# Chapter 8
# 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 Nyandarua County, Central Kenya

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**Abstract** Three experiments were conducted to evaluate the performance of maize, sorghum, common bean and pigeon pea varieties under different water management in a cool and wet region of Central Kenya, as a part of the studies at analogue sites. The first experiment evaluated the growth and performance of three varieties (early maturing: EM, medium maturing: MM and late maturing: LM) of maize (*Zea mays* L), sorghum (*Sorghum bicolor L.*), pigeon pea (*Cajanus cajan*) and common bean (*Phaseolus vulgaris L.*). The second experiment evaluated maize and sorghum 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. Maize, sorghum, pigeon pea and common bean took more than 180, 245, 217 and 95 days respectively, to reach physiological maturity. The MM maize variety (DK8031), EM pigeon pea

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variety (ICPL 84091) and LM common bean variety (GLP 24) yielded the greatest grain of 4,938, 881 and 620 kg/ha respectively, among the respective crop varieties. The sorghum varieties were attacked by fungal and rust diseases leading to yield losses in all seasons. Soil water conservation in general did not have a significant effect on crop yield though there were yield improvements. In the plant density trial, the medium plant densities of pigeon pea (33,333 pl/ha) and common bean (148,148 pl/ha) resulted in the greatest grain yields. The highest grain yield of maize (4,184 kg/ha) and sorghum (47 kg/ha) was obtained in plots with 20 kg/ha of nitrogen fertilizer. Based on the results of this study, pigeon pea and common bean can be introduced in the farming systems to improve crop diversity. The production of the tested sorghum varieties should be discouraged in this region because they are prone to fungal and rust diseases due to the cold and wet weather conditions.

**Keywords** Climate change · Maize · Sorghum · Piegeonpea · Bean · Moisture conservation · Fertility management

## 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). Erratic rainfall impacts negatively on crop yield and the episodic food insecurity in Kenya is mainly contributed by season to season variability in rainfall. Temperature affects the function of plant physiological processes (photosynthesis, respiration, leaf expansion rate) during crop growth and yield development (Hay and Porter 2006). Variations in temperature and rainfall due to climate change in any location may have negative or positive effects on crop growth and yields resulting in food insecurity. To avoid climate-induced food shortages, adaptation to impacts of climate change is fundamental (Lobell et al. 2008).

The climate-induced food shortages can be avoided through more efficient irrigation, soil and water management, improved crop varieties and better land cultivation practices (Naab et al. 2013). The capacity for farmers to adopt these management practices depends upon access to information on season conditions and improved technologies that make best use of the season (Mutunga and Hardee 2009). Such information is often lacking because it is site-specific in terms of soil and climate conditions. Currently in Kenya, there is an ongoing research aimed at developing promising strategies for adapting agriculture to climate change using analogue locations.

The main goal of the research project is to improve the ability of rainfed farmers to adapt to progressive climate change through crop, soil and water management innovations and appropriate crop genotype choices. In order to achieve the object of this study, three trials were implemented: (1) to assess the growth and performance of an early, medium and late maturing varieties of maize, sorghum, pigeon pea and common bean, (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 study was implemented in five sites with different climatic conditions from warm dry to very cool climate. One of the study sites selected for this study is Oljororok which has very cool and wet climate regime. This site is one of the major agricultural production areas in Kenya but it has been experiencing some rainfall and temperature changes due to climate change recently. Farmers have reported increased temperatures and more erratic rainfall patterns than before. The hypothesis of the study was that sorghum and leguminous crops such as pigeon pea and the common bean which are currently not grown in the humid areas may be the future crops for integrating the farming systems due to the emerging climate change. This paper presents some of the results obtained at this study site which is in Nyandarua County, central Kenya.

## Materials and Methods

### *Study Site*

The study was conducted at the Oljororok KARI experimental station from April 2012 to February 2014. The Oljororok site lies on latitude 0.04S and 36.35E at an elevation of 2,400 m above sea level. Its agro-ecological zone is described as Upper Highland sub-zone 2–3 (Pyrethrum, wheat and barley Zone) with average annual rainfall and temperatures of 820–990 mm and 14.0 °C, respectively (Jaetzold et al. 2006). Though the general rainfall pattern in Kenya is a bimodal type where the 'long rains crop season' fall between March and May and the 'short rains crop season' between October and December, the Oljororok site is very cool and wet, receiving rainfall throughout the year. This study was conducted between March 2013 and February 2014. The mean monthly rainfall and temperatures at the site during the study period were 0.6–295 mm and 13.9–19.4 °C, respectively (Table 8.1). The soil is classified as Ando luvic phaeozem which is deep dark brown soil, well drained with a clay loam texture (Jaetzold et al. 2006).

**Table 8.1** Weather conditions at Oljororok during the study period (from March 2013 to February 2014)

| Month | 2012 | | | | 2013 | | | | 2014 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rainfall (mm) | Tmax (°C) | Tmin (°C) | RH (%) | Rainfall (mm) | Tmax (°C) | Tmin (°C) | RH (%) | Rainfall (mm) | Tmax (°C) | Tmin (°C) | RH (%) |
| Jan | 0.0 | 22.8 | 5.1 | 43.5 | 55.3 | 24.8 | 8.1 | 58.1 | 0.6 | 22.7 | 7.0 | 69.0 |
| Feb | 29.8 | 23.3 | 6.3 | 49.4 | 0.0 | 23.4 | 7.0 | 48.5 | 55.8 | 23.1 | 8.7 | 59.2 |
| Mar | 3.5 | 24.9 | 6.9 | 41.7 | 124.6 | 26.7 | 12.1 | 56.6 | | | | |
| Apr | 266.9 | 22.8 | 10.1 | 66.9 | 295.1 | 22.0 | 10.1 | 58.1 | | | | |
| May | 206.3 | 21.3 | 8.9 | 73.4 | 106.7 | 21.7 | 6.9 | 48.5 | | | | |
| June | 105.9 | 20.9 | 7.9 | 73.4 | 98.5 | 21.0 | 8.0 | 56.6 | | | | |
| July | 173.8 | 19.6 | 8.6 | 78.9 | 214.1 | 22.7 | 11.5 | 72.3 | | | | |
| Aug | 142.3 | 20.2 | 7.6 | 73.4 | 229.4 | 23.0 | 10.0 | 77.4 | | | | |
| Sep | 80.0 | 21.5 | 6.9 | 68.2 | 66.8 | 23.3 | 11.4 | 67.3 | | | | |
| Oct | 120.7 | 21.6 | 8.6 | 66.4 | 91.0 | 23.2 | 10.5 | 60.8 | | | | |
| Nov | 34.6 | 21.1 | 9.4 | 67.6 | 130.3 | 20.3 | 9.7 | 73.7 | | | | |
| Dec | 77.2 | 20.8 | 9.1 | 66.4 | 159.5 | 22.5 | 12.4 | 69.4 | | | | |

*T*max maximum temperature, *T*min minimum temperature, *RH* relative humidity

## Field Experiments

### Assessment of the Performance of Cereal and Legume Crop Varieties Under Very Cool Climate

The objective of this trial was 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 the very cool climatic conditions in Nyandarua County. The experimental design was a completely randomized block design (RCBD) replicated three times. Basal phosphorus fertilizer (40 kg N/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 and on 30th April 2013, during the long rains season of 2012 and 2013 using the crop varieties and plant spacing indicated in Table 8.3.

### 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 N fertiliser rates (0, 20 and 40 kg N/ha). Treatments were arranged in a split-split plot design with tillage as main plots, N rates as sub-plots and crops as sub-sub-plots. All treatments were replicated three times. The plot size was 6 × 5 m. Maize (DK8031 variety) and sorghum (Kari Mtama 1 variety) were planted at a spacing of 75 by 30 cm (44,444 plants/ha) and 75 by 20 cm (66,666 plants/ha) respectively, on 16th April and on 30th April 2013, during the long rains season of 2012 and 2013, respectively.

### 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 (KK8) and pigeon pea (ICEAP 00557) grown under different plant densities. The soil water management practices evaluated were flat tillage and tied ridges. 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. Under each soil management practice, the performance of 3 plant densities (low, medium and high) of pigeon pea and common bean were compared (Table 8.2). The plot size was 6 × 5 m replicated three times. Phosphorus fertilizer was applied at 40 kg P/ha in all plots at sowing. Pigeon pea and common bean were planted at a row spacing of 100 and 45 cm respectively.

**Table 8.2** Plant population used for different treatments

| Crop | Plant population | | |
|---|---|---|---|
| | Low (pl/ha) | Medium (pl/ha) | High (pl/ha) |
| Common bean | 111,111 | 148,148 | 185,185 |
| Pigeon pea | 25,000 | 33,333 | 41,666 |

**Table 8.3** Days to physiological maturity and average yields (kg/ha) for different crop varieties

| Crop variety | Variety name | Plant spacing (cm) | Days to maturity | Grain | TDM |
|---|---|---|---|---|---|
| *Maize* | | | | | |
| EM | DH04 | 75 × 30 | 180 | 3,810 | 9,777 |
| MM | DK8031 | 75 × 30 | 189 | 4,938 | 14,457 |
| LM | WH403 | 75 × 30 | 189 | 4,754 | 13,586 |
| *Sorghum* | | | | | |
| EM | Macia | 75 × 20 | - | 634 | 13,735 |
| MM | Kari Mtama 1 | 75 × 20 | - | 203 | 9,044 |
| LM | Gadam | 75 × 20 | - | 1,117 | 11,219 |
| *Bean* | | | | | |
| EM | Kat Bean 9 | 45 × 15 | 95 | 478 | 1,063 |
| MM | KK8 | 45 × 15 | 111 | 464 | 1,868 |
| LM | GLP 24 | 45 × 15 | 110 | 620 | 1,939 |
| *Pigeon pea* | | | | | |
| EM | ICPL 84091 | 50 × 10 | 217 | 881 | - |
| MM | ICEAP 00557 | 100 × 30 | 287 | 762 | - |
| LM | ICEAP 00040 | 150 × 50 | 277 | 565 | - |

*TDM* above ground total dry matter, *EM* early maturing variety, *MM* medium maturing variety, *LM* late maturing variety

# Results

## *Performance of Crop Varieties*

The performance of maize, sorghum, common bean and pigeon pea varieties are given in Table 8.3.

**Maize** The average days to physiological maturity and the yield for maize varieties during the study period (LR2012 and LR2013 crop seasons). The EM variety matured at around 180 days after sowing and 10 days earlier the varieties. The maize crop growth cycle extended into the short rains seasons which start in October. Grain yield was highest with MM variety (4,938 kg/ha) followed by LM variety (4,757 kg/ha) and least with EM variety (3,810 kg/ha). The LM maize variety also out-yielded EM and LM varieties dry matter by 4,680 and 871 kg/ha, respectively.

**Sorghum** The MM variety (Kari Mtama 1) had the least grain yield value 203 kg/ha which was more than 67 % significantly ($P \leq 0.05$) lower than the yields for the other varieties (Table 8.3). No grain yield was obtained during the LR2013 season due to severe fungal and rust disease attack. The LM variety gave the highest average dry matter yield (13,735 kg/ha) which was 51 and 22 % more than dry matter yield for MM and EM maturing varieties, respectively. It was difficult to get the actual days to maturity for sorghum due to the rust disease which occurred during the grain filling stage and caused the grain to rot. From field observation, however, physiological started at around 245 days after sowing and harvesting was always done in February of the succeeding year.

**Common bean** The days to maturity and the yield data for common bean varieties in Table 8.3 is for three crop seasons (LR2012, SR2012 and LR2013). On average, LM variety took fewer days (95) to reach physiological maturity while maturity period for the other two varieties were similar at around 110 days after sowing. Significant varietal yield differences occurred in LR2012 season but it was dry matter yield only that showed significant differences in SR2012/13 season. The highest average grain yield were recorded with EM (620 kg/ha) followed by MM (464 kg/ha) and then LM (478 kg/ha) crop variety. Dry matter yield also followed grain yield trend. During the three seasons, the highest bean yield production occurred during the SR2012 and least in LR2012 season.

**Pigeon pea** The MM variety took the longest period (287DAS) to reach physiological maturity followed by LM and the EM variety in a decreasing order. Though the grain yields were not 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 continued into the succeeding season and there was too much leaf fall. The EM variety was harvested in two flushes while the other varieties were harvested in one flush.

### Effect of Water Conservation and Nitrogen Fertiliser Application on Crop Yield

**Maize** Effect of tillage and nitrogen application rates on maize yields is given in Figs. 8.1 and 8.2, respectively. Both tillage and N fertilizer did not have a significant effect on maize yield. Average maize grain yield under tied ridges was 3,977 kg/ha compared to 4,158 kg/ha under flat tillage system. Biomass yield under tied ridges and flat tillage were very almost equal at 10,955 and 10,802 kg/ha, respectively. When averaged across the tillage systems, the maximum grain (4,184 kg/ha) in plots with 20 kg/ha of N fertilizer and was 14 and 336 kg/ha more than the yields in plots with 0 and 40 KgN/ha, respectively. The greatest dry matter (10,996 kg/ha) was also obtained in plots with 20 KgN/ha fertilizer.

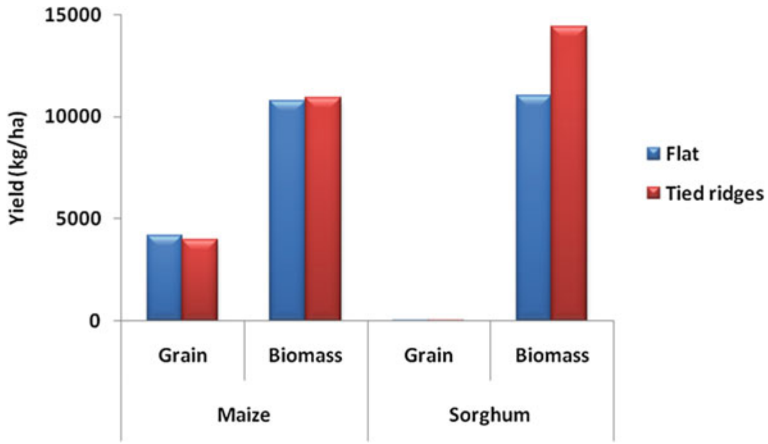


**Fig. 8.1** Effect of water conservation tillage on maize and sorghum yields

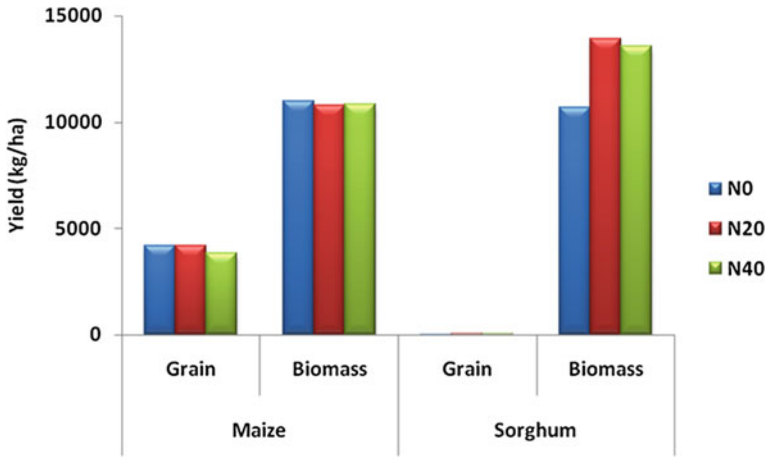


**Fig. 8.2** Effect of nitrogen fertilizer rates on maize and sorghum yields (N0 = 0 kg N/ha, N20 = 20 kg N/ha, N40 = 40 kg N/ha)

**Sorghum** The effect of tillage on mean sorghum yield for LR2012 and LR2013 seasons is presented in Fig. 8.1. Tied ridges increased sorghum biomass yields by 31 % from 11,021 to 14,435 kg/ha while grain yields were similar at 33 and 30 kg/ha for flat and tied ridges tillage, respectively. Significant effect of tillage was observed on biomass yield during the LR2012 season only. The sorghum plots with 20 kg N/ha gave the highest dry matter yield of 13,935 kg/ha and lowest 10,674 kg/ha in plots with 0 kg N/ha, when averaged across the tillage methods (Fig. 8.2). The overall grain yield was negligible due to rot caused by fungal and rust diseases.

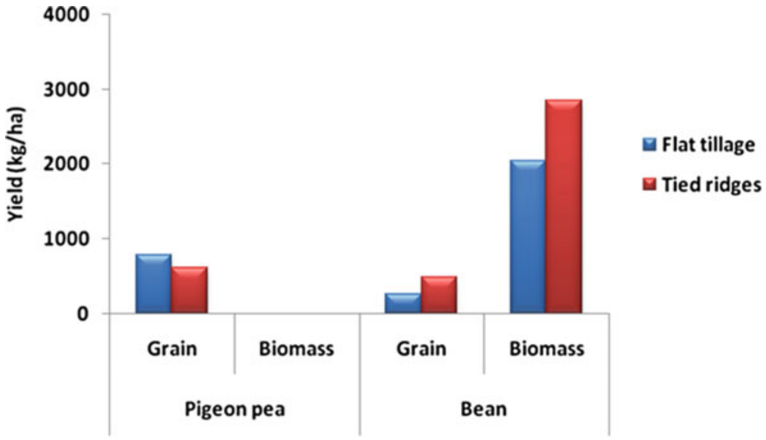


**Fig. 8.3** Effect of flat tillage and tied ridges on pigeon pea and common bean yields

### Effect of Water Conservation and Plant Population on Crop Yield

**Pigeon pea** Tillage did not have a significant effect on the pigeon pea grain yield. When grain yield was considered across the plant densities, the grain yield under tied ridges (612 kg/ha) was 21 % less than that under the flat tillage (Fig. 8.4). The medium plant density (33,333 plant/ha) gave the highest grain (719 kg/ha) followed by low (688 kg/ha) and high plant density (687 kg/ha).

**Common bean** The effect of tillage and plant density on common bean grain and dry matter yields during the LR2012 and SR2012/13 season is given in Figs. 8.3 and 8.4. Tied ridges had a significant effect on bean grain yield improvement during

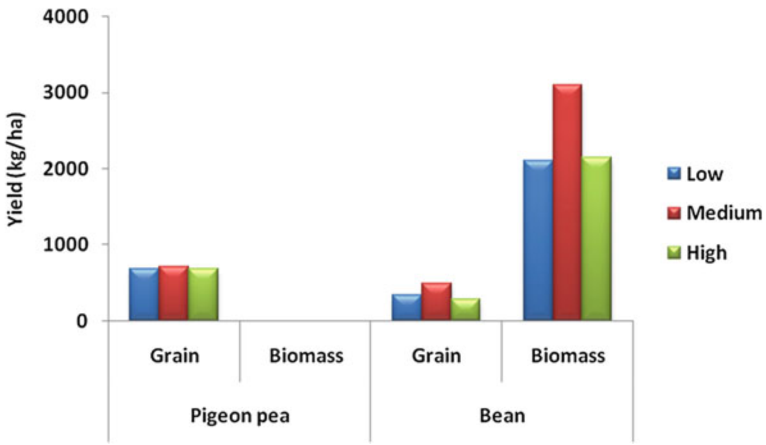


**Fig. 8.4** Effect of plant density on pigeon pea and common bean yields

the SR2012 season only. However, average yields for the two seasons showed that the tied ridge tillage yielded higher grain (84 %) and dry matter (38 %) than the flat tillage treatments. Though the bean yield was not significantly affected the plant population in any of the seasons, the medium plant population (148,148 plant/ha) resulted in the greatest grain (491 kg/ha) and dry matter (3,105 kg/ha).

## Discussion

### *The Performance of Crop Varieties*

The performance of crop varieties appeared to be affected by the weather conditions. The maturity period for maize, sorghum, pigeon pea and common bean increased by more than 99, 155, 113 and 10 days respectively, when compared to the mean number of days which the crops take to mature in the lower altitudes areas which are warmer and drier (KARI 2006). For example while the optimum temperature for pigeon pea cultivation is 18–38 °C, the mean temperatures during the study period ranged from 13.9 to 19.4 °C. The delayed maturity could largely be attributed to the cold weather conditions in Oljororok. Because of the extended crop cycles, only crop season could be achieved with maize and sorghum in Oljororok unlike in the in lower altitude areas where there are two crop seasons (long rains and short rains) per year.

Though the days to maturity for beans did not change much compared to the other crops, the wet and cold conditions prevailing during long rains seasons encouraged frost and fungal diseases which caused the bean plants to rot; the most affected was the KAT bean 9 bean variety. The highest yields for common bean were obtained during the SR2012 when compared to the long rains season. During the LR2012 (April to September, 2012), the total rainfall and mean temperature were 975 mm and 14.6 °C while the rainfall and mean temperature in SR2012 season (October 2012 to March 2013) were 214 mm and 16.5 °C, respectively. The higher temperatures and drier climatic conditions prevailing in 2012 must have favoured the growth of common bean crop leading to better grain yields. Thus, the short rains seasons are the most suitable for common bean production in Oljororok region.

The most productive crop varieties for maize and pigeon pea at the study site were found to be DK8031 and ICPL 84091, respectively. The yields of 4,938 kg/ha obtained from the DK8031 maize variety are similar to the yields for the highland maize varieties being grown in the area. In general, the maximum legume grain yield of ICPL 84091 pigeon pea variety (881 kg/ha) and GLP24 bean variety (620 kg/ha) obtained in this study were the range of yields production reported under rainfed conditions in Kenya (Katungi et al. 2009). Sorghum grain yield was very low because of fungal and rust disease attack on the crop during the grain filling stage. Kari Mtama 1 sorghum variety was the most affected variety by the diseases. In view of the low yields, the growth of the studied sorghum is not recommended in this region.

### 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 considered across the tillage systems, the highest grain yield of maize and sorghum were obtained in plots with 20 kg N/ha. These results suggest application of 20 kg/ha of N fertilizer was adequate for crop growth at the study site. Although sorghum biomass was high, overall grain yield was negligible (less than 47 kg/ha) due to frost, fungal and rust diseases which caused sorghum heads to rot. The prevalence of the diseases tended to coincide with grain filling stage (November–December).

### 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 the 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.

## Conclusions

Among the tested crop varieties, the most productive varieties at the study site are DK8031, Gadam, ICPL 84091 and GLP 24 for the tested maize, sorghum, pigeon pea and common bean varieties, respectively. The grain production in all sorghum varieties were very low due to frost, fungal and rust diseases. Water conservation using tied ridges did not have a significant effect on the crops yield. The medium plant densities for pigeon pea (33,333 plants/ha) and common bean (148,148 plants/ha) were found to be the most appropriate plant densities for the region. In general, the yield obtained from pigeon pea variety and common bean crops in this study were the range of yields production under rainfed agriculture in Kenya. Based on the results of this study, pigeon pea and common bean can be introduced in the farming systems to improve crop diversity. The best season for growing common bean is during the short rains season when it is warm. In view of the low yields, the growth of the sorghum varieties under study is not recommended.

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