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Economics of Maize and Bean Production: Why Farmers need to Shift to Conservation Agriculture for Sustainable Production

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A B S T R A C T

Maize and dry bean are the most important food crops that feed over 85% of Kenyan households. However, the productivity of these crops is low due to the high costs of land preparation and weed control, soil infertility and limited soil moisture under the current conventional tillage system of production. A study was carried in Embu County and Kirinyaga County to determine the economic returns of a maize-bean rotation system under different tillage systems and fertilizer regimes. Maize was produced during the long rains under no-till with crop residue retention (NT+CR) and conventional tillage with no crop residue retention (CT-CR) and inorganic fertilizer regimes (NK, NP, PK, NPK, and NPK+CaMgZnBS). Dry bean was planted in the short rains in the same plots where maize under different nutrient management regimes and tillage systems had been grown and harvested. The trial was laid out in a split-plot design with the tillage method as the main plot and fertilizer as sub-plot. Economic performance was assessed using partial budget analysis based on labor data and prices of all inputs used during the production period. Grain yields were reduced by 10% to reflect farmers' yield levels. Maize and dry bean grains were sold at the prevailing farm gate prices. Results showed that maize-bean rotation was KE 22,718 cheaper under no-till with crop residue retention (NT+CR) than under conventional tillage with no crop residue retention (CT-CR). On average, NT+CR recorded KE 29,569 higher net benefit than CT-CR. The NT+CR tillage recorded a benefit to cost ratio of 3.7 compared to 2.7 recorded under CT-CR tillage system. The NT+CR with NK combined was the most profitable treatment with a benefit to cost ratio of 4.92 for maize and 4.33 for maize-bean rotation system. Based on this research, combination of no-till with crop residue retention has the potential to improve economic status and alleviate poverty among resource-constrained farmers.

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Introduction

Maize (*Zea mays* L.) and dry bean (*Phaseolus vulgaris* L.) is considered the most important food crops in Kenya. These crops are depended upon by over 85% of Kenyan households for food, income, soil improvement and maintenance, livestock feed and fuel (Muui et al., 2007; Rockström et al., 2009). However, despite the importance, the productivity of maize and bean has remained low at 1-2 t/ha and below 1 t/ha, respectively (CIAT, ICRISAT, and IITA, 2013; Otieno, 2019) and unable to meet rising population food demands (Olwande, 2012). Such low yields among smallholders who are the main producers in Kenya are largely due to drought (Purcell et al., 2007) and high soil infertility (Okalebo et al., 2007; Abate et al., 2012).

The high level of soil infertility reported across the country is due to low and inefficient use of soil fertility sources (Otieno et al., 2018). Across the country, fertilizer application is a practice only considered for maize but not for bean production. This leaves beans deficient of nutrients and only relies on BNF and soil for supply leading to low yields. Again, these fertilizers are mainly N-P based leading to unbalanced soil nutrients supply and further mining of other nutrients like K, S, Ca, Mg, Zn, and B from the soil. Coupled with conventional tilling of land that disturbs soil structure every season, the current system demands a lot of labour and finances for the purchase of adequate inputs for maize and bean production and do not provide a stable ecosystem for better nutrient recycling.

Low and erratic rainfall interferes with growth which consequently results in a low yield of maize and bean crops (Abate et al., 2012). Tilling of land during preparation and within-season and control of weeds coupled with the burning of crop residues destabilize soil structure and expose already limited soil moisture to a greater degree of losses through evapotranspiration leading to water stress. Any attempt by farmers to augment this soil moisture limitation through irrigation has failed because of weak financial capabilities to buy, install and maintain the system (Neubert et al., 2007). Moreover, the conventional method of crop production with its high level of farm operations demands a lot of labor per season which translates to a high cost of production beyond farmers' capability. Averting the current situation calls for the adoption of a new system which is cost-effective and sustainable. Conservation agriculture through its key principles- crop rotation, crop residue management (Hobbs et al., 2008; Erenstein et al., 2008; Shaxson et al., 2008), minimum soil disturbance and inorganic fertilizer application (Vanlauwe et al., 2014) is praised for its benefits in improving soil health, conserving soil water and increasing crop yields (FAO, 2011; Giller et al., 2011; Kihara et al., 2011). Combination of crop residue retention with no-till ensures soil structure is less disturbed and moisture conserved for crop growth. Growing maize and bean in a rotation system ensure a mutualism and greater utilization of farm resources- bean benefiting from residual fertilizers left after maize production while maize benefit from the N fixed by bean in the following season. The buildup of crop residue would also provide a thick layer of mulch that help in weed control and reduce direct sun heating on the ground. All these benefits would sum up and translate to low production cost and increased revenue generation. Therefore, this study was carried out to determine and compare the economic benefit of a maize-bean rotation system under conservation agriculture and conventional tillage system.

Materials and Methods

Study Site Description

The trials were carried out at the Kirinyaga Technical Institute (KTI) farms in Kirinyaga County and Kenya Agricultural and Livestock Research Organization (KALRO)'s, Crop Research Centre farms in Embu County during 2013/2014 short rains, 2014 long rains, and 2014/2015 short rain seasons. Kirinyaga site was located on longitude 370 19' 10.4''E and latitude 000 30' 18.3'' S while Embu site located on longitude 370 19' 10.4''E and latitude 000 33' 29.4''S. The two regions are located within a similar recommendation domain characterized by a similar agro-ecological zone, soil type, and cropping system. All sites were located in upper midland zones. The sites are characterized by humic nitisols, which originated from basic volcanic rocks. The soils are deep and highly weathered. The two sites have bi-modal rainfall pattern, wet seasons from March to May (long rains season) and October to December (short rains season) (Nicholson, 2000). Rainfall amounts range from 1100 mm to 1550 mm per year while mean daily temperature ranges from 12°C to 23°C.

Experimental Design and Treatments

The trial was a maize-bean rotation system where DK 8031 maize variety and EM-bean 14 Roscoco dry bean variety were used as the main crop and rotational crop respectively. Maize was produced during the long rains with the application of inorganic fertilizer whereas dry beans were produced in the short rain under the residual fertilizer nutrients. The trial was laid out in a split-plot design. Tillage methods (no-till with crop residue retention (NT+CR) and conventional tillage with no crop residue retention (CT-CR)) were assigned to main plots whereas fertilizer regimes (NK, NP, PK, NPK, and NPK+CaMgZnBS) were assigned to sub-plots. During maize production, N, P, K, Ca, Mg, Zn, B, and S nutrients were applied at the rates of 120, 40, 40, 10, 10, 5 and 26.3 kg/ha from urea, triple superphosphate (TSP), muriate of potash (MOP), calcium sulfate, magnesium sulfate, zinc sulfate, and borax nutrient sources respectively. Each treatment was replicated 3 times with each plot measuring 8 m by 10 m. Paths of 1.5 m and 1 m wide were left between blocks and plots, respectively.

Agronomic Practices

In the conventional tillage system, land preparation involved tilling of plots using a Hand-hoes before the onset of rains. On NT+CR plots, a mixture of Dual Gold 960EC® and Weedal 480 SL at a rate of 1.5 l/ha each was used, two days after planting, to ensure crops emerged on weed-free fields. Both maize and dry bean were planted at the onset of effective rain during their respective seasons at a plant spacing of 75 cm × 25 cm and 50 cm × 15 cm, respectively. During 2014 long rains, one-third of N full doses of all other nutrients were applied to the maize crop at planting. The remaining two- thirds (80 kg N) was applied in equal proportions as first and second topdressing at V_4 and V_{10} growth stages of maize, respectively. No fertilizer was applied during dry bean cultivation in the 2014/2015 short rains. Herbicides, 2, 4-D and Basagram® were used at rates of 1.5 l/ha each to control weeds on no-till plots during maize and dry bean production, respectively. A maximum of two hand weeding was done on conventional tillage plots using hand-hoes. Pests were monitored regularly and remedial action taken as required. Bulldock® 0.05 GR at the rate of 6 kg ha^{-1} was applied to the maize crop approximately 30 days after the crop emergence to control the maize stalk borer *(Busseola fusca).* Manual harvesting of both crops was done at maturity.

Data Collection and Analysis

Data were collected right from seed acquisition to the sale of products for both crops. All data collected were in monetary values- seed, fertilizer, labor, herbicides, pesticides costs, maize, bean and stover selling prices. The economic performance of a maize-bean rotation system under different tillage methods and fertilizer regimes was assessed through a partial budget analysis using labor data and prices of all applied inputs (seed, herbicides, fertilizers, and pesticides) from each of the plots during the entire period of study (CIMMYT, 1988). The sum of these costs is referred to as total variable costs (TVC) and excluded costs incurred relating to the harvest and sale of produce (CIMMYT, 1988). Harvested yields in each treatment were reduced by 10% to adjust to realistic farmers' yields, according to CIMMYT Economic Program (1988). This is because the management operations, in terms of planting, fertilizer application and weed control, are more precisely carried out on research plots than on farmer's plots, thus a reduction by 5% on yields is applied. In addition, research plots are smaller and tend to be more uniform than farmer plots leading to overestimation of yields from such research plots; thus, a reduction of 5% on yields is applied. Field benefits were also calculated. Field benefit (FB) refers to the revenue accrued from the sale of crops after deducting all costs involved during harvesting, processing, and sale of the crop from gross field benefits. For maize, it was obtained from the sale of grains and stover whereas only grains were sold for bean since there were no leaves that could be used as livestock feed at the time of harvesting. The costs of fertilizers, pesticides, herbicides, and labor were obtained from local agro-dealers, scientists and farmers involved in maize and dry bean production in Embu and Kirinyaga. Labor cost was KE 200 man-day^{-1}. Man-day is a unit of production equivalent to the work one person can do in a day. One man-day is equivalent to 8 working hours in Kenya. Dry grains were sold at unit market prices of KE 40 per kilogram for maize during August-October, 2014 and KE 70 per kilogram for beans during February-April, 2015. Maize stover is a popular livestock feed in the study area and thus was sold at KE 2000 per ton. The stover was collected from the field by the buyers using their own labor and transport. Maize and beans were harvested and sold immediately without the farmer incurring any storage costs. Net benefit (NB) and benefit to cost ratio (BCR) were calculated according to the CIMMYT Economic Program Manual (1988).

Results

Production of maize and dry bean resulted in higher total variable cost (TVC) under conventional tillage (CT-CR) than under conservation tillage (NT+CR) (Table 1 and 2), both as individual crops and under the rotation system. Maize and bean production as individual crops resulted in TVC of KE 55,553 and KE 21,425, respectively, under NT+CR and TVCs of KE 68,096 and KE 31,600, respectively, under CT-CR. The total variable cost of producing maize due to fertilizer application ranged between KE 35,297 (NK) and KE113,417 (NPK+ZnBMgCaS) under NT+CR and between KE47,600 (NK) and KE125,720 (NPK+ZnBMgCaS) under CT-CR systems.

Production of maize under NT+CR system resulted in KE 14,592 higher field benefit (FB) than under CT-CR system at Embu. However, a contrary observation was made in Kirinyaga where CT-CR recorded KE 21,654 more than NT+CR system. During bean production, a consistently high FB was observed under NT+CR than under CT-CR in both sites. In both sites, treatment NPK+ZnBMgCaS resulted in highest FB for maize and beans under all tillage methods. At Embu, maize production recorded FB ranging from KE 170,259 (NK under CT-CR system) to KE 210,867 (NPK+ZnBMgCaS under NT+CR) while production of bean on residual fertilizer recorded FB ranging from KE 67,760 (PK under CT-CR) to KE 117,824 (NPK+ZnBMgCaS under NT+CR). At Kirinyaga, a range of KE 134,768 to KE 184,031 and KE 48,182 to KE 98,272 was recorded due to maize and bean production, respectively.

Table 1 Effect of tillage method and fertilizer regime on economic returns of a maize-bean rotation system at Kenya Agriculture and Livestock Research Organization, Embu trial site during 2014/2015 long and short rains season

Yield (t/ha)	Mz	Bn	Mz TVC KE/ha	Bn TVC KE/ha	Mz NB KE/ha	Bn NB KE/ha	Mz BCR	Mz-Bn BCR
Tillage method								
NT+CR (CA)	4.9	1.4	55,553	21,425	135,740	71,695	4.06	4.00
CT-CR (CT)	4.5	1.3	68,096	31,600	108,605	49,325	2.91	2.72
SEm ±	0.1	0.0	8.0	8.0	3,381.0	2,638.0	0.07	0.06
Fertilizer regime								
NK	4.6	1.3	41,449	26,513	137,519	54,514	4.45	3.96
NP	4.6	1.3	50,169	26,513	130,979	54,772	3.69	3.52
NPK	4.7	1.4	55,769	26,513	129,910	67,133	3.39	3.49
NPK+ZnBMgCaS	5.1	1.7	119,569	26,513	80,576	81,671	1.69	2.14
PK	4.5	1.1	42,169	26,513	131,880	44,463	4.24	3.69
SEm ±	0.1	0.1	13.0	13.0	5,470.0	4,268.0	0.12	0.10
Interaction								
CA NK	4.8	1.3	35,297	21,425	152379	62,156	5.32	4.78
CA NP	4.9	1.3	44,017	21,425	146,168	62,720	4.32	4.19
CA NPK	4.9	1.6	49,617	21,425	143,733	84,437	3.90	4.21
CA NPK+ZnBMgCaS	5.4	1.8	113,417	21,425	97,450	96,399	1.86	2.44
CA PK	4.5	1.2	35,417	21,425	138,970	52,766	4.92	4.37
CT NK	4.3	1.2	47,600	31,600	122,659	46,872	3.58	3.14
CT NP	4.4	1.2	56,320	31,600	115,789	46,823	3.06	2.85
CT NPK	4.5	1.3	61,920	31,600	116,086	49,828	2.88	2.77
CT NPK+ZnBMgCaS	4.8	1.5	125,720	31,600	63,702	66,942	1.51	1.83
CT PK	4.4	1.1	48,920	31,600	124,790	36,160	3.55	3.00
SEm ±	0.2	0.1	18.0	18.0	7,560.0	5,898.0	0.17	0.13

SEM= Standard error of means, Mz= Maize, Bn= Bean, TVC= Total variable cost, NB= Net benefit, BCR= Benefit to cost ratio.

Table 2 Effect of tillage method and fertilizer regime on economic returns of a maize-bean rotational system at Kirinyaga

Technical Institute trial site during 2014/2015 long and short rains seasons.

Yieldt/ha	Mz	Bn	Mz TVC KE/ha	Bn TVC KE/ha	Mz NB KE/ha	Bn NB KE/ha	Mz BCR	Mz-Bn BCR
Tillage method								
NT+CR (CA)	3.8	1.1	55,553	21,425	101,255	48,129	3.34	3.34
CT-CR (CT)	4.4	1.0	68,096	31,600	110,366	29,386	2.95	2.67
SEm ±	0.1	0.0	8.0	8.0	2,083.0	1,848.0	0.04	0.04
Fertilizer regime								
NK	4.1	0.8	41,449	26,513	122,796	22,440	4.04	3.41
NP	4.2	0.9	50,169	26,513	119,837	30,845	3.42	3.20
NPK	4.3	1.1	55,769	26,513	117,929	42,384	3.14	3.17
NPK+ZnBMgCaS	4.3	1.4	119,569	26,513	55,974	66,091	1.47	1.94
PK	3.8	0.9	42,169	26,513	112,519	32,029	3.69	3.32
SEm ±	0.1	0.0	13.0	13.0	3,371.0	2,990.0	0.07	0.07
Interaction								
CA NK	3.9	0.8	35,297	21,425	124,214	26,757	4.52	3.88
CA NP	3.9	1.0	44,017	21,425	115,166	45,153	3.62	3.64
CA NPK	4.0	1.2	49,617	21,425	113,909	54,666	3.3	3.55
CA NPK+ZnBMgCaS	4.1	1.5	113,417	21,425	53,636	76,847	1.47	2.06
CA PK	3.3	0.9	35,417	21,425	99,351	37,222	3.81	3.58
CT NK	4.2	0.8	47,600	31,600	121,378	18,123	3.55	2.93
CT NP	4.5	0.8	56,320	31,600	124,508	16,536	3.21	2.76
CT NPK	4.6	1.0	61,920	31,600	121,948	30,102	2.97	2.78
CT NPK+ZnBMgCaS	4.6	1.3	125,720	31,600	58,311	55,334	1.46	1.81
CT PK	4.4	0.9	48,920	31,600	125,687	26,835	3.57	3.06
SEm ±	0.1	0.1	18.0	18.0	4,658.0	4,131.0	0.10	0.09

SEM= Standard error of means, Mz= Maize, Bn= Bean, TVC= Total variable cost, NB= Net benefit, BCR= Benefit to cost ratio.

AT Embu, NT+CR system resulted in higher maize (KE 135,740) and bean (KE 71,695) net benefits (NB) than CT-CR system. This trend was also observed at Kirinyaga under bean production. However, during maize production at Kirinyaga, CT-CR system recorded KE 9,111 higher NB than NT+CR system.

Under NT+CR, maize and bean production resulted in KE 27,135 and KE 22,370, respectively, more net benefits (NB) than under CT-CR system at Embu site. Maize-bean rotation system under NT+CR system recorded KE 49,505 (at Embu) and KE 9,632 (at Kirinyaga) higher NBs than under CT-CR system.

Under NT+CR and CT-CR, lower maize NB was recorded due to NPK+ZnBMgCaS treatment application on both sites. However, the highest NB of KE 152,379 due to NK under NT+CR and KE 125,687 due to PK under CT-CR were recorded at Embu and Kirinyaga sites, respectively.

Across both the sites, dry bean recorded the highest NB due to NPK+ZnBMgCaS treatment under NT+CR. The lowest dry bean NBs of KE 36,160 and KE 16,536 were due to PK and NP treatments at Embu and Kirinyaga sites, respectively, both under CT-CR system. Net benefits of the maize-bean rotation system ranged from KE 228,178 to KE 113,645 across both sites.

Maize production under NT+CR recorded higher benefit to cost ratio (BCR) of 4.06 and 3.34 than under CT-CR at Embu and Kirinyaga, respectively. Across all sites, the application of fertilizer regimes recorded maize BCR that varied between 1.46 and 5.32. Across both sites, treatments NPK+ZnBMgCaS and NK recorded the lowest and highest maize BCR, respectively.

At Embu and Kirinyaga, maize-bean rotation under NT+CR recorded higher BCR of 4.00 and 3.34 than CT-CR. The NK Fertilizer regime application recorded higher maize-bean BCR under NT+CR than under CT-CR in both sites (Table 1 and 2). Lower maize-bean BCR was recorded due to NPK+ZnBMgCaS in all sites.

Discussion

The no-till with crop residue retention (NT+CR) resulted in lower total variable cost (TVC) of maize-bean rotation system than under conventional tillage with no crop residue retention (CT-CR). Higher net benefit (NB) and benefit to cost ratio (BCR) were recorded under NT+CR than under CT-CR. These findings are in resonance with Micheni et al. (2014) who reported higher net benefits of maize and dry bean under no-till plots than under conventionally tilled plots. In a long term trial in Spain et al. (2004) reported higher gross margins under reduced tillage than under conventional tillage. These findings may be due to the reduced number of man-days required for management practices like cultivation and weed control under NT+CR system compared to a CT-CR system and time-saving (Pannell, Llewellyn, and Corbeels, 2014). The omission of pre-plant activities such as cultivation may have reduced the cost of production under no-till plots (Uri, 1999). Similarly, Mloza-Banda and Nanthambwe. (2011) reported that constant tilling of land during land preparation and several weeding regimes as the key practices make conventional tillage system of production more expensive than no- tillage. Despite the effectiveness of herbicides on reducing weeds, the chemicals could pose health and ecological risks if not used well. During selection of herbicides, farmers should consider the following: Product efficacy (only products that are effective in the control of the targeted weeds should be used); effects on beneficial organisms (only used herbicides that do not have adverse effects on beneficial insects) and impacts on human health (the products should have least or no effect on human health both in the short and long term periods (Otieno, 2019).

No-till and crop residues retention under conservation agriculture may have helped in the retention of soil moisture and release of nutrients upon the decay of these residues. Noticeably higher water retention was recorded under no-till with crop residue retention than under conventional tillage with no crop residue retention at Embu and Kirinyaga (Otieno et al., 2017). The effect of this is an increased yield of dry bean, which was high enough to help absorb the costs of production (Lampurlanes, Angas, and Cantero-Martinez 2001; Lal, Follett, and Kimble, 2003). However, Kihara et al. (2011) reported a loss in revenue under reduced tillage than under convention tillage of maize and soybean in western Kenya. According to them, this loss in revenue was due to the underperformance of maize crop under reduced tillage plots compared to conventional tillage plots.

Treatment NK under NT+CR resulted in higher NB and BCR than all other treatments in both sites. However, lower NB and BCR were recorded due to NPK+ZnBMgCaS treatment applications under both sites. These findings are in agreement with a report by Mucheru-muna et al. (2013) that showed higher benefit to cost ratio due to use of inorganic fertilizers in central highlands of Kenya under NT+CR than under CT-CR. Mazvimavi et al. (2012) also found higher net benefit and benefit to cost ratio of maize in rotation with legume crops under zero tillage with crop residue retention than under conventional tillage system.

The low net benefit and benefit to cost ratio due to NPK+ZnBMgCaS treatment may be due to the high cost of production that could not be adequately be offset by the field benefits accrued from the yield increments realized due to the application of the treatment (Otieno et al., 2018). Production of dry bean on residual fertilizers provided an extra nutrient supply that increased total grain yield under the rotation system with a minimal increase in total variable cost. This resulted in high net return and benefit to cost ratio realized in a maize-bean rotation system.

Maize-bean rotation system has the potential of generating enough revenue to take care of the money initially invested for production of maize, as evidenced by a high benefit to cost ratio. Adoption of no-till with crop residues retention is therefore possible and may help farmers to generate income.

Conclusion and Recommendation

The no-till with crop residue retention recorded lower total variable cost and higher net benefit on maize and bean than conventional tillage with no crop residue retention at Embu and Kirinyaga sites. Application of NPK+ZnBMgCaS resulted in higher total variable cost and field benefit but lower net benefit and benefit to cost ratio under maize production. The highest net benefit and benefit to cost ratio was recorded on both sites due to the application of NK fertilizer under no-till with crop residue retention. Production of dry bean on residual fertilizer recorded lower total variable with an increased net benefit under both tillage systems. The total variable costs and net benefit, respectively, were lower and higher under no-till with crop residue retention than under conventional tillage with no crop residue retention. Despite the increased cost of production as a result of adopting the proposed new system compared to the old practice of applying low fertilizer rates, the revenue accrued is high enough for farmers to make significant profits- this means farmers could even take input loans to implement the increased fertilizer rates and still be able to pay back at the end of the season. This shows the potential of conservation agriculture to increase food production in the country. For the purpose of policy and future research, we would like to make the following recommendation:

- Based on this data, farmers could be advised to apply N-K based fertilizers for better revenue generation.
- In the future;
  - Multi-season trails across different agro-ecological are necessary to understand better adoption complexities and performance of maize-bean rotation system in varying low prices of the produces under conservation agriculture.
  - Other benefits such as an increase in soil living organisms and the reduction of greenhouse gasses under conservation agriculture need to be understood and modeled economically to add to the current stated benefits.

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Conflicts of Interest

The authors declare no conflict of interest.

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