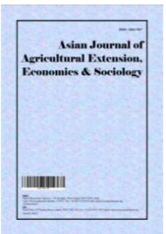

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Financial Returns of Maize and Bean Production under Selected Tillage Practices in Semi-arid Area of Mwala Sub County, Kenya

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Authors' contributions

This work was carried out in collaboration among all authors. Author ANK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors PTG and CKKG managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

An on-farm experiment was carried out to assess the short term financial returns over four cropping seasons of selected tillage practices and cropping systems in semi-arid Mwala Sub County of Kenya. The tillage treatments were Disc Ploughing (DP), Disc Ploughing and Harrowing (DPH), Ox-ploughing (OX), Subsoiling – Ripping (SSR), Hand hoeing with Tied Ridges (HTR), and Hand hoeing (H) only. There were three cropping systems of Sole Maize (SM), Sole Bean (SB), and Maize - Bean intercrop (M + B), which were investigated in a Split-Plot Design with four replications. Input and output prices were obtained from the local markets and used to compute the financial returns. Across the tillage practices, higher net returns were realized in DPH (USD 1165), DP (USD 1014), and SSR (USD 866). In the cropping systems, the intercrop (USD 1051) and sole bean (USD 954) reported higher benefits than sole maize (USD 692). Based on marginal analysis, it is

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economically viable to recommend the SSR with sole bean systems to farmers in Mwala Sub County as it produced the higher BCR (> 2) and an MRR (> 100 %) which is comfortable to most farmers.

Keywords: Maize and bean yields; financial analysis; semi-arid areas; Mwala Sub County.

1. INTRODUCTION

Intercropping is a common practice in most smallholder farming systems of East Africa and Kenya in particular [1]. Maize (*Zea mays* L.) and common beans (*Phaseolus vulgaris* L.) which rank first and second in importance as a staple food in Kenya [2] are commonly intercropped. While these crops are important for addressing food and nutrition security in the country, the yields are often low. For instance, the average maize yield is about 2 metric tonnes per hectare (Mg ha^{-1}) and beans less than 1 Mg ha^{-1} [3] against a potential of over 6 Mg ha^{-1} and 2 Mg ha^{-1} respectively [3]. Such low yields are mainly due to the use of the unimproved seed, sub-optimal fertilizer rates, and traditional crop husbandry practices [3,4]. The cost of acquiring modern inputs remains beyond the reach of the majority of smallholder farmers who form the bulk of agricultural producers [5]. Intercropping of the maize and beans has also led to their reduced individual yields [6]. The yield reduction could probably be attributed to competition for moisture, nutrients, and solar radiation associated with intercropping mixtures [7].

Although there has been an increase in maize and bean production in Kenya, this increase is largely due to the expansion of cultivated land into marginal areas. The productivity per unit area of land has continued to decline [8]. The low productivity of both maize and beans is mainly associated with poor agronomic practices and cropping systems [9] and climate variability in semi-arid areas where agricultural farms are mainly under rainfed farming [10].

To improve the fertility of soils and increase the yields, 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 [11,1]. Other benefits of intercropping include a reduction in farm input use, diversification of diet and increased income, labor use efficiency, and higher yields [12,13]. An assessment of selected tillage practices and the cropping systems is thus necessary to determine their possible contribution to crop yields in these semi-arid areas.

Soil moisture conservation through tillage practices is one of the appropriate ways of addressing soil moisture deficits especially in rainfed agriculture [9]. Identification of the best tillage methods that not only improve rain infiltration but also conserve adequate soil moisture for plant growth is thus imperative [14]. Several studies have been carried out and several efficient soil and water management practices have been identified in East Africa [15,16,17]. However, the cost-benefit of such tillage practices is not well documented in Kenya especially in the semi-arid Mwala Sub County. This study sought to evaluate the financial benefits from maize and bean production under different tillage practices and cropping systems in the semi-arid Mwala Sub County of Kenya.

2. MATERIALS AND METHODS

2.1 Experimental Site Description

This study was conducted in Mbiuni Location, Mwala Sub County, Kenya (1°15'S, 37°22'E). The area is characterized by low, erratic, and poorly distributed bimodal rainfall that makes crop production difficult under rainfed conditions. The long rains begin mid-March and end in May while short rains start mid-October and end in late November. Drought periods in the mid-season commonly occur in both seasons and impose a high risk to crop production in the Sub County. The mean annual rainfall for Mwala Sub County is 596 mm with mean monthly temperatures of 18°C to 25°C [18]. Maize and beans dominate household consumption. Pulses are grown in the Sub County and the predominant ones are beans, pigeon peas, cowpeas, green grams, and chickpeas.

2.2 Experimental Design and Layout

The trials were started in 2012 and ran for four cropping seasons during the long (LR) (March-May) and short rains (SR) (October – December) (i.e. LR 2012, SR 2012, LR 2013, SR 2013). The treatments consisted of six tillage practices: Disc Ploughing (DP), Disc Ploughing and Harrowing

(DPH), Ox-ploughing (OX), Hand hoeing with Tied Ridges (HTR), Hand hoeing (H) only, and Subsoiling – Ripping (SSR). The cropping systems treatments were Sole Maize (SM), Sole Bean (SB), and Maize - Bean intercropped (M + B). The treatments were arranged in a Split-Plot Design with tillage practices as the main plots and the cropping system as the subplots, with four replications.

2.3 Crop Management

A dryland maize variety (DH 02) and beans (rose coco - GLP 2) were used as the test crops. These crops were planted in rows in 25 m^2 plots. Maize crop was planted at a spacing of 90 × 30 cm in pure stands with the sole bean plants planted at a spacing of 45 × 15 cm. In the intercropping plots, the beans were at a spacing of 90 × 15 cm, grown between the maize rows. In the tied ridging plots, maize and beans were planted in the same row but in alternating hills at the same spacing. Thinning to a single plant per hill for maize and two plants for the legume was done four weeks after germination.

In each cropping system, nitrogen was applied at 60 kg N ha^{-1} (DAP 18:46:0) at planting to the maize and 60 kg N ha^{-1} (CAN 26:0:0) top dressed when maize was knee-high as recommended. The bean seeds were inoculated with Bio-Fix© biofertilizer before sowing. All the plots were hand-weeded using a hand hoe as is usually practiced by local farmers.

2.4 Grain yield Measurements

The final maize grain yields were determined from plants harvested in a sample area of 2 × 2 m at the centre of the plot. For beans, the grain yields were measured at maturity. Maize harvesting was done after the crops were dry in the field. The cob weights were sun-dried, shelled by hand, and standardized to 12.5% moisture content using a moisture meter. The yields were calculated based on the mean experimental plot area and later converted to metric tons per hectare (tonnes/ha = Mg ha^{-1}).

2.5 Financial Analysis

The financial returns of the tillage and cropping systems were determined by a partial budget analysis [19]. The purpose of the partial budget analysis was to evaluate the differences in costs and benefits among the different tillage practices and cropping systems. Cumulative input and output data for the four seasons were used. The crop yields were adjusted by 10% to cater for field and post-harvest losses [19]. The gross income for each crop was determined by multiplying the adjusted grain yield and the prevailing market prices at harvesting time for maize and beans. A mean market price of US Dollars (USD) 0.45 per kg for maize and USD 0.90 per kg for bean was used. The total variable cost was obtained by summing up the cost of seed, fertilizer, and labor under each cropping system (Table 1). In this regard, the average price of maize and bean seed used was USD 3.98 and USD 4.32 per 2 kg packet, respectively. The cost of fertilizer was USD 45.5 for DAP and USD 31.8 per 50 kg bag for the CAN fertilizer. Labor used for the various activities was at USD 4.54 per person per day (man/day). The gross margins were calculated as gross incomes less the total variable costs of production. The benefit-cost ratio (returns per shilling invested) was then computed as the total gross income divided by the total variable costs.

The marginal analysis was done to evaluate how the costs varied with the net benefits. The marginal analysis involves dominance analysis and calculating the marginal rate of returns (MRR) for the non-dominated treatments. In this regard, the tillage practices and cropping systems combinations were arranged in order of increasing variable costs. Treatment dominance was assessed by comparing those practices with lower gross margins (and higher total variable costs) than other practices with higher gross margins (and lower total variable costs). In dominance analysis, the former practices are usually considered dominated by the latter [19]. Because the dominated options are usually not the best to recommend to farmers, they were usually eliminated from further consideration such as calculation of MRR. The MRR is needed to further fine-tune farmer recommendations and allows focus on the non-dominated alternatives. In this study, the MRR was calculated as the ratio of the difference between the additional benefit gained and the additional cost incurred from a switch from one non-dominated option to another [19]. Based on this analysis, the recommendation was made by arranging the treatments in the order of increasing costs and then considering the MRR between each pair of treatments. The treatment with the highest net benefits and a minimum MRR of 100 % was recommended for farmers to adopt.

Considering the variability of input prices and market prices of agricultural commodities in each cropping season, a sensitivity analysis was done. This was done to test the non-dominated treatments and their ability to withstand the possible price changes. Differences in profitability are due to differences in prices that farmers receive for their produce, which can be due to the price fluctuations over seasons and years and across locations [20]. In this analysis, the marginal analysis was redone using the alternative set of input and output prices. Based on these differences, the sensitivity analysis was performed by changing prices with plus or minus 50 %, which is in line with similar studies [21,22]. Different scenarios assumed about the input and output prices changes are as follows:

- Output and input prices increasing by 50% from the current level.
- Output and input prices increasing by 100% from the current level.
- Output and input prices decreasing by 50% from the current level.

3. RESULTS AND DISCUSSION

3.1 Maize and Bean Grain Yields

Mean seasonal maize grain yields were 4.78 Mg ha^{-1} in LR 2012, 3.81 Mg ha^{-1} in SR 2012, 2.16 Mg ha^{-1} in LR 2013, and 2.73 Mg ha^{-1} in SR 2013 [6]. Higher maize grain yields were obtained in the sole maize plots in LR 2012 (5.01 Mg ha^{-1}), SR 2012 (4.19 Mg ha^{-1}), and the SR 2013 season (2.82 Mg ha^{-1}). There was a 3.6% increase in yields in the intercropping systems as compared to the sole maize in the LR 2013 season. The mean seasonal bean grain yields were 0.78 Mg ha^{-1} in LR 2012, 1.28 Mg ha^{-1} in SR 2012, and 1.40 Mg ha^{-1} in SR 2013. No bean yield data were recorded in LR 2013 due to poor rainfall distribution and prolonged dry conditions in the growing season [23]. Intercropping reduced the seasonal means of bean grain yields ($P < 0.05$) with a 54% decrease by intercropping (0.73 Mg ha^{-1}) compared to the sole bean (1.6 Mg ha^{-1}) [6].

3.2 Partial Budget Analysis

Results of the partial budget analysis of the different tillage and cropping systems are presented in Table 2. The average total labor costs associated with each tillage practice show a decreasing trend of DPH > DP > SSR > HTR > OX > H under the three cropping systems with values ranging from USD 288 to USD 362 (Tables 1 and 2). The higher costs in DPH and DP are attributable to the cost of hiring a tractor and the additional cost of a harrow at USD 17 for an acre of land for the DPH plots. The costs in SSR plots were due to the changing of the tillage implements (subsoiler then ripper) while in the HTR plots, additional costs were incurred due to the initial establishment and maintenance of the ridges. There were also some challenges observed in the use of the subsoiler and ripper implements like the maintenance of straight lines and some repetitions had to be done to increase the depth of the implement in the soil. This has been observed elsewhere by Steiner and Rockstrom [24].

On average, the input costs were the same for all the tillage but differed within the cropping systems. The total variable (labor + inputs) costs per tillage also showed a similar trend with the labor costs and ranged from USD 607 to USD 774 (Tables 1 and 2). The total variable costs for the sole bean crop (USD 361) were less than for maize (USD 735) and the intercrop (USD 833) for all the tillage practices. This can be attributed to the absence of any nitrogenous fertilizer application on bean crops. Farmers in this area hardly use any mineral fertilizer on bean crops, though phosphorus fertilization is necessary for root development, nodulation, nitrogen fixation process, pod formation, and filling in legumes [25]. Similar findings were observed by Zerihun et al. [26] working in the sub-humid maize belt of Western Ethiopia, who found a 34 - 36% reduction in the total variable costs in sole bean production as compared to sole maize production. The maize and bean intercrop increased the production costs due to the combined cost of maize and bean seed and sowing of the two crops.

According to Javeed et al. [27], the net benefits variability is more vital than variability in grain yields. An average trend by tillage on the net benefits, show a decreasing order of DPH > DP > SSR > OX > HTR > H, with values of USD 709 to USD 1165 under the three cropping systems (Table 2). This finding contradicts a review by Knowler and Bradshaw [28], who found more net benefits in conservation tillage practices and attributed it to reduced cost of production such as labor, fuel, and machinery with conservation tillage. The savings in production costs in the conservation tillage practices (SSR and HTR) in this study could not offset the benefits (Table 4) and yields [6], accrued by the conventional tillage methods (DP, DPH, OX, and H). This has been one of the key factors discouraging the adoption of conservation tillage practices in the maize-legume based smallholder farming systems [29].

The average net benefits by cropping systems were USD 1051(intercrop), USD 954 (sole bean) to USD 692 in the sole maize plots (Table 2). This is despite the low yields obtained by the intercrop systems in this study [6]. The comparative advantage of intercropping is attributed to the additional yields of maize and beans. This premise is supported by reviews done by Seran and Brintha [30] and Matusso et al. [31] who found that intercropping provided higher cash returns to smallholder farmers than sole cropping. Rusinamhodzi et al. [32] also state 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.

The higher net benefits obtained from intercropping are also consistent with the overall land equivalent ratios (LER) reported elsewhere in this study (an average LER of 1.36) which underpins the higher grain yield advantage of intercropping over sole cropping. The benefit-cost ratio (BCR) for all the treatments was greater than parity (Table 2), which means that the costs invested in the production of maize and beans were recovered from the benefits realized [33]. The BCR associated with each tillage practice show a decreasing trend of DPH > DP > OX > SSR > HTR > H with ranges of 2.2 to 3.0 (Table 2). The cropping systems showed a BCR trend of 3.6 (sole bean), 2.3 (intercrop), and 1.9 in the sole maize. Higher numerical values of BCR indicate higher net returns generated from the treatment combination while less BCR is due to higher cost of production. The BCR was higher than the threshold level of 2 in most of the treatments as was also found by Ronner et al. [22]. Therefore from this study, the DPH, DP, and OX under the sole bean and intercropping system would be the best options for the smallholder farmers in the semi-arid Mwala Sub County.

3.3 Marginal Analysis

3.3.1 Dominance analysis

Dominance analysis was used to further evaluate the marginal benefits of various treatment regimes based on incremental costs [19] and the results are shown in Table 3. The dominance analysis of the pooled data showed that sole maize and intercropping systems were dominated, having lower gross margins (net benefits) than those of sole bean with lower total variable costs.

When the tillage practices were considered, HTR was dominated by its cropping systems combinations. The domination can be attributed to the increased total costs with lower net benefits accrued (Table 2). This shows that the variable costs of the treatments had a direct impact on the overall returns of the treatments as corroborated by Khaliq et al. [34] in the rainfed areas of Islamabad, Pakistan. The domination of the tied ridges treatment could probably explain the decline in their popularity in recent years. The amount of labor required under the hand hoe cultivation has led to the low adoption of the tied ridges [35]. The dominated treatments were excluded from the calculation of MRR (Table 4).

3.3.2 Marginal rate of return

All non-dominated alternatives had greater than 100 % MRR as shown in Table 4. This implies that their costs are such that they do provide an acceptable rate of return. A minimum MRR of 100 % is generally acceptable to farmers [19] and was observed in all the non-dominated treatments. By switching from handhoe to ox plough, a farmer would do even better and would do even better by switching to SSR, DP and DPH, since the MRR between the tillage practices gives a rate of return above the 100 %. Hence, notwithstanding, the fact that a switch from hand hoe (H) to ox plough (OX) yields the highest MRR, a farmer's overall net benefits would still improve if additional investment is made to acquire SSR, DP, and DPH. The most appropriate one would be subsoiling – ripping (SSR) under the sole bean as the MRR is comfortably above the minimum (100%).

Subsoiling - ripping allows water to infiltrate the lower regions of the profile quickly, where more water is stored than would be without subsoiling and thus enhance deeper rooting of plants [36,24]. This additional water-holding capacity contributes to higher yields and most importantly, because subsoiling does not destroy crop residues on the surface, the practice is compatible with conservation agriculture [36,35,37]. The SSR would help reduce some drudgery associated with the handhoe, save time, and enhance some farm operations as well as improve soil and crop productivity [27]. The soil type at the study site is an Acrisol [38], which may become very hard in the dry seasons and land preparation for the next rainy season is difficult, especially by hand [39,40].

Table 1. Average cost of production for maize and beans under different tillage practices and cropping systems in Mbiuni Location, Mwala Sub County, Kenya

Variable Costs (USD)	Hand hoeing (H)			Handhoeing with tied ridges (HTR)			Disc Ploughing (DP)			Disc Ploughing + Harrowing (DPH)			Ox-ploughing (OX)			Subsoiling-ripping (SSR)		
	SB	SM	MB	SB	SM	MB	SB	SM	MB	SB	SM	MB	SB	SM	MB	SB	SM	MB
Labor costs																		
Land preparation	68.18	68.18	68.18	90.91	90.91	90.91	127.84	127.84	127.84	142.05	142.05	142.05	85.23	85.23	85.23	113.64	113.64	113.64
Planting and fertilizer application	45.45	45.45	56.82	45.45	45.45	56.82	45.45	45.45	56.82	45.45	45.45	56.82	45.45	45.45	56.82	45.45	45.45	56.82
First weeding	56.82	56.82	68.18	56.82	56.82	68.18	56.82	56.82	68.18	56.82	56.82	68.18	56.82	56.82	68.18	56.82	56.82	68.18
2nd weeding with fertilizer application	56.82	56.82	68.18	56.82	56.82	68.18	56.82	56.82	68.18	56.82	56.82	68.18	56.82	56.82	68.18	56.82	56.82	68.18
Harvesting	45.45	45.45	56.82	45.45	45.45	56.82	45.45	45.45	56.82	45.45	45.45	56.82	45.45	45.45	56.82	45.45	45.45	56.82
Total labour costs	272.73	272.73	318.18	295.45	295.45	340.91	332.39	332.39	377.84	346.59	346.59	392.05	289.77	289.77	335.23	318.18	318.18	363.64
Inputs																		
Maize seed (DH 02)	-	39.77	39.77	-	39.77	39.77	-	39.77	39.77	-	39.77	39.77	-	39.77	39.77	-	39.77	39.77
Bean seed (GLP 2)	51.82	-	51.82	51.82	-	51.82	51.82	-	51.82	51.82	-	51.82	51.82	-	51.82	51.82	-	51.82
100 kg DAP fertilizer	-	227.27	227.27	-	227.27	227.27	-	227.27	227.27	-	227.27	227.27	-	227.27	227.27	-	227.27	227.27
100 kg CAN fertilizer	-	159.09	159.09	-	159.09	159.09	-	159.09	159.09	-	159.09	159.09	-	159.09	159.09	-	159.09	159.09
Total input costs	51.82	426.14	477.95	51.82	426.14	477.95	51.82	426.14	477.95	51.82	426.14	477.95	51.82	426.14	477.95	51.82	426.14	477.95
Total variable costs (labor + input costs)	324.55	698.86	796.14	347.27	721.59	818.86	384.20	758.52	855.80	398.41	772.73	870.00	341.59	715.91	813.18	370.00	744.32	841.59

SB = Sole Bean, SM = Sole Maize, MB = Maize + Bean intercrop, 1 USD = KES 88

Table 2. Partial budget analysis of maize and bean production under different tillage practices and cropping systems in Mbiuni Location, Mwala Sub County, Kenya

	Hand hoeing (H)			Handhoeing with tied ridges (HTR)			Disc Ploughing (DP)			Disc Ploughing + Harrowing (DPH)			Ox-ploughing (OX)			Subsoiling-ripping (SSR)		
	SB	**SM**	**MB**	**SB**	**SM**	**MB**	**SB**	**SM**	**MB**	**SB**	**SM**	**MB**	**SB**	**SM**	**MB**	**SB**	**SM**	**MB**
Grain yield (t/ha)																		
Maize	-	3.44	3.09	-	3.20	2.97	-	3.57	3.45	-	4.07	3.62	-	3.40	2.85	-	3.12	2.72
Bean	1.00	-	0.56	1.30	-	0.77	1.83	-	0.75	2.16	-	0.77	1.62	-	0.70	1.73	-	0.91
Adjusted yields (t/ha)																		
Maize	-	3.10	2.78	-	2.88	2.67	-	3.21	3.10	-	3.66	3.26	-	3.06	2.56	-	2.81	2.45
Bean	0.90	-	0.50	1.17	-	0.69	1.74	-	0.68	1.94	-	0.69	1.46	-	0.63	1.56	0.00	0.82
Gross income (USD)																		
Maize	-	1407.27	1264.09	-	1309.09	1213.64	-	1459.09	1411.36	-	1663.64	1481.82	-	1390.91	1163.64	-	1277.27	1113.64
Bean	818.18	-	458.18	1063.64	-	627.27	1497.27	-	618.18	1767.27	-	627.27	1327.27	-	572.73	1418.18	-	745.45
TGI (USD)	818.18	1407.27	1722.27	1063.64	1309.09	1840.91	1497.27	1459.09	2025.00	1767.27	1663.64	2109.09	1327.27	1390.91	1736.36	1418.18	1277.27	1859.09
TVC (USD)	324.55	698.86	796.14	347.27	721.59	818.86	384.20	758.52	855.80	398.41	772.73	870.00	341.59	715.91	813.18	370.00	744.32	841.59
NB (USD)	493.64	708.41	926.14	716.36	587.50	1022.05	1113.07	700.57	1169.20	1368.86	890.91	1239.09	985.68	675.00	923.18	1048.18	532.95	1017.50
BCR	2.52	2.01	2.16	3.06	1.81	2.25	3.90	1.92	2.37	4.44	2.15	2.42	3.89	1.94	2.14	3.83	1.72	2.21

Cropping systems: SB = Sole Bean, SM = Sole Maize, MB = Maize + Bean intercrop, TGI = Total Gross Income, TVC = Total Variable Costs, NB = Net Benefits, BCR = Benefit Cost Ratio, USD = US Dollars, 1 USD = KES 88

Table 3. Dominance analysis of costs and returns in maize and bean production under different tillage practices and cropping systems in Mbiuni Location, Mwala Sub County, Kenya

Tillage	Cropping system	TVC (USD)	Net benefits (USD)
Handhoe	sole bean	324.54	493.64
Ox plough	sole bean	341.59	985.68
Handhoe + tied ridges	sole bean	347.27	76.36 D
Subsoiling + ripping	sole bean	370.00	1048.18
Disc plough	sole bean	384.20	1113.07
Disc plough + harrowing	sole bean	398.40	1365.23
Handhoe	sole maize	698.86	708.41 D
Ox plough	sole maize	715.91	675.00 D
Handhoe + tied ridges	sole maize	721.59	587.50 D
Subsoiling + ripping	sole maize	744.32	532.95 D
Disc plough	sole maize	758.52	758.52 D
Disc plough + harrowing	sole maize	772.73	890.91 D
Handhoe	intercrop	796.14	924.09 D
Ox plough	intercrop	813.18	923.18 D
Handhoe + tied ridges	intercrop	818.86	1022.05 D
Subsoiling + ripping	intercrop	841.60	1017.50 D
Disc plough	intercrop	855.80	1180.57 D
Disc plough + harrowing	intercrop	870.00	1239.09 D

D = dominated treatment, TVC = Total Variable Costs, USD = US Dollars, (1 USD = KES 88)

Table 4. Financial returns of the non-dominated tillage practices and cropping systems in Mbiuni Location, Mwala Sub County, Kenya

Tillage	Cropping system	Grain yield	Adjusted yields	Total gross income (USD)	TVC (USD)	Net benefits (USD)	MAC	MNB	MRR	BCR
H	SB	1.00	0.90	818.18	324.55	493.64				2.52
OX	SB	1.62	1.46	1327.27	341.59	985.68	17.04	492.04	2887	3.89
SSR	SB	1.73	1.56	1418.18	370.00	1048.18	28.41	62.50	220	3.83
DP	SB	1.83	1.74	1497.27	384.20	1113.07	14.20	64.89	457	3.90
DPH	SB	2.16	1.94	1767.27	398.41	1365.23	14.21	252.16	1775	4.44

Tillage: H = Hand hoeing, DP = Disc Ploughing, DPH = Disc Ploughing + Harrowing, OX = Ox-ploughing, SSR = Subsoiling - Ripping, Cropping systems: SB = Sole Bean, MAC = Marginal Cost (USD/ha), MNB = Marginal Net Benefits (USD/ha), MRR = Marginal Rate of Return, BCR = Benefit Cost Ratio, 1 USD = KES 88

Table 5. Sensitivity analysis with output and input prices are increased by 50 % in Mbiuni Location, Mwala Sub County, Kenya

Tillage	Cropping system	Total gross income (USD)	TVC (USD)	Net benefits (USD)	MAC	MNB	MRR	BCR
HTR	SB	1227.27	486.82	740.45				2.52
HTR	SM	2113.64	1048.30	1065.34	561.48	324.89	58	2.02
H	SM	2577.27	1194.20	1383.07	145.90	317.73	218	2.16
H	MB	2761.36	1228.30	1533.07	34.10	150.00	440	2.25
SSR	SB	3040.91	1283.69	1757.22	55.39	224.15	405	2.37
DP	SM	3163.64	1305.00	1858.64	21.31	101.42	476	2.42

Tillage: H = Hand hoeing, HTR = Hand hoeing with tied ridges, DP = Disc Ploughing, SSR = Subsoiling - Ripping, Cropping systems: SB = Sole Bean, SM = Sole Maize, MB = Maize-Bean intercrop, TVC = Total Variable Costs, USD = US Dollar, MAC = Marginal Cost (USD/ha), MNB = Marginal Net Benefits (USD/ha), MRR = Marginal Rate of Return, 1 USD = KES 88

Table 6. Sensitivity analysis with output and input prices increased by 100 % in Mbiuni Location, Mwala Sub County, Kenya

Tillage	Cropping system	Total gross income (USD)	TVC (USD)	Net benefits (USD)	MAC	MNB	MRR	BCR
H	SB	1636.36	649.09	987.27				2.52
DP	SB	2818.18	1397.73	1420.45	748.64	433.18	58	2.02
DPH	SM	3681.82	1637.73	2044.09	240.00	623.64	260	2.25
SSR	SB	4054.55	1711.59	2342.95	73.86	298.86	405	2.37
DP	SM	4218.18	1740.00	2478.18	28.41	135.23	476	2.42

Tillage: H = Hand hoeing, DP = Disc Ploughing, DPH = Disc Ploughing + Harrowing, SSR = Subsoiling - Ripping, Cropping systems: SB = Sole Bean, SM = Sole Maize, TVC = Total Variable Costs, USD = US Dollar, MAC = Marginal Cost (USD/ha), MNB = Marginal Net Benefits (USD/ha), MRR = Marginal Rate of Return, 1 USD = KES 88

Table 7. Sensitivity analysis with output and input prices are decreased by 50 % in Mbiuni Location, Mwala Sub County, Kenya

Tillage	Cropping system	Total gross income (USD)	TVC (USD)	Net benefits (USD)	MAC	MNB	MRR	BCR
H	SB	409.09	162.27	246.82				2.52
H	MB	704.55	349.43	355.11	187.16	108.29	58	2.02
SSR	SB	859.09	398.07	461.03	48.64	105.91	218	2.16
SSR	SM	920.45	409.43	511.02	11.36	50.00	440	2.25
DP	SB	1013.64	427.90	585.74	18.47	74.72	405	2.37
DP	SM	1054.55	435.00	616.48	7.10	33.81	476	2.42

Tillage: H = Hand hoeing, DP = Disc Ploughing, SSR = Subsoiling - Ripping, Cropping systems: SB = Sole Bean, SM = Sole Maize, MB = Maize-Bean intercrop, TVC = total variable costs, USD = US Dollar, MAC = marginal cost (USD/ha), MNB = marginal net benefits (USD/ha), MRR = marginal rate of return, 1 USD = KES 88

3.4 Sensitivity Analysis of the Different Tillage Practices and Cropping Systems

3.4.1 Sensitivity analysis with output and input prices increased by 50%

The sensitivity analysis was to analyze whether lower or higher input and output prices affected the order of profitability of the different tillage-cropping systems combinations [20]. The dominance analysis after the 50% increase in input and output prices are shown in Table 5. The net benefits increased with the increase in input and output prices. A 50% increase in the input and output prices led to the domination of OX, DPH, and their cropping system combinations. From the analysis, a switch from HTR (sole bean) to its sole maize is not advisable (MRR 58%). The current tillage of hand hoe would still be better for the farmers under sole maize and intercrop options.

3.4.2 Sensitivity analysis with output and input prices increased by 100%

The dominance analysis after the 100% increase in input and output prices are shown in Table 6. All the MRR except for DP (sole bean) were above 100%. A switch from hand hoe (H) to disc plough (DP) under sole bean would not be advisable when the prices increase due to a low rate of returns (58%). A switch from hand hoe (H) to disc plough + harrowing (DPH) under sole maize would be the best recommendation for the farmers. This is because the MRR is comfortably above the minimum and thus the change will be accepted by the farmers.

3.4.3 Sensitivity analysis with output and input prices decreased by 50%

The sensitivity analysis after the 50% decrease showed that net benefits were lower as shown in Table 7. The HTR, OX, and DPH as tillage practices were dominated as well as the intercropping systems except for handhoe. A switch of hand hoe under sole bean to its intercrop would not be recommended due to its low rate of returns (58 %). When the input and outputs decrease, the most appropriate recommendation would be subsoiling – ripping (SSR) under the sole bean. The MRR is comfortably above the minimum (100%) to be accepted by the farmers.

4. CONCLUSION

It was concluded that there are significant variations in the value of net benefits from the different tillage and cropping system combinations. Intercropping of maize and bean produced higher financial returns compared to sole maize cropping, as all the treatments in the latter were mostly dominated. The treatments were dominated due to their higher total costs vis-à-vis the lower net benefits realized. The savings in total variable costs in some tillage practices such as H, OX, and HTR could not sufficiently offset the benefits of increased yields in the tractor-ploughed plots i.e. DP and DPH.

The choice of an appropriate tillage practice remains the biggest challenge in subsistence farming. Thus, appropriate tillage(s) could be one of the panaceas for reducing the cost of production and hence increasing net benefits. From the sensitivity analysis from the 3 price scenarios, it was observed that the profitability of farming is highly dependent on the input and output prices. Differences in profitability are due to differences in prices that farmers receive for their produce, which can be due to the price fluctuations over seasons and years and across locations. 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. Inferring from the financial analysis of the present study and reality of resource constraints present in semi-arid areas, it is economically viable to recommend SSR under sole bean systems in Mwala Sub County (BCR >2, MRR > 100%, higher yields and can sustain a 50% decrease in input and output prices).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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