Financial return of sorghum and cowpea production under selected water harvesting and integrated soil fertility management options in central Kenya highlands †

[Retorno financiero de la producción de sorgo y caupí en el marco de opciones seleccionadas de captación de agua y gestión integrada de la fertilidad del suelo en las tierras altas de Kenia central]

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SUMMARY

Background: Crop production in the arid and semi-arid lands (ASALs) is constrained by erratic rainfall and poor soil fertility. The reduction in yields from farmers' fields demonstrates the need for appropriate agricultural production technologies, innovations and management practices. **Objective:** To determine, on-farm, the effect of water harvesting, cropping systems and Integrated Soil Fertility Management (ISFM) technologies on sorghum and cowpea productivity and profitability in Central Kenya Highlands. **Methodology:** The treatments were arranged in a factorial structure with 3 levels of water harvesting (Tied Ridges-TR, Contour Furrows-CF and Farmers Practice-FP), 2 cropping systems (Sole and Intercrop) and 6 soil fertility management options laid out in a partially balanced incomplete block design (PBIBD), replicated thrice. Sorghum and cowpea grains and biomass yields were determined at harvesting and cost of production data was collected to determine cost benefit analysis. Data was subjected to Analysis of variance and means separated using Least Significant Difference (LSD) at $p \leq 0.05$. **Results:** The results showed that Net benefit, BCR and return to labour were significantly ($p<0.0001$) affected by the treatments in both study sites. The FP-sole 40P20NM2.5 was most superior with the highest BCR (2.53) and return to labour (4.1). The sole cropping systems recorded significantly higher BCR and return to labour (USD 1.4 and USD 2.8) than those under intercropping system. The fertilizer combinations (40P20M2.5) had higher BCR and return to labour of USD 1.5 and USD 2.9 as compared to experiment "controls". The lowest net benefit, BCR (<1) and return to labour was recorded in treatments regarded as experiment "controls" in both study sites. **Implication:** The results suggests that only low-input technologies with organic inputs are currently suitable and need to be adopted through a known crop intensification technologies that could be enhanced in these drought prone areas of central Kenya Highlands. **Conclusion:** Conventional tillage (FP) under sole cropping produced better returns on the money invested with minimal nutrient replenishment for producing improved sorghum than with farmers conventional way (traditional practice of no fertilizer input) in drier parts of this study.

Key words: Sorghum and cowpea; net benefit; return to labour; Central Kenya Highlands.

RESUMEN

Antecedentes: La producción de cultivos en las tierras áridas y semiáridas (ASAL) se ve limitada por las lluvias erráticas y la escasa fertilidad del suelo. La reducción de los rendimientos de los campos de los agricultores demuestra la necesidad de tecnologías, innovaciones y prácticas de gestión apropiadas para la producción agrícola. **Objetivo:** Determinar, en campo, el efecto de la recolección de agua, los sistemas de cultivo y las tecnologías de Manejo Integrado de la Fertilidad del Suelo (ISFM) sobre la productividad y rentabilidad del sorgo y el caupí en las tierras altas de Kenia Central. **Metodología:** Los tratamientos se organizaron en una estructura factorial con 3 niveles de recolección de agua (Tied Ridges-TR, Contour Furrows-CF y Farmers Practice-FP), 2 sistemas de cultivo (Sole e Intercrop) y 6 opciones

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de manejo de la fertilidad del suelo dispuestas en un diseño de bloques incompletos parcialmente equilibrado (PBIBD), replicado tres veces. Se determinaron los rendimientos de granos de sorgo y caupí y biomasa en la cosecha y se recopilaron datos de costo de producción para determinar el análisis de costo-beneficio. Los datos se sometieron a análisis de varianza y separación de medias mediante la diferencia mínima significativa (LSD) en $p \leq 0.05$. **Resultados:** Los resultados mostraron que el beneficio neto, la BCR y el retorno al trabajo de parto se vieron afectados significativamente ($p<0.0001$) por los tratamientos en ambos sitios de estudio. La FP-sole 40P20NM2.5 fue la más superior con el BCR más alto (2.53) y el retorno al trabajo de parto (4.1). Los sistemas de cultivo único registraron un BCR y un retorno a la mano de obra significativamente más altos (USD 1.4 y USD 2.8) que los del sistema de cultivos intercalados. Las combinaciones de fertilizantes (40P20M2.5) tuvieron un BCR más alto y un retorno al trabajo de trabajo de USD 1.5 y USD 2.9 en comparación con los "controles" del experimento. El beneficio neto más bajo, BCR (<1) y el regreso al trabajo de parto se registraron en los tratamientos considerados como "controles" experimentales en ambos sitios de estudio**.** **Implicación:** Los resultados sugieren que solo las tecnologías de bajos insumos con insumos orgánicos son actualmente adecuadas y deben adoptarse a través de tecnologías conocidas de intensificación de cultivos que podrían mejorarse en estas áreas propensas a la sequía de las tierras altas centrales de Kenia. **Conclusión:** La labranza convencional (PF) bajo cultivo único produjo mejores retornos sobre el dinero invertido con una reposición mínima de nutrientes para producir sorgo mejorado que con la forma convencional de los agricultores (práctica tradicional sin insumos de fertilizantes) en las partes más secas de este estudio.

Palabras clave: Sorgo y caupí, beneficio neto, retorno al trabajo; Tierras altas de Kenia central.

INTRODUCTION

Sub-Saharan Africa (SSA) has an estimated 315 million or one in two people who survive on less than one dollar per day and the prevalence of undernourishment is 27.8% of population in Kenya (FAO, IFAD, UNICEF, WFP and WHO. 2021). In Kenya, over 13 million of the 38 million people live below the poverty line of less than U.S$1 a day (World Bank, 2018). Agriculture is key to Kenya's economy, contributing to 55% of the Gross Domestic Product (GDP), 26% directly and another 27% indirectly through linkages with other sectors (World Bank, 2018; FAO, 2022). The sector also employs more than 40% of the total population and more than 70% of Kenya's rural people. Therefore, agriculture in Kenya is large and complex, with a multitude of public, parastatal, non-governmental and private sectors (World Bank, 2018; FAO, 2022).

Maize cropping in Sub-Saharan Africa (SSA) is generally characterized by yields < 2 t ha^{-1}, far below the world average of more than 5.5 t ha^{-1} (FAO, 2021). Intercropping is a common practice in most smallholder farming systems of East Africa and Kenya in particular (Odendo *et al*., 2011). Maize (*Zea mays* L.) and common beans (*Phaseolus vulgaris* L.) are ranked the 1st and 2nd important staple food crops in Kenya, and they are commonly intercropped (CIMMYT, 2003). These crops address food and nutrition security in the country, but the yields are often low. For instance, the average maize yield is about 2 t ha^{-1} and beans less than 1 t ha^{-1} against a potential of above 6 t ha^{-1} and 2 t ha^{-1} respectively (Government of Kenya, 2018). Such low yields are mainly caused by use of uncertified seeds, lack or low use of organic and inorganic fertilizers and employing of traditional crop husbandry practices (Opala *et al*., 2015).

The cost of acquiring modern inputs remains a big challenge beyond the reach of most smallholder farmers in agricultural production systems (Cornelis *et al.*, 2013). Intercropping of a cereal and legume in a cropping system has been reported to reduce individual crop yields resulting to low economic return especially in semi-arid areas of Kenya (Karuma *et al.*, 2016). The crop yield reduction in intercropping cereal and legume may be attributed by competition for moisture, nutrients, and solar radiation associated with intercropping systems (Belel *et al.*, 2014). Although there has been an increase of production of cereals and legumes in Kenya, this has been as result of cultivation in marginalized lands showing the productivity per unit area of land has continued to decline (Gebremichael *et al.*, 2019).

The low productivity of cereals and legumes is mainly associated with poor agronomic practices and cropping systems and climate variability in semi-arid areas where agricultural farms are mainly under rain-fed agriculture (Wamari *et al.*, 2012). In drier areas, common beans are often replaced by cowpea or groundnut where farmers commonly intercrop to secure food production by averting risk, and to maximize utilization of land and labour (Mucheru-Muna *et al.*, 2010). When crops are complimentary in terms of growth pattern, aboveground canopy, routing system, and their water and nutrient demand, intercropping effectively enables a more efficient utilization of available resources (sunlight, moisture and soil nutrients), and can result in relatively higher yields than when crops are grown separately, as pure stands (Gebremichael *et al.*, 2019).

Therefore, to improve soil fertility farmers integrate legumes in the cropping system to take advantage of improved utilization of growth resources by the crops, and improved reliability from season to season for enhanced crop yields (Odendo *et al.*, 2011). Other benefits of intercropping include a reduction in farm input use, diversification of diet and increased income, labor use efficiency, and higher yields (Dolijanović *et al.*, 2009). Soil moisture conservation through tillage practices is one of the appropriate ways of addressing soil moisture deficits especially in rain-fed agriculture (Sibomana, 2016). Identification of the best tillage methods that not only improve rain infiltration but also conserve adequate soil moisture for plant growth is thus imperative (Opala *et al.*, 2015). Study by Olarinde *et al.* (2012) has revealed and identified several efficient soil and water management practices in East Africa. However, the cost-benefit analysis of soil water management practices on growing intercrop of sorghum and cowpea is not well documented in dry and medium potential areas of Embu and Kirinyaga Counties in Kenya. Therefore, the adoption of any new technology depends on farmer's perceptions of financial benefits, particularly when additional labour is required in the establishment and management of these technologies (Mucheru-Muna *et al.*, 2014). Therefore, it is of paramount importance to account for economic returns of introduced soil fertility management options and water harvesting technologies. The main objective of this study was to investigate various water harvesting and integrated soil fertility management techniques for sorghum and cowpea production in Mbeere South and Kirinyaga West Sub-Counties of Central Kenya Highlands. The specific objective was to quantify the costs and benefits of different water harvesting and integrated nutrient management technologies under sorghum and cowpea productivity

MATERIAL AND METHODS

Description of the study area

The study was conducted in Kirinyaga West Sub-County of Kirinyaga County in Long rains 2011, 2012 and short rains 2012 (Figure 1). These study sites represent areas that may be classified as being under acute food, lower poverty levels and livelihood crisis (Maina *et al.*, 2012). The experimental site was located at Karima primary school in Kirinyaga County. The study trials were researcher-managed, and the local farmers were involved in learning and exposure to the technologies at physiological maturity stage by conducting field days towards the end of the season.

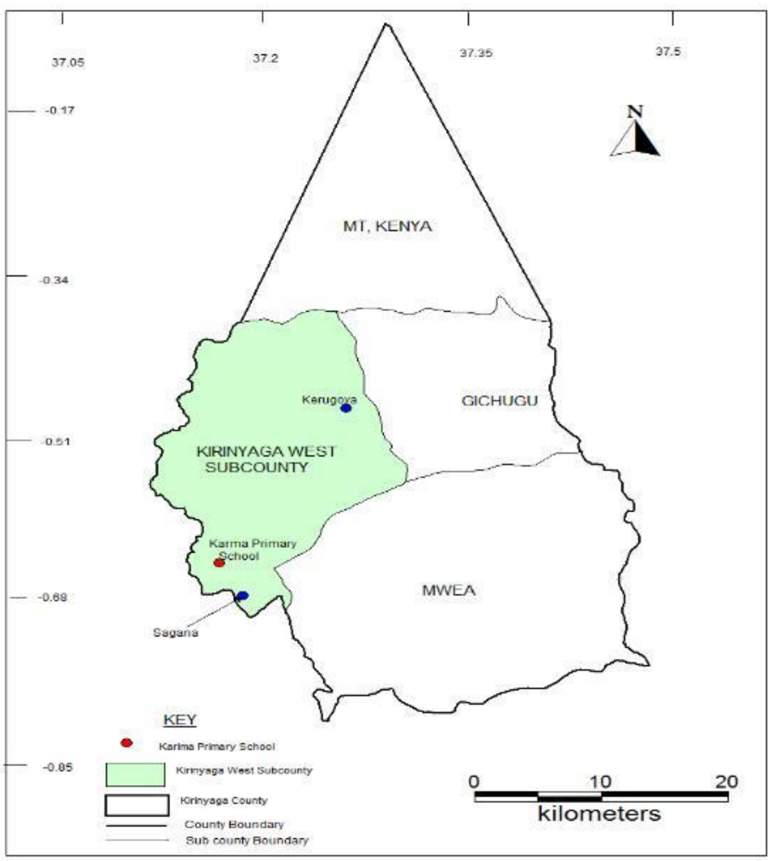

Figure 1. Map showing study site in Kirinyaga West Sub-County (Source: Author, 2024).

The rainfall distribution is received in two seasons; the long rains (LR) lasting from March to June, and short rains (SR) from October to December (Jaetzold *et al.*, 2007). Kirinyaga West Sub-County study site is classified as medium potential area with declining potential occupying a total area of 1478.1 km^2 and lies on the southern slopes Mt. Kenya. The County lies between latitudes 0^0 1^1 and 0^o 40^1 south and longitudes 37^o and 38^1 east at an altitude of 1,480 metres to 6,800 metres above the sea level. It receives a mean rainfall between 900-2,700 mm per annum and has a temperature of between 14 ^{0}C and 30 ^{0}C. The soils in this County are volcanic which are known as andisols favourable for maize crop production (Jaetzold *et al.*, 2007). In addition, Kirinyaga West Sub-County is covered by eight agro-ecological zones namely; forest zone (UH0), tea-dairy (LH1), coffee-tea zone (UM1), main coffee zone (UM2), marginal coffee zone (UM3), sunflower-maize zone (UM4), cotton zone (LM3) and marginal cotton zone (LM4) (Jaetzold *et al.*, 2007; Government of Kenya, 2020). In Kirinyaga West Sub-County, the study was carried out in agro-ecological zone (UM4) and it received rainfall distribution for 3 seasons as shown (Figure 2).

Farming systems

In Kirinyaga West Sub-County, the main farming systems are mixed farming, arable farming, subsistence farming, and plantation farming. Within the mixed farming system, intercropping is done according to different maturity periods of crops, e.g., intercropping tea or coffee bushes with avocado trees is quite common. Arable farming, where farmers grow crops on a piece of land designated for vegetables, legumes, grains, etc., is also widespread. Subsistence farmers mostly produce food crops such as maize, beans, and potatoes. Plantation farming involves growing one type of crop (e.g., tea, coffee, rice, or avocadoes) at a large scale for commercial reasons. Plantation farming requires a substantial amount of capital. It mostly occurs in the upper areas of the county, where tea and coffee are cultivated, and in the lower regions, which are given over to rice production (County Government of Kirinyaga, 2018).

Soil type of study areas

Soil types in the two areas varied in soil texture, sand, silt and clay. The soil texture (Table 1) is silty loams in Kirinyaga West based on soil textural triangle (Ryan *et al.*, 2001). The soil pH ranged from strongly acidic to moderately acidic in Karima site. This agrees with observations by Karuma (2019) who reported that low soil pH levels are associated with high Al saturation in some parts of Eastern Kenya. The main cause of acidic soil was the loss of exchangeable bases through leaching from the top soil and their replacement with Al ions where the soil solution is occupied mostly by aluminium and hydrogen ions.

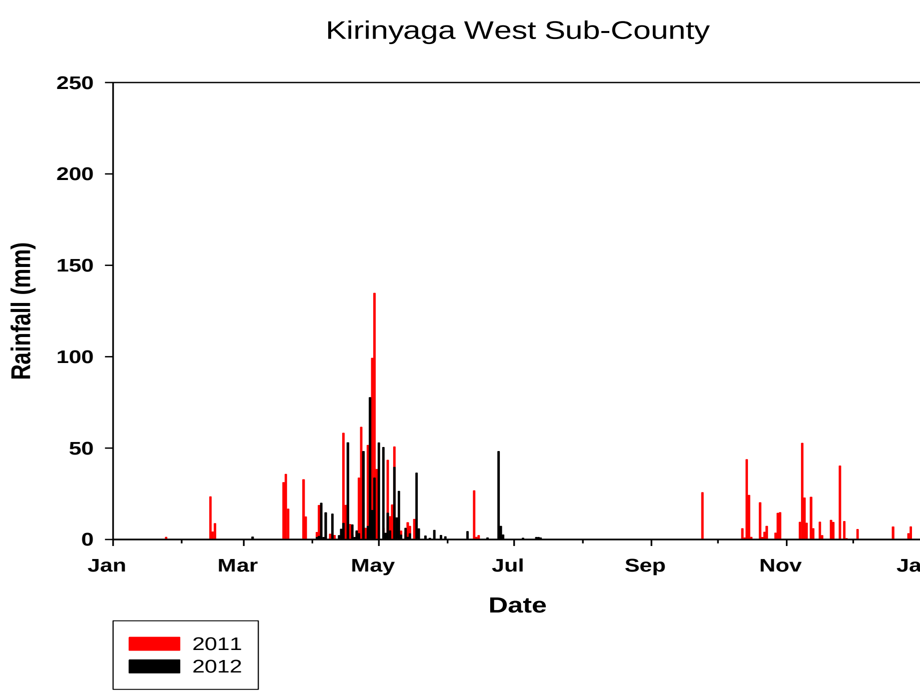

Figure 2. Rainfall distribution of LR 2011, 2012 and SR 2011 in Kirinyaga West Sub-County

The soils at both experimental sites had moderate organic C (1.8%) and total N (0.13%) which gives a C:N ratio of 14.5 which are known to enhance N mineralization. Phosphorus (P) was found to be high, ranging from 31.48 to 52.8 ppm with P considered to be adequate at the range of 13 to 22 ppm. This could be possibly due to continuous addition of inorganic P fertilizers since P is a major plant nutrient needed for numerous metabolic processes for improved crop production. The source of P is different from that of N because P is not usually supplied through biochemical fixation, but it comes from other external sources to meet plant requirements. Therefore, the results indicated that there was need for a blanket application of P to maintain its levels to avoid its depletion in the soils.

Table 1. Baseline soil characterization in Karima site, Kirinyaga West Sub-County.

Soil parameters	Kirinyaga West Sub-County Soil
Sand (%)	12
Silt (%)	78
Clay (%)	10
Soil type classification	Silty loam
pH (1:2.5 water)	5.2
Total N (%)	0.13
Total P (%)	-
Total organic Carbon (%)	1.88
C:N ration	14.5
P (ppm)	52.8
K (ppm)	445.3
Ca (ppm)	1017.6
Mg (ppm)	484.3
Cu (ppm)	5.5
Zn (ppm)	0.74
Fe (ppm)	52.2
Mn (ppm)	1729.5

Experimental Design and management

The study design was an experiment with treatments arranged in a factorial arrangement layout in Partially Balanced Incomplete Block Design (PBIBD). There were three factors; 1. Water harvesting techniques at 3 levels (Tied Ridges, contour furrows and conventional tillage/farmers Practice), 2. Cropping systems at two levels (Sole sorghum-Gadam, Sorghum and cowpea (M66) intercrop and 3. Soil fertility amendment options at 6 levels (Control, 40 kg P /ha + 40 kg N /ha, 40 kg P /ha + 20 kg N /ha, 40 kg P /ha + 40kg N /ha + Manure 5 t/ha, 40 kg P /ha + 20 kg N /ha + Manure 2.5 t/ha and manure 5 t/ha). This structure gave 36 treatment combinations (3 * 2* 6= 36). The experiment was replicated 3 times, giving a total of 108 plots in each of the sites with a blanket application of P at 40 kgha^{-1} (Table 2). The experiment was conducted during LR 2011, SR 2011 and LR 2012.

Land preparation was done using hand-hoe up to a depth of 15 cm and this represented farmers practice plots. Tied ridges and contour furrows were made manually as these were not yet mechanized. The furrows were made at spacing of 75 cm in the whole plots which represented contour furrows. Then for tied ridges plots, the furrows were cross tied (small ridges joining big ridges) which were made at 1 m intervals to prevent water movement along the furrow and create small check dams for rainwater harvesting within a plot. The ridges were 0.15 m, whereas the ties were 0.10 m in height. Fertilizer and Farmyard Manure (FYM) application was done by banding along shallow furrows.

Dry planting and weeding were done on need basis to ensure clean plots throughout the season. Inorganic fertilizers (NPK 23:23:0 and Triple Super Phosphate, TSP) were also applied along the shallow furrows and thoroughly mixed with soil during planting. The crops were planted in rows in 24 m^2 plots with a designed net plot of 2.25 m x 2 m at the center of the plot. Inter and intra row spacing between the sorghum pure stands was 0.75 m by 0.2 m, respectively. Sorghum and cowpea were planted in the same row but in alternating hills at the same spacing in intercrop plots. Thinning to a single plant per hill for sorghum and cowpea was done 2 to 3 weeks after emergence.

Economic data

The financial returns of combinations of water harvesting, cropping systems and soil fertility management options at different levels were determined by a partial budget analysis (CIMMYT, 2003). The purpose of the partial budget analysis was to evaluate the differences in costs and benefits among the different treatments. Cumulative input and output data for the three seasons were used. The Cost Benefit Analysis was carried out to calculate the cost for production and profitability associated with each treatment. The cost for production parameters were collected throughout the 3 seasons in 2 study sites; the cost for fertilizer, certified seeds and manure was based on local agro-vet prices in each study site. Other related costs for labour data such as land preparation, construction of water harvesting structures, fertilizer application, planting, thinning and crop yields harvesting was collected by recording the time taken and the number of individuals performing the activities (CIMMYT, 1988) (Table 3).

Table 2. Treatments arrangement structure for Kirinyaga West Sub-Counties.

Water harvesting techniques (3 levels)	Cropping systems (2 levels)	Organic and inorganic fertilizer rates (6 levels)
Tied Ridges (TR)	(i) Sole sorghum (Gadam)	i. Control
		ii. 40 kg P/ha + 40 kg N/ha (optimal rate)
Contour furrow (CF)	(ii) Sorghum and cowpea (M66)	iii. 40 kg P/ha + 20 kg N/ha (half optimal rate)
		iv. 40 kg P/ha + 40 kg N/ha + Manure 5 t/ha (optimal rates)
Farmers Practice (FP)		v. 40 kg P/ha + 20 kg N/ha + Manure 2.5 t/ha (half optimal rates)
		vi. Manure 5 t/ha

Table 3. Parameters used in calculation of economic benefit analysis in Karima site, Kirinyaga West Sub-County

Parameter	Mbeere South Sub-County (USD)			Kirinyaga West Sub-County (USD)		
	LR 2011	SR 2011	LR 2012	LR 2011	SR 2011	LR 2012
Price of TSP (0:46:0) fertilizer (USD kg^{-1} P)	1.24	1.24	1.3	1.24	1.24	1.3
Price of NPK (23:23:0) fertilizer (USD kg^{-1} N)	0.79	0.79	0.83	0.79	0.79	0.83
Price of manure (USD t^{-1})	11.28	11.28	11.84	11.28	11.28	11.84
Price of sorghum seed (USD kg^{-1})	1.41	1.41	1.48	1.41	1.41	1.48
Price of cowpea seed (USD kg^{-1})	1.69	1.69	1.78	1.69	1.69	1.78
Labour cost (USD day^{-1})	3.38	3.38	3.55	3.38	3.38	3.55
Price of sorghum grains (USD kg^{-1})	0.56	0.34	0.47	0.62	0.34	0.53
Price of cowpea grains (USD kg^{-1})	0.62	0.62	0.89	0.96	0.68	0.95
Price of sorghum stover (USD t^{-1})	67.67	56.39	65.1	67.67	56.39	71.01
Price of cowpea stover (USD t^{-1})	33.83	22.56	35.51	39.47	22.56	35.51

Note: Exchange rate 88.69 Ksh = 1 USD year 2011, Exchange rate 84.49 Ksh = 1 USD year 2012

The cost for net return was collected from market prices given the amount of sorghum and cowpea yields from each treatment for 3 seasons. The net benefit, benefit-cost ratio (BCR) (returns per shilling invested) and return to labour were used as economic tool in assessing treatments profitability and they were calculated using the following Equations 1-3;

Net benefits = {Gross benefits - Total costs of production} ……………………………….Equation 1

Benefit cost ratio = {Net benefits/ Total costs of production}………………………………. Equation 2

Return to labour = {(Gross benefit - Cost of inputs)}/Cost of labour…………….……...Equation 3

Data analysis

Biophysical data for the growth parameters, yield and economic returns was subjected to Analysis of variance (ANOVA) by use of SAS software version 9.4. Treatment means were separated using the Least Significant Different (LSD) method at 5% level of significant. Interaction effects were also performed to determine if combination of factors at different levels were significantly different. Correlation and regression were also conducted to determine if there were significant associations between variables.

RESULTS

Treatment Effects on Sorghum and Cowpea Grain Yields in Kirinyaga West Sub-County

The yields of sorghum and cowpea varied over the three seasons; i.e., >SR 2011>LR 2012 >LR 2011. Generally, grain yields increased with time from the 1st to the 3rd season in this study. However, SWH methods did not improve sorghum (p=0.0714, p=0.2018 and p=0.4902) and cowpea (p=0.1663, p=0.8756 and p=0.7856) grain yields during the LR 2011, SR 2011 and LR 2012, respectively. Similarly, cowpea seed yields remained statistically similar across the treatments (p>0.05) except from those with the highest yields during the LR 2011, 2012 and SR 2011 seasons, respectively (Table 4).

Statistically significant interaction effects of SWH* soil fertility options on cowpea production (p=0.0229) during the SR 2011 were observed. While all other factors did not show statistically significant interactions during the three cropping seasons. Cropping patterns' effects on sorghum grain yields during the LR 2011 and LR 2012 seasons were statistically significant (p=0.0024 and p=0.0048) but not in SR 2011 (p=0.0589). Soil fertility management options had significant effects (p<0.0001, p<0.0001 and p<0.0001) and (p=0.0434, p=0.0131 and p=0.0032) on sorghum and cowpea seed yields in LR 2011, SR 2011, and LR 2012, respectively (Table 4).

Table 4. Sorghum and Cowpea Grain Yields in Various Treatments During the LR 2011, SR 2011 and LR 2012 Cropping Seasons in Karima site, Kirinyaga West Sub-County.

Soil Water Harvesting	Cropping patterns	Soil fertility amendment practices	Sorghum yields (t/ha)			Cowpea yields (t/ha)		
			LR 2011	SR 2011	LR 2012	LR 2011	SR 2011	LR 2012
Tied ridging	Intercropping	20N+40P	0.3c	1.7bc	2.9bc	0.22ab	0.84ab	1.36ab
Tied ridging	Intercropping	20N+40P+M2.5	0.5bc	2.6ab	3.4bc	0.19ab	0.86ab	1.79ab
Tied ridging	Intercropping	40N+40P	0.2c	1.7bc	2.1cd	0.19ab	1.57a	1.84ab
Tied ridging	Intercropping	20N+40P+M5	0.6bc	1.7bc	2.5c	0.2ab	1.18ab	1.46ab
Tied ridging	Intercropping	Control	0.1c	0.2c	0.4d	0.04b	0.54b	0.48b
Tied ridging	Intercropping	M5	0.1c	2.4ab	2cd	0.13b	0.85ab	0.97b
Tied ridging	Monocropping	20N+40P	0.5bc	2b	2.1cd	.	.	.
Tied ridging	Monocropping	20N+40P+M2.5	1.8a	3.5a	5.6a	.	.	.
Tied ridging	Monocropping	40N+40P	0.5bc	2.7ab	3.1bc	.	.	.
Tied ridging	Monocropping	20N+40P+M5	0.8bc	2.9ab	3bc	.	.	.
Tied ridging	Monocropping	Control	0.1c	0.6c	1.2d	.	.	.
Tied ridging	Monocropping	M5	0.3c	2.1b	2.4c	.	.	.
Contour furrow	Intercropping	20N+40P	0.3c	2.1b	2.1cd	0.06b	0.94ab	1.18ab
Contour furrow	Intercropping	20N+40P+M2.5	0.4bc	2.6ab	1.9cd	0.14b	1.34ab	1.67ab
Contour furrow	Intercropping	40N+40P	0.1c	1.8b	2.6c	0.13b	1.28ab	1.54ab
Contour furrow	Intercropping	20N+40P+M5	0.7bc	2b	3.1bc	0.2ab	1.53ab	1.9a
Contour furrow	Intercropping	Control	0.1c	0.5c	0.5d	0.07b	0.22b	0.48b
Contour furrow	Intercropping	M5	0.1c	1.4bc	1.9cd	0.17ab	1.13ab	1.55ab
Contour furrow	Monocropping	20N+40P	0.5bc	2.6ab	3bc	.	.	.
Contour furrow	Monocropping	20N+40P+M2.5	0.9bc	2.7ab	2.8bc	.	.	.
Contour furrow	Monocropping	40N+40P	0.1c	2.3b	2cd	.	.	.
Contour furrow	Monocropping	20N+40P+M5	0.6bc	1.6bc	2.4c	.	.	.
Contour furrow	Monocropping	Control	0.1c	1.2bc	1.2d	.	.	.
Contour furrow	Monocropping	M5	0.3c	1.7bc	1.6cd	.	.	.
Farmers Practice	Intercropping	20N+40P	0.2c	1.5bc	2cd	0.09b	1.05ab	1.41ab
Farmers Practice	Intercropping	20N+40P+M2.5	0.8bc	2.1b	2.5c	0.33a	1.45ab	1.35ab
Farmers Practice	Intercropping	40N+40P	0.9bc	1.8b	2.5c	0.13b	1.33ab	1.79ab
Farmers Practice	Intercropping	20N+40P+M5	0.5bc	2.4ab	3.8b	0.31ab	1.09ab	1.46ab
Farmers Practice	Intercropping	Control	0c	0.3c	0.7d	0.14b	0.31b	0.78b
Farmers Practice	Intercropping	M5	0.5bc	2.2b	2.4c	0.19ab	1.13ab	1.91a
Farmers Practice	Monocropping	20N+40P	0.3c	1.6bc	2.4c	.	.	.
Farmers Practice	Monocropping	20N+40P+M2.5	0.9bc	1.9b	3.2bc	.	.	.
Farmers Practice	Monocropping	40N+40P	1b	2.4ab	1.7cd	.	.	.
Farmers Practice	Monocropping	20N+40P+M5	1.2ab	1.7bc	3.5bc	.	.	.
Farmers Practice	Monocropping	Control	0c	0.5c	0.8d	.	.	.
Farmers Practice	Monocropping	M5	0.1c	1.9b	1.8cd	.	.	.
CV (%)			13.39	11.9	10.5	13.1	12	10.4
$LSD_{(0.05)}$			0.622	1.19	1.13	0.178	0.848	0.834
SWH			0.0714	0.2018	0.4902	0.166	0.875	0.785
Cropping patterns			0.0024	0.0589	0.0048	.	.	.
Fertility management			0.0001	0.0001	0.0001	0.043	0.013	0.003
SWH*Cropping patterns			0.1575	0.1575	0.2236	.	.	.
SWH*Fertility management			0.0875	0.0875	0.2315	0.022	0.109	0.929
Cropping system*Fertility management			0.2065	0.2065	0.6049	.	.	.
SWH*Cropping patterns*Fertility management			0.4298	0.7318	0.4298	.	.	.

Note: Means followed by different letters in the same column are statistically different (p≤0.05) between the treatments. Monocropping=>Sorghum alone, Intercropping=>Sorghum plus cowpea.

The treatment under Tied ridging plus soil fertility amendment of 20N+40P+M2.5 under mono-cropping system was the highest producer (5.6 t ha^{-1}) of sorghum grain yields in LR 2012 compared to LR 2011 and SR 2011. Cowpea grain yields remained statistically at par in most treatments except in Farmers Practice-Intercropping-20N+40P+M2.5, Tied ridging-Intercropping-40N+40P and Farmer Practice-Intercop-M5 at 0.33 t ha^{-1}, 1.57 t ha^{-1} and 1.91 t ha^{-1} relative to the control group at 0.14 t ha^{-1}, 0.54 t ha^{-1} and 0.78 t ha^{-1} in LR 2011, SR 2011 and LR2012, respectively. The Contour Furrow and Farmers Practice Intercropping under soil fertility management options of 20N+40P+M5 and M5 respectively, recorded the highest cowpea yields of 1.9 t ha^{-}1 in LR 2012. Generally, the results also indicated that sorghum and cowpea grain yields production was lowest in experiment treatments regarded as “Controls”.

Cost benefits analysis for sorghum and cowpea production in Kirinyaga West Sub-County

Net benefit, BCR and return to labour they were significantly (p<0.0001) affected by the treatments (Table 5). TR-intercrop M5, CF-intercrop 40P40N, TR-intercrop M5, CF-intercrop 40P40N, TR-sole 40P20NM2.5 and CF-intercrop 40P40NM5 were the most profitable treatments with a net benefit of USD 2,350.01, USD 2090.61, USD 2,042.67, USD 1,814.63, USD 1,763.48 and USD 1,676.66 per hector, respectively.

Table 5. Net benefit, BCR and return to labour under various treatments in Karima site, Kirinyaga West Sub-County.

Water harvesting	Cropping systems	Soil fertility management	Net benefit (USD)	BCR (USD)	Return to labour (USD)
Tied Ridges	Intercrop	40P20N	1353.40bc	1.56bc	2.7bc
Tied Ridges	Intercrop	40P20NM2.5	1376.67bc	1.52bc	2.8bc
Tied Ridges	Intercrop	40P40N	1484.23b	1.64bc	2.9bc
Tied Ridges	Intercrop	40P40NM5	1465.29b	1.49bc	2.8bc
Tied Ridges	Intercrop	C	188.13cd	0.23cd	2.6bc
Tied Ridges	Intercrop	M5	2042.67ab	2.27b	3.6bc
Tied Ridges	Sole crop	40P20N	999.21bc	2.22bc	3.6bc
Tied Ridges	Sole crop	40P20NM2.5	1763.48ab	3.61a	5.4a
Tied Ridges	Sole crop	40P40N	1077.54bc	2.22bc	3.8b
Tied Ridges	Sole crop	4P40NM5	500.45cd	0.89cd	2.2c
Tied Ridges	Sole crop	C	88.08cd	0.22cd	1.2c
Tied Ridges	Sole crop	M5	510.43cd	0.93cd	2.1c
Contour furrows	Intercrop	40P20 N	1117.26bc	1.37bc	1.2c
Contour furrows	Intercrop	40P20NM2.5	1814.63ab	2.13bc	3.5bc
Contour furrows	Intercrop	40P40N	2090.61ab	2.46ab	3.9b
Contour furrows	Intercrop	40P40NM5	1676.66ab	1.82bc	3.3bc
Contour furrows	Intercrop	C	119.40cd	0.15cd	1.2c
Contour furrows	Intercrop	M5	933.43bc	1.10c	2.3c
Contour furrows	Sole crop	40P20N	1257.39bc	3.19ab	4.8ab
Contour furrows	Sole crop	40P20NM2.5	727.63c	1.68bc	3.1bc
Contour furrows	Sole crop	40P40N	946.26bc	2.20bc	3.8b
Contour furrows	Sole crop	40P40NM5	265.87cd	0.53cd	1.7c
Contour furrows	Sole crop	C	77.63cd	0.22cd	2.9bc
Contour furrows	Sole crop	M5	646.17c	1.52bc	1.2c
Farmers Practice	Intercrop	40P20N	1445.88bc	1.94bc	3.2bc
Farmers Practice	Intercrop	40P20NM2.5	1398.95bc	1.78bc	3.1bc
Farmers Practice	Intercrop	40P40N	1435.44bc	1.84bc	3.2bc
Farmers Practice	Intercrop	40P40NM5	2350.01a	2.77ab	4.5ab
Farmers Practice	Intercrop	C	-95.92d	-0.14d	0.9c
Farmers Practice	Intercrop	M5	1042.35bc	1.34bc	2.6bc
Farmers Practice	Sole crop	40P20N	596.17cd	1.83bc	3.3bc
Farmers Practice	Sole crop	40P20NM2.5	1043.01bc	2.86ab	4.8ab
Farmers Practice	Sole crop	40P40N	443.17cd	1.23bc	2.7bc
Farmers Practice	Sole crop	40P40NM5	1076.52bc	2.46ab	4.8ab
Farmers Practice	Sole crop	C	60.59cd	0.21cd	1.2c
Farmers Practice	Sole crop	M5	952.92bc	2.67ab	4.5ab

Water harvesting	Cropping systems	Soil fertility management	Net benefit (USD)	BCR (USD)	Return to labour (USD)
CV%			63	62.8	42.4
$LSD_{(0.05)}$			723.28	1.15	1.44
p_value			0.0001	0.0001	0.0001

Note: Means followed by different letters in the same column are significantly different (p≤0.05) between the treatments, C=Control, 40P40N=40 kg P/ha + 40 kg N/ha, 40P20N=40 kg P/ha + 20 kg N/ha, 40P40NM5=40 kg P/ha + 40 kg N/ha + Manure 5 t/ha, 40P20NM2.5=40 kg P /ha + 20 kg N/ha + Manure 2.5 t/ha, M5=manure 5 t/ha. Sole=Sorghum alone, Intercrop=Sorghum plus cowpea, exchange rate 86.59 Ksh = 1 USD.

There were 12 treatments which were most superior with the highest net benefit (USD >946.26), BCR (>USD 2.13) and return to labour (>USD 3.5) per hector and they were significantly different (*p*<0.05) from the rest of the treatments, and they recorded a BCR of greater than 2 (Table 5). Treatment TR-sole 40P20NM2.5 and CF-sole 40P20N were the most superior with the highest BCR of USD 3.61 and USD 3.19 and return to labor of USD 5.4 and USD 4.8 per hector, respectively. Generally, there was no significant difference recorded among water harvesting and cropping systems in the medium high potential areas of this study. The lowest net benefit, BCR (<1) and return to labour was recorded in treatments regarded as experiment “controls”

The lowest net benefit, BCR (<1) and return to labour was recorded in treatments regarded as experiment “controls” (Figure 3). The most superior treatment (CF-sole Control) in this category recorded a net benefit, BCR and return to labour of USD 175.12, USD 0.50 and USD 2.8 per hector, respectively (Table 4.23). Treatments under sole cropping systems recorded significantly higher BCR and return to labour (USD 1.4 and USD 2.8) than those under intercropping system.

For water conservation methods, farmers practice generated significantly higher BCR and return to labour of USD 1.2 and USD 2.5 per hector respectively, as compared to other water harvesting technologies (Figure 4). However, all the water harvesting methods had BCR of greater than 1.

The fertilizer combinations (40P20M2.5) had higher BCR and return to labour of USD 1.5 and USD 2.9 as compared to control which had USD 0.1 and USD 1.1 per hector, respectively. However, the treatment with fertilizer combination (40P20M2.5) was not different from 40P20N, 40P40P and M5 (Figure 5).

DISCUSSION

The findings from the Cost Benefit Analysis results (Table 5) showed that various treatments were costed to be able to get the value for sorghum and cowpea grains yields versus labour cost for production in both study sites. Based on this analysis, the recommendation to farmers has been concluded by considering profitability derived from individual treatments. Differences in profitability were due to differences in prices that farmers receive for their produce, which can be due to price fluctuations over seasons and years and across different study sites. The results have identified 3 and 12 treatments in Mbeere South and Kirinyaga West, respectively, with the highest net benefits, return to labour and BCR above 2 could be most and highly proposed for recommendation to farmers for adoption (FAO, IFAD, UNICEF, WFP and WHO, 2021).

The recommended treatments for adoption by farmers were different from each individual study site. These treatments recorded the highest net benefit, return to labour and BCR (>1). Similar findings have been reported by (Karuma *et al.*, 2020) and (Kamanga *et al.*, 2010) that treatments with BCR (>1) means that the cost of investment of sorghum and cowpea production has been recovered from the benefit realized. A break-even point is reached when a BCR of 1 is realized and determines the cost of recovery in any new farming technology. Only a few selected treatments had a BCR of above 2 in both study sites. A technology with a BCR above 2 is considered the minimum BCR in determining adoption of a given farming practice in smallholder farming systems (Ronner *et al.*, 2016; FAO, IFAD, UNICEF, WFP and WHO, 2021). However, the treatments regarded as controls were unable to reach the minimum requirement of BCR (>1) due to lack of investments on either inorganic or organic inputs resulting to the low net benefits realized. An explanation for this could be as a result of the very low yields recorded in controls during the two seasons. Similar results have been reported that farmers lack ability to invest in agricultural inputs and there is need to contain nutrient losses to realize increased crop productivity (Mucheru-Muna *et al.*, 2021; Oduor *et al.*, 2021).

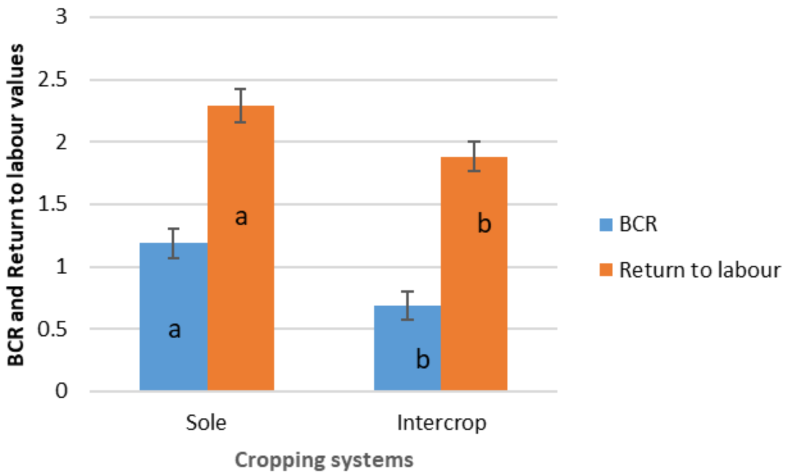

Figure 3. BCR and return to labour effect of cropping systems in Karima site, Kirinyaga West Sub-County.

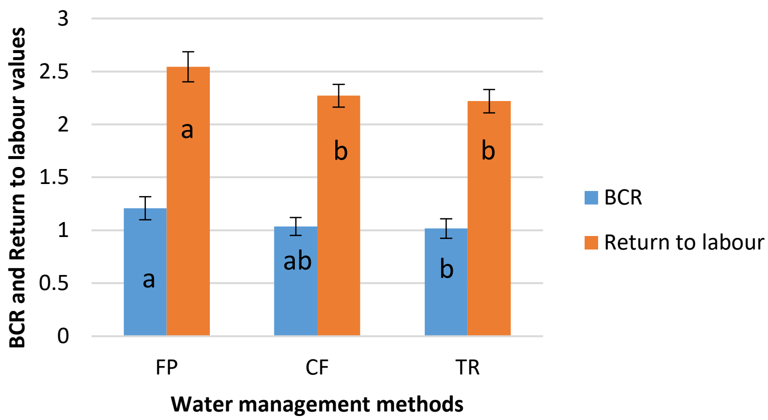

Figure 4. BCR and return to labour effect of water harvesting methods in Karima site, Kirinyaga West Sub-County.

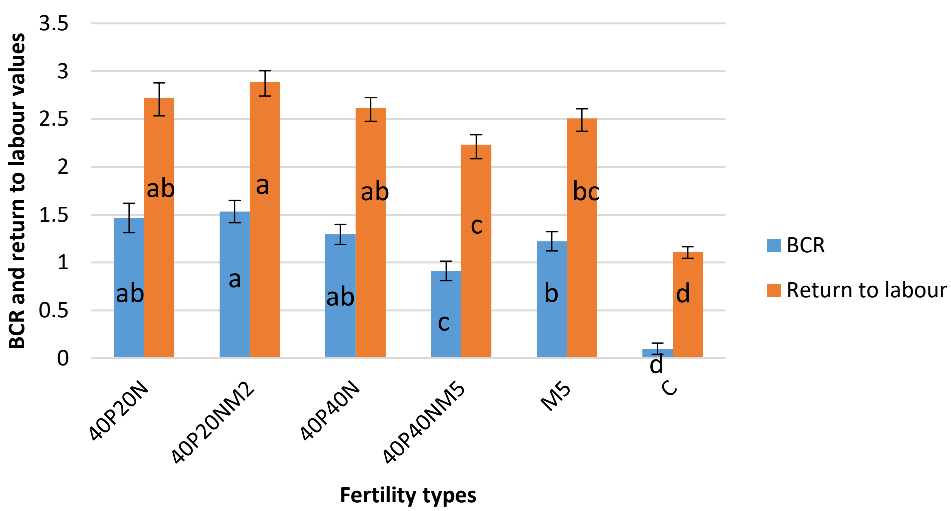

Figure 5. BCR and return to labour effect of soil fertility management options in Karima site, Kirinyaga West Sub-County.

The results have demonstrated that combination of minimal addition of organic and inorganic inputs (40P20M2.5) rate has highest net benefit, return to labour and a positive BCR (>1) as compared to experiment controls. This was as a result of higher sorghum and cowpea yields that were observed under these treatments. These findings agree with Hörner and Wollni (2022) observation that integrated soil fertility management strategies resulted in increased labor productivity and financial returns. The observations are also in agreement with those of Mutegi *et al.* (2012) and Mucheru-Muna *et al.* (2014) who observed higher net benefits, BCR and return to labour when combining *Tithonia diversifolia* with inorganic fertilizer over the sole application of fertilizers and control treatments. This study has reported that integration of minimal organic and inorganic fertilizers was a more economically feasible investment amongst the smallholder farmers of Mbeere South and Kirinyaga West Sub-Counties.

Similar observations were highlighted by Karuma *et al.* (2020) that synchronization process between soil nutrients release and crop uptake hence improved crop yields and consequently higher economic returns. This explains the finding that, on average, the half optimal combination of organic inputs and inorganic fertilizers had higher economic net benefit, BCR and return to labour than the recommended rate of fertilizer (40P40NM5). This is also in agreement with Mucheru-Muna *et al.* (2007) who reported similar results that there was higher return to labour in treatments with combined organics and inorganics as opposed to the controls. Also, similar results on higher economic returns are often associated with different soil fertility management technologies and water conservation technologies which have been highlighted in different studies (Hobbs *et al.*, 2008; Olarinde *et al.*, 2012).

There is limited purchasing power of inorganic fertilizers for use at recommended rates and use of organic inputs in combination with half rates of inorganic fertilizers in the area by smallholder farmers. This may become a chief supplement or complement to ameliorating nutrient deficiencies hence leading to higher crop yields and economic net benefit. With this in consideration, the combination of organic inputs and inorganic fertilizers has been recognized and regarded as a more economically feasible alternative for low input systems, offsetting the huge costs of purchasing inorganic fertilizers (Mucheru-Muna *et al.,* 2007; Mutegi *et al.,* 2012). Therefore, the results of this study confirmed that integrating organic inputs with inorganic fertilizers can be a viable option to the constricted use of inorganic fertilizers. Nonetheless, this approach may also be hindered by the high proportional requirements for organic inputs, labour necessities for cutting, carrying and incorporating these organics Karuma *et al.* (2020).

The findings also demonstrated that sole crops significantly performed better with higher net benefit in low potential areas (AEZ LH3) as compared to medium to high potential area (AEZ UM4) in Mbeere South and Kirinyaga West Sub-Counties, respectively. This could be as a result of previously reported higher sorghum and cowpea yields in this study. Explanation for this observation could be as a result of intra-specific nutrient competition posed by intercropping sorghum and cowpea in production systems as compared to maize legume intercrop. Contrary, results have been reported by (Zerihun *et al.*, 2014; Karuma *et al.*, 2016) that maize and bean had higher net benefits obtained from intercropping which were also consistent with the overall land equivalent ratios (>1) which underpins the higher grain yield advantage of intercropping over sole cropping.

Despite the low yields obtained by the intercrop systems in drier part of this study, the advantage of intercropping could have attributed to the additional yields of both crops but resulted in lower economic returns. Matusso *et al.* (2012) reported similar observations that comparative advantage of intercropping is attributed to the additional yields of intercrop which determines economic return. The same finding has also been reported by (Seran and Brintha, 2010) who found that intercropping provided higher economic returns to smallholder farmers than sole cropping systems. Rusinamhodzi *et al.* (2011) also reported that maize-legume intercropping reduces the risk of crop failure, improves productivity per unit area, and can provide a pathway to food security in vulnerable production systems.

Conventional tillage (FP) performed better and generated significantly higher BCR and return to labour as compared to the other water harvesting methods. This could be associated with the higher labour demand for construction of contour furrows and tied ridges by increasing labour for productivity in drier part of this study. These findings agree with (Miriti *et al.,* 2012) who reported that tied ridges produced higher maize grain yields but they were not economically viable due to intensive labour incurred during construction of ridges. Similar observation by (Hörner and Wollni, 2022) reported that higher labor demand could lead to increased labor of productivity in any farming systems.

Water harvesting methods and cropping systems did not observe any significant differences on BCR and return to labour in the wet part of this study. A possible explanation is that either of the water harvesting methods and cropping system could be recommended to farmers for adoption. This was as a result of even rainfall distribution in medium potential area and there was no need for construction of water harvesting methods as compared to drier parts of the study. Bayu *et al.* (2012) obtained similar results where yields response to the relative performance of tied ridges varies with several factors, including fertilization, total amount, and rainfall distribution, among others, during the cropping season.

The experimental controls recorded a significantly lower labour cost of production, but they resulted in low crop yields (Table 4). However, the labour costs were significantly higher in the treatments which received optimal rates of combination of organic and inorganic fertilizers followed by half optimal rates which recorded higher crop yields. On the other hand, treatments which received organic fertilizer alone recorded higher labour cost compared to control in both sites. A possible explanation for this observation could be as a result that crop yields (output) can highly influence the economic returns achieved in an enterprise. These findings agree with Mucheru-Muna *et al*. (2007) who reported that the controls recorded a significantly lower non-labour cost as compared to organic, organic + inorganic fertilizer and sole inorganic fertilizer treatments as they recorded higher crop yields.

CONCLUSION

The results reported in the study on economic data demonstrated clear evidence that there is need to incorporate water harvesting and integrated soil fertility management technologies on sorghum and cowpea productivity in Central Kenya Highlands. It was concluded that there are significant variations in the value of net benefits from the different water harvesting technologies, cropping system and soil fertility management options combinations. Conventional tillage (FP) under sole cropping produced better returns on the money invested with minimal nutrient replenishment for producing improved sorghum than with farmers conventional way (traditional practice of no fertilizer input) in drier parts of this study. On the other hand, the results concluded that any of the water harvesting methods, either under sole or intercropping could be suitable for recommendation to farmers for adoption in medium potential area of this study.

This concludes that recommendations to farmers are site specific and they can be used in designing local credit programs for resource-poor sorghum and cowpea producers in Central Kenya Highlands. The results also suggest that only low-input technologies with organic inputs are currently suitable and need to be adopted through a known crop intensification technologies that could be enhanced in these drought prone areas. Thus, there is a need to continually review farmers' recommendations based on past agronomic experiments, in the light of the present (and future) economic circumstances. This could be considered by CBOs, NGOs and EABL as an alternative food security initiative towards climate change mitigation in drought prone areas of drier parts of Central Kenya Highland.

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Compliance with ethical standards do not apply. Not applicable. There were no animal or human subjects used in this study by any of the authors.

Data availability. Data is available with Peterson Njeru (njerupeterson1@gmail.com) upon reasonable request.

Author contribution statement (CRediT). P N.M. Njeru – conceptualization, funding acquisition, methodology, project administration, investigation, data curation, formal analysis, visualization, Writing – original draft. **J. Mugwe -** supervision, validation, writing – review and editing. **M. Mucheru-Muna –** supervision, validation, writing – review and editing. **D. Lelgut –** project administration, supervision, writing – review and editing.

REFERENCES

Bayu, W., Rethman, N.F. and Hammes, P.S., 2012. Effects of tied-ridge, nitrogen fertilizer and cultivar on the yield and nitrogen use efficiency of sorghum in semi-arid Ethiopia. *Archives of Agronomy and Soil Science*, 58(5), pp.547-560. https://doi.org/10.1080/03650340.2010.532488.

Belel, M.D., Halim, R.A., Rafii, M.Y. and Saud, H.M., 2014. Intercropping of corn with some selected legumes for improved forage production: A review. *Journal of Agricultural Science*, *6*(3), p.48. http://dx.doi.org/10.5539/jas.v6n3p48

CIMMYT, 2003. Maize-bean conservation agriculture systems. *International Maize and Wheat Improvement Center (CIMMYT), Nairobi, Kenya*, pp. 22.

CIMMYT, 1988. From agronomic data to farmer recommendations: An economic training manual. Completely revised edition. Mexico D. F.

Cornelis, W.M., Araya, T., Wildermeersch, J., Mloza-Banda, M.K., Waweru, G., Obia, A. and Verbist, K., 2013. Building resilience against drought: the soil-water perspective. In: Boever, D. *et al.* (Eds). Desertification and Land degradation: Processes and Mitigation. Belgium: UNESCO Chair of Eremology, Ghent University, pp.1-15.

County Government of Kirinyaga, 2018. Kirinyaga County Integrated Development Plan 2018-2022. Kenya. *County Government of Kirinyaga, Kirinyaga, Kenya*.

Hörner, D. and Wollni, M., 2022. Does integrated soil fertility management increase returns to land and labor? Plot-level evidence from Ethiopia. *Agricultural Economics*, *53*(3), pp.337-355. https://doi.org/10.1111/agec.12699

Dolijanović, Ž., Kovačević, D., Oljača, S. and Simić, M., 2009. Types of interactions in intercropping of maize and soya bean. *Journal of Agricultural Sciences*, *54*(3), pp.179-187. http://dx.doi.org/10.2298/JAS0903179D

FAO, 2022. Agriculture in Kenya. Food and Agriculture Organization; 2018. https://www.fao.org/kenya/fao-in-enya/kenya-at-a-glance/en/.

FAO, 2021. The agriculture sector in Kenya; 2021. https://www.fao.org/kenya/fao-in-kenya/kenya-at-aglance/en/

FAO, IFAD, UNICEF, WFP and WHO, 2021. *The State of Food Security and Nutrition in the World 2021. Transforming food systems for food security, improved nutrition and affordable healthy diets for all*. Rome: Food and Agriculture Organization.

Gebremichael, A., Bekele, B. and Tadesse, B., 2019. Evaluation of the effect of sorghum-legume intercropping and its residual effect on yield of sorghum in yeki woreda, sheka zone, Ethiopia. *International Journal of Agricultural Research, Innovation and Technology*, *9*(2), pp.62-66. https://doi.org/10.3329/ijarit.v9i2.45412

Government of Kenya, 2018. National Climate Change Action Plan (Kenya) 2018-2022. *Ministry of Environment and Forestry, Nairobi, Kenya*.

Government of Kenya, 2020. Agricultural sector development strategy 2010-2020. *Government of Kenya, Nairobi, Kenya*, pp.120.

Hobbs, P.R., Sayre, K. and Gupta, R., 2008. The role of conservation agriculture in sustainable agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1491), pp.543-555. https://doi.org/10.1098/rstb.2007.2169

Jaetzold, R., Schmidt, H., Homet, Z.B. and Shisanya, C.A., 2007. Farm management handbook of Kenya: Natural conditions and farm information. 2nd Edition (Vol. 11/C). *Nairobi: Central Province, Ministry of Agriculture/GTZ.*

Kamanga, B.C.G., Waddington, S.R., Robertson, M.J. and Giller, K.E., 2010. Risk analysis of maize-legume crop combinations with smallholder farmers varying in resource endowment in central Malawi. *Experimental agriculture*, *46*(1), pp.1-21. https://doi.org/10.1017/S0014479709990469

Karuma, A.N., 2019. Soil Morphology, Physico-chemical Properties, Classification and Potential of Selected Soils in Kenya. *International Journal of Plant and Soil Science*, *30*(6), pp.1-12. https://doi.org/10.9734/ijpss/2019/v30i630193

Karuma, A.N., Gachene, C.K., Gicheru, P.T., Mtakwa, P.W. and Amuri, N., 2016. Effects of tillage and cropping systems on maize and beans yield and selected yield components in a semi-arid area of Kenya. *Tropical and Subtropical Agroecosystems*, *19*(2), pp.167-179.

Karuma, A.N., Gicheru, P.T. and Gachene, C.K., 2020. Financial returns of maize and bean production under selected tillage practices in semi-arid area of Mwala Sub County, Kenya. *Asian Journal of Agricultural Extension, Economics and Sociology*, *38*(10), pp.11-23. https://doi.org/10.9734/ajaees/2020/v38i1030424

Maina, I., Miruka, M., Rono, B., Njeru, P.N.M., Amboga, S., Gitari, J., Mahasi, M. and Murithi, F., 2012. Adaptive strategies and local innovations of smallholder farmers in selected agri-food systems of Central Kenya. *African Crop Science Journal*, *20*(1), pp.77-84.

Matusso, J.M.M., Mugwe, J.N. and Mucheru-Muna, M., 2012. Potential role of cereal-legume intercropping systems in integrated soil fertility management in smallholder farming systems of Sub-Saharan Africa. In: Third RUFORUM Biennial Meeting: Research Application Summary, Entebbe, Uganda, 24 - 28 September 2012. Uganda: Third RUFORUM Biennial Meeting, pp.1815–1843. http://ir-library.ku.ac.ke/handle/123456789/9350

Miriti, J.M., Kironchi, G., Esilaba, A.O., Heng, L.K., Gachene, C.K.K. and Mwangi, D.M., 2012. Yield and water use efficiencies of maize and cowpea as affected by tillage and cropping systems in semi-arid Eastern Kenya. *Agricultural Water Management*, *115*, pp.148-155. https://doi.org/10.1016/j.agwat.2012.09.002

Mucheru-Muna, M.W., Ada, M.A., Mugwe, J.N., Mairura, F.S., Mugi-Ngenga, E., Zingore, S. and Mutegi, J.K., 2021. Socio-economic predictors, soil fertility knowledge domains and strategies for sustainable maize intensification in Embu County, Kenya. *Heliyon*, *7*(2). https://doi.org/10.1016/j.heliyon.2021.e06345

Mucheru-Muna, M., Mugendi, D., Kung'u, J., Mugwe, J. and Bationo, A., 2007. Effects of organic and mineral fertilizer inputs on maize yield and soil chemical properties in a maize cropping system in Meru South District, Kenya. *Agroforestry Systems*, *69*(3), pp.189-197. https://doi.org/10.1007/s10457-006-9027-4

Mucheru-Muna, M., Mugendi, D., Pypers, P., Mugwe, J., Kung'u, J., Vanlauwe, B. and Merckx, R., 2014. Enhancing maize productivity and profitability using organic inputs and mineral fertilizer in central Kenya small-hold farms. *Experimental Agriculture*, *50*(2), pp.250-269. https://doi.org/10.1017/S0014479713000525

Mucheru-Muna, M., Pypers, P., Mugendi, D., Kung'u, J., Mugwe, J., Merckx, R. and Vanlauwe, B., 2010. A staggered maize–legume intercrop arrangement robustly increases crop yields and economic returns in the highlands of Central Kenya. *Field crops research*, *115*(2), pp.132-139. https://doi.org/10.1016/j.fcr.2009.10.013

Mutegi, E.M., Kung'u, J.B., Muna, M., Pieter, P. and Mugendi, D.N., 2012. Complementary effects of organic and mineral fertilizers on maize production in the smallholder farms of Meru South District, Kenya. *Agricultural sciences*, *3*(2), pp.221-229. http://dx.doi.org/10.4236/as.2012.32026

Odendo, M., Bationo, A. and Kimani, S., 2011. Socio-economic contribution of legumes to livelihoods in Sub-Saharan Africa. In: Bationo *et al*. (Eds.) *Fighting poverty in Sub-Saharan Africa: the multiple roles of legumes in Integrated Soil Fertility Management* (pp. 27-46). Dordrecht: Springer Netherlands. http://dx.doi.org/10.1007/978-94-007-1536-3_2

Oduor, N., Kiboi, M.N., Muriuki, A., Adamtey, N., Musafiri, C.M. and Ngetich, F.K., 2021. Soil management strategies enhanced crop yield, soil moisture, and water productivity in Nitisols of the Upper Eastern Kenya. *Environmental Challenges*, *5*, p.100375. https://doi.org/10.1016/j.envc.2021.100375.

Olarinde, L.O., Oduol, J.B., Binam, J.N., Diagne, A., Njuki, J. and Adekunle, A.A., 2012. Impact of the adoption of soil and water conservation practices on crop production: baseline evidence of the Sub-Saharan Africa challenge programme. *Journal of Agriculture and Environmental Science*, *12*(3), pp.293-305.

Opala, P.A., Kisinyo, P.O. and Nyambati, R.O., 2015. Effects of *Tithonia diversifolia*, farmyard manure and urea, and phosphate fertiliser application methods on maize yields in Western Kenya. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, *116*(1), pp.1-9. http://nbn-resolving.de/urn:nbn:de:hebis:34-2015011347180

Ronner, E., Franke, A.C., Vanlauwe, B., Dianda, M., Edeh, E., Ukem, B., Bala, A., Van

Heerwaarden, J. and Giller, K.V., 2016. Understanding variability in soybean yield and response to P-fertilizer and rhizobium inoculants on farmers' fields in northern Nigeria. *Field Crops Research*, *186*, pp.133-145. https://doi.org/10.1016/j.fcr.2015.10.023

Rusinamhodzi, L., Corbeels, M., Van Wijk, M.T., Rufino, M.C., Nyamangara, J. and Giller, K.E., 2011. A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. *Agronomy for Sustainable Development*, *31*(4), pp.657-673. https://doi.org/10.1007/s13593-011-0040-2

Ryan, J., Estefan, G. and Rashid, A., 2001. *Soil and Plant Analysis Laboratory Manual (2nd ed.)*. International Center for Agricultural Research in the Dry Areas (ICARDA) and the National Agricultural Research Center (NARC).

Seran, T.H. and Brintha, I., 2010. Review on maize based intercropping. *Journal of Agronomy*, *9*(3), pp.135-145.

Sibomana, J.D., 2016. *Effects of integrated soil fertility management and tied-ridging on maize-soybean yields and selected soil properties in Tharaka-Nithi County, Kenya*. Master of Science Thesis, Kenyatta University, Kenya.

Wamari, J.O., Sijali, V.I., Kheng, L.H., Miriti, J.M. and Esilaba, A.O., 2012. Use of Aquacrop model to predict maize yields under varying rainfall and temperature in a semi-arid environment in Kenya. *Journal of Meteorology and Related Sciences*, *6*, pp.23-32.

World Bank, 2018. World Agricultural financing-*World Bank Macroeconomy*, 2018. pp.32–80.

Zerihun, A., Tadesse, B., Shiferaw, T. and Kifle, D., 2014. Conservation agriculture: maize-legume intensification for yield, profitability and soil fertility improvement in maize belt areas of Western Ethiopia. *International Journal of Plant and Soil Science*, *3*(8), pp.969-985.