing, medium maturing and late maturing) of maize, sorghum, pigeon pea and common bean. The experimental design was a completely randomized block design (RCBD) replicated three times. The second experiment evaluated maize and sorghum yield response to water conservation and three fertiliser rates (0, 20 and 40 kg N/ha). The third experiment assessed the effect of water conservation measures on crop yields of common bean and pigeon pea grown under three plant densities (low, medium and high). Tied ridge tillage was used as the water conservation measure and disc plough as the control in the second and third experiments. Results showed that water conservation in general did not have a significant effect on crop yield though they were improved. The medium density pigeon pea gave the highest grain (719 kg/ha) followed by low (688 kg/ha) and high plant density (687 kg/ha), though not significant at 0.95 confidence level. Similar trends were observed with common bean grain and dry matter yield. Tied ridges tended to lower maize yield compared to flat tillage while it increased sorghum yields but the difference was insignificant. When average across the tillage systems, the highest maize grain (5553 kg/ha) and dry matter (14298 kg/ha) yield was obtained in plots without N fertilizer. Sorghum dry matter was highest (11333 kg/ha) in plots with 40 kg N/ha and lowest (7903 kg/ha) in plots with 20 kg/ha N. In the variety experiment, the EM pigeon pea variety (ICPL 84091) yielded the greatest grain (881 kg/ha) while the late maturing variety (ICEAP 00040) gave the least (565 kg/ha). The LM maize variety (DK8031) yielded the highest grain (5701 kg/ha) and dry matter (18843 kg/ha). The LM sorghum variety (Macia) had 47% and 49% dry matter yield advantage over MM (Kari Mtama 1) and EM (Gadam) varieties, respectively. The yields for common bean varieties tended to vary with seasons. So what are the conclusions?

Key words: climate change, water conservation, crop variety, plant density, soil fertility

Introduction

Global projections suggest that the ongoing climate change could have substantial impact on agricultural production and thus threatening food security by the end of the 21st century (IPCC, 2007, Naab *et al.*, 2013). Changes in temporal and spatial temperature and rainfall patterns will have great impacts on rain fed agriculture because of its direct dependence on rainfall and temperature. The crop water cycle is dependent on rainfall and changes in rainfall pattern both in time and quantity will directly impact on the crop development (Tao et al., 2003). Temperature affects the function of plant physiological processes (photosynthesis, respiration, leaf expansion rate) during crop growth and yield development (Hay and Porter, 2006). Inadequate rainfall and increased temperatures are likely to cause significant negative impact on crop yield. To avoid climate-induced food shortages, adaptation to impacts of climate change is fundamental (Lobell et al., 2008).

It has been suggested that rainwater harvesting, soil and water conservation, irrigation, use of more adaptive crop genotypes and crop diversification are some of management practices that can help reduce agriculture vulnerability to climate change impacts (Naab *et al.,* 2013; Kabubo-Mariara and Karanja, 2007). The capacity to adapt however depends on the information to technologies, skills to use technologies, local socio-economic and governance institutions that facilitate the adoption (Mutunga and Hardee, 2009). Such information is often lacking because it is site-specific in terms of soil and climate conditions. This study was therefore initiated to generate this important information and enhance the ability of farmers to adapt to progressive climate change through crop, soil and water management innovations and appropriate crop genotype choices under very cool wet climate conditions in Nyandarua County. This is ongoing research and will involve climate risk analyses, crop growth simulation modeling and field-based research to generate required information on current and future climate risk and their preferred climate change adaptation strategies. In order to achieve the object of this study, we implemented three trials: (1) to assess the growth and performance of an early, medium and late maturing varieties of maize, sorghum, pigeon pea and common bean under very cool climate regime and calibrate APSIM crop simulation model, (2) to determine the effect of water conservation and fertiliser application on productivity of maize and sorghum, and (3) to determine the effect of water conservation and plant population on productivity of common bean and pigeon pea. This paper presents some of the results from the study.

Materials and methods

Study site

The study is being conducted at the Oljororok Kenya Agricultural Research Institute station from April 2012 to March 2013. The Oljororok site lies on latitude 0.04 S and 36.35 E at an elevation of 2400 m above sea level. Its agro-ecological zone is described as Upper Highland sub-zone 3 (UH 3) with mean annual rainfall and temperatures of 1195 mm and 13.8^{o} C, respectively. The climate conditions during the study period are presented in Table 1. The soil is classified as Ando luvic phaeozem.

Field experiments

Assessment of the performance of cereal and legume crop varieties under very cool climate. The objective of this trial is to assess the growth and performance of three varieties (early maturing: EM, medium maturing: MM and late maturing: LM) of maize, sorghum, pigeon pea and common bean under very cool climate in Nyandarua County. The trial design was a completely randomized block design with 4 replications. Basal phosphorus fertilizer (40 Kg P/ha) and nitrogen fertilizer (20 Kg N/ha) was applied at the time of planting in all plots. The maize and sorghum plots were later top dressed with 20 kg N/ha after thinning. The trial was planted on 19th April 2012, during the long rains season using the varieties and plant spacing indicated in Table 2.

Determining the effect of water conservation and fertiliser application on productivity of maize and sorghum. The objective of this trial was to assess maize and sorghum response to soil moisture and soil fertility. The treatments consisted of two soil water management practices (flat tillage and tied ridges) and three fertiliser rates (0, 20 and 40 kg N/ha). Treatments were arranged in a split-split plot design with tillage as main plots, P rates as sub-plots and crops as sub-sub-plots. All treatments were replicated three times. The plot size was 6 x 5 m. Maize (WH403 variety) and sorghum (Kari Mtama 1 variety) were planted at a spacing of 75 cm by 30 cm (44,444 plants/ha) and 75 by 20 cm (66,666 plants/ha) respectively, on 16th April 2012. All plots received 20 kg P/ha at sowing. Maize was harvested on 14th November, 2012 and sorghum on 31st January 2013.

Table 1. Climatic conditions at Oljororok during the study period

Year	Month	Rainfall (mm)	Tmax (^{0}C)	Tmin (^{0}C)	Relative humidity (%)
2012	Jan	0.0	22.8	5.1	43.5
	Feb	29.8	23.3	6.3	48.1
	Mar	3.5	24.9	6.9	41.7
	Apr	266.9	22.8	10.1	66.9
	May	206.3	21.3	8.9	73.4
	Jun	105.9	20.9	7.9	73.4
	Jul	173.8	19.6	8.6	78.9
	Aug	142.3	20.2	7.6	73.4
	Sep	80.0	21.5	6.9	68.2
	Oct	120.7	21.6	8.6	66.4
	Nov	34.6	21.1	9.4	67.6
	Dec	77.2	20.8	9.1	66.4
2013	Jan	55.3	24.8	8.1	58.1
	Feb	0.0	23.4	7.0	48.5
	Mar	124.6	26.7	12.1	56.6
	Apr	295.1	22.0	10.1	58.1
	May	106.7	21.7	6.9	48.5
	Jun	98.5	21.0	8.0	56.6
	Jul				
	Aug				
	Sep				
	Oct				
	Nov				
	Dec				

Table 2. Crop varieties and plant spacing used

Crop	Variety	Spacing
Maize	Early: DH04	75 X 30 cm
	Medium: WH403	75 X 30 cm
	Late: DK8031	75 X 30 cm
Sorghum	Early: Gadam	75 X 20 cm
	Medium: Kari Mtama 1	75 X 20 cm
	Late: Macia	75 X 20 cm
Bean	Early: Kat B9	45 X 15 cm
	Medium: KK8	45 X 15 cm
	Late: GLP 24	45 X 15 cm
Pigeon pea	Early: ICPL 84091	450 X 10 cm
	Medium: ICEAP 00557	100 X 30 cm
	Late: ICEAP 00040	150 X 50 cm

Determining the effect of water conservation and plant population on productivity of common bean and pigeon pea. This trial assessed the effect of water conservation measures on crop yields of common bean and pigeon pea grown under different plant densities. The soil water management practices evaluated were flat tillage and tied ridges. Under each soil management practice, the performance of 3 plant densities (low, medium and high) of pigeon pea and beans were compared (Table 2). The treatments were arranged in a split-split plot design with tillage as main plots, plant densities as sub-plots and crops as sub-sub-plots. The plot size was 6x5 m replicated three times. Fertilizer rate applied was 40 kg P/ha in all plots at sowing. The trial was planted on 16th April 2012 at the crop spacing given in Table 3.

Table 3. Plant spacing and population used

Crop	Spacing (row, within row) and plant population		
	Low	Medium	High
Bean (KK8)	45x20 cm 111,111 pl/ha	45x15 cm 148,148 pl/ha	45x12 cm 185,185 pl/ha
Pigeonpea (ICEAP 00557)	100x40 cm 25,000 pl/ha	100x30 cm 33,333 pl/ha	100x24 cm 41,666 pl/ha

Results

Performance of crop varieties

Maize: Days to maturity and the yield for maize varieties are given in Table 4. Days to maturity and the maize yield did not differ significantly among the varieties. Grain yield was highest for LM variety (5701 kg/ha), followed by MM variety (5692 kg/ha) and least with EM variety (5193 kg/ha). The LM maize variety also out-yielded MM and EM varieties by 4157 kg/ha and 5905, respectively. The dry matter yield for MM and EM varieties was not significantly different. The days to maturity for the three varieties tended to differ by 10 days with EM variety taking the shortest period (175 days) and LM maize variety the longest period (195 days). Maize crop growth cycle extended into the short rains season

Sorghum: There were significant varietal grain yield differences but not with total dry matter (Table 4). The MM variety had the least grain value which was significantly ($P \leq 0.05$) lower than the other varieties. The grain yield values for MM and EM varieties were significantly different. The LM variety gave the highest dry matter yield (20260 kg/ha) which 47% and 49% greater than dry matter yield for MM and EM maturing varieties, respectively. It was difficult to the actual days to maturity for sorghum due to head smut disease.

Pigeon pea: The MM variety took the longest period (287DAS) to reach maturity followed by LM and the EM variety in a decreasing order (Table 4). Though the grain yields were significantly different, the EM variety yielded the greatest grain (881 kg/ha) while the LM variety gave the least (565 kg/ha). We did not collect the dry matter yield because the harvesting of pods was to continue in the succeeding season.

Common bean: Table 4 present days to maturity and the yield for common bean varieties during the LR2012 and SR2012/13 crop seasons. During the SR2012/13 season, LM variety took fewer days (98) to mature than in the SR2012 season. The days to maturity for the other two varieties were similar in both seasons. Significant varietal yield differences occurred in LR2012 season but it was dry matter yield only that showed significant differences in SR2012/13 season. The grain yield for EM (1013 kg/ha), MM (912 kg/ha) and LM (819 kg/ha) maturing varieties obtained during the SR2012/13 season were 239, 334 and 29% respectively, greater than the yields during the LR2012 season. Dry matter yield also increased by 1625 kg/ha (226%), 1585 kg/ha (104%) and 941kg/ha (49%) for EM, MM and LM varieties respectively in LR2012 season.

Table 4. Mean yields (kg/ha) for different crop varieties

	LR2012			SR2012		
Crop variety	Days to maturity	Grain	TDM	Days to maturity	Grain	TDM
Maize						
DH04	175	12938	5193			
WH403	185	14686	5692			
DK8031	195	18843	5701			
LSD(0.05)	NS					
Sorghum						
Gadam	-	1198b	13601a			
Kari Mtama 1	-	406a	13750a			
Macia	-	1825b	20260a			
LSD(0.05)		657	NS			
Pigeon pea						
ICPL 84091	217a	881a	-			
ICEAP 00557	287c	762a	-			
ICEAP 00040	277b	565a	-			
LSD(0.05)	9	NS				
Bean						
Kat B9	91	298a	718a	91	1013a	2343a
KK8	105	210a	1517b	106	912a	3102b
GLP 24	112	632b	1900b	98	819a	2841b
LSD(0.05)	NS	224	558			263

LR2012= long rain season of 2012, SR2012= short rain season of 2012, TDM= total dry matter, NS= not significant, Variety means within a crop with the same letter are not significant different at P≤0.05 level

Effect of water conservation and nitrogen fertiliser application on crop yield

Maize: Tied ridges tended to lower maize yield compared to flat tillage but the decrease was not significant (Table 5). When averaged across the tillage systems, the highest grain (5011 kg/ha) and dry matter (14067 kg/ha) was obtained in plots without N fertilizer; while the least yield were obtained in the plots with 40 kg N/ha.

Sorghum: The yields of sorghum were not affected by tillage and N fertilser rates (Table 5). However, the dry matter values were highest in the ridges. The sorghum plots with 40 kg N/ha gave the highest dry matter of 14067 kg/ha and lowest 7903 kg/ha in plots with 0 kg N/ha, when averaged across the tillage methods. The overall grain yield was negligible due to destruction by the head smut disease.

Effect of water conservation and plant population on crop

Pigeon pea: Tillage did not have a significant effect on the pigeon pea grain yield (Table 6). When averaged across the plant densities, the grain yield under tied ridges was less than under the flat tillage. The medium plant density (33333 plant/ha) gave the highest grain (719 kg/ha) followed by low (688 kg/ha) and high plant density (687 kg/ha).

Table 5. Effect of tillage and nitrogen application rates on maize and sorghum yields (kg/ha) during long rains season of 2012

Factor	Maize	Sorghum

	Grain	TDM	Grain	TDM
Tillage				
Flat	5011	14067	37	8121
Tied ridges	5124	13425	32	11684
LSD(0.05)	NS	NS	NS	NS
N-rates (kg/ha)				
0	5553	14298	48	10472
20	5084	14041	26	7903
40	4566	12900	29	11333
LSD(0.05)	NS	NS	NS	NS

TDM= total dry matter, NS= not significant

Common bean: The effect of tillage and plant density on pigeon pea and common bean grain and dry matter yields during the LR2012 and SR2012/13 season is given in Table 6. Tillage had a significant effect on bean grain yield during the SR2012/13 season only. However, the tied ridge tillage yielded higher grain and dry matter than the flat tillage. Though the bean yield was not significantly affected the plant population, the medium plant population (148148 plant/ha) resulted in the greatest grain and dry matter in both seasons.

Table 6. Effect of tillage and an plant density on pigeon pea and common beans yields (kg/ha)

	Pigeon pea (LR2012)		Common bean (LR2012)		Common bean (SR2012)	
Factor	Grain	TDM	Grain	TDM	Grain	TDM
Tillage						
Flat	783	-	265	1904	263a	2203
Tied ridges	612	-	358	2323	614b	3379
LSD(0.05)	NS		NS	NS	329	NS
Plant density						
Low	688	-	201	1554	486	2652
Medium	719	-	446	2643	536	3567
High	687	-	287	2144	292	2156
LSD(0.05)	NS		NS	NS	NS	NS

LR2012= long rain season of 2012, SR2012= short rain season of 2012, TDM= total dry matter; NS= not significant, means with the same letter are not significant at P≤0.05

Discussion

The performance of crop varieties

The performance of crop varieties appeared to be affected by the weather conditions. For example, the wet and cold conditions prevailing during LR2012 season encouraged fungal diseases which caused the bean plants to wither and rot: the most affected was KATB9 bean variety. During the LR2012 (April to September, 2012), the total rainfall and mean temperature were 975 mm and 14.6^{0}C while in SR2012 season (October 2012 to March 2013), total rainfall and mean temperature were 214 mm and 16.5^{0}C, respectively. The highest common bean yields obtained during the SR2012 were therefore due to the higher temperatures drier climatic conditions. The short rains season is therefore the most suitable for common bean production. The high rainfall (77 mm) conditions that prevailed in December 2012 when sorghum was reaching maturity stage caused sorghum heads to rot, drastically reducing grain yield.

These results suggest that the most productive crop varieties at the study site are DK8031 maize variety, Macia sorghum variety and ICPL 84091 pigeon pea variety. Yields for common bean varieties tended to vary with seasons.

Effect of water conservation and nitrogen fertiliser application on crop yield

Water conservation using tied ridges did not have a significant effect on maize and sorghum yield. Similar findings have been reported by Miriti et al. (2012). When averaged across the tillage systems, the highest yield of maize were obtained in plots without N fertilizer while sorghum dry matter was greatest in plots with 40 kg N/ha. These results suggest that soil nitrogen status were sufficient for maize but not for sorghum. Sorghum demand for N was high probably because of its high biomass production.

Effect of water conservation and plant population on crop

Though water conservation through ridge tillage resulted in the highest crop yields, the effect was significant on common bean grain yield only in one season. The medium plant densities for pigeon pea and common bean gave the highest yield, suggesting that plant densities of 148,148 plants/ha for common bean and 33,333 plants/ha for pigeon pea were the most appropriate plant densities. The reduced yield in higher plant densities was probably due to increased competition for soil moisture and nutrients.

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