Research Article

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Increasing potato equivalent yield increases returns to investment under potato-legume intercropping systems

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Abstract: In order to enhance sustainable intensification of potato-based cropping systems, especially in sub-Saharan Africa (SSA), there is a need to investigate the economic viability of investing in this lucrative venture. This study evaluated the economic returns under legume intercropping systems using value/cost ratio (VCR) and benefit/cost ratio (BCR) under treatments comprising of potato intercropped with dolichos (*Lablab purpureus* L.) (P-D), climbing bean (*Phaseolus vulgaris* L.) (P-B) and garden pea (*Pisum sativum* L.) (P-G), and a potato pure stand control (P-S). Across the seasons, tuber yield was not significantly ($p < 0.05$) affected by intercropping with P-D, whereas under P-B and P-G, it decreased by 19% and 16%, respectively compared to P-S. P-G, P-B and P-D recorded 6, 7 and 12% higher potato equivalent yield (PEY) relative to P-S. P-D was the most profitable intercropping system with VCR of 35 and BCR of 5.1 as compared to values recorded in P-S of 31 and 5, respectively. Regression of VCR against PEY resulted in a stronger coefficient (0.98) compared to that of BCR against PEY (0.82) implying that VCR is a simple tool that could be adopted for economic returns to investment studies such as potato-legume intercropping systems.

Keywords: Gross returns; Net returns; Profitability; Benefit/cost ratio; Value/cost ratio

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1 Introduction

Low crop production is jeopardising food security, particularly in Africa, where the population is projected to increase exponentially from the current 1.2 billion to 1.7 and 2.5 billion by 2030 and 2050, respectively (UNDESA, 2017). As the population continues to increase, the traditional cultural practice of expanding croplands to increase food production is no longer tenable, especially in sub-Saharan Africa (SSA) (Lambin et al. 2013). Therefore, given that land is an inelastic resource, the only viable option is to improve production of the current croplands, which can be achieved by adopting sustainable intensification strategies such as intercropping (Garnett et al. 2013; Sharma et al. 2017; Gitari et al. 2018; Nyawade et al. 2019c). Due to small land holdings of < 1 ha, farmers intercrop potato with other crops particularly legumes to cushion against crop failure and increase returns per cultivated area (Nyawade et al. 2019b).

Through efficient utilization of resources like land, soil nutrients, light and water, intercropping systems have been proved to be yielding higher relative to mono culture systems (Singh et al. 2016; Gitari et al. 2018). This is particularly important given that potato is considered a heavy nutrient feeder crop (particularly for nitrogen) of which about 50% comes from inorganic fertilizers (Gitari 2018; Rens et al. 2018). In SSA, fertilizer use is often constrained as farmers have not only meagre financial capacity, but also they are inadequately informed, which make them sceptical about the viability of investing in this valuable input (Jansen et al. 2013; Dawi et al. 2017). Despite the high cost of fertilizers, especially in Africa, there is need to incentivise small-holder potato growers to invest in fertilizer use under the existing potato intercropping systems. Under intercropping systems with different types of yields, calculation of returns to fertilizer use can be complicated especially when detailed information regarding the total cost of production is not available. By converting all the yields from the intercropping systems into potato equivalent yield (Gitari et al. 2018), a value/cost ratio (VCR) can be applied to show the profitability of different cropping systems (Niyuhire et al. 2017). This is a nutrient/output ratio that indicates the economic value of the extra yield gained by unit investment in the usage of fertilizers.

As an indicator for assessing returns to fertilizer use, VCR has been applied on studies focusing on monocropping systems (Kaizzi, et al. 2012, 2018; Dawi et al. 2017; IFDC 2017; Niyuhire et al. 2017). The VCR differs from the benefit/cost ratio (BCR), which gives returns to the overall investment cost of production. There is a dearth of literature dedicated to the use of these ratios, particular under intercropping systems involving potato and legumes. Therefore, this study aimed to assess the economic viability of fertilizer use in potato-legume intercropping systems using VCR and BCR. This has a far-reaching effect of ending poverty and achieving food security as postulated in the first and second Sustainable Development Goals (SDGs), respectively (UNDESA, 2017).

2 Materials and Methods

2.1 Site Description

The study was conducted over four successive seasons (from 2014 to 2016) in a clayey Nitisol in a Research Farm based at the University of Nairobi, Kenya (1° 15' S, 36° 44' E, and 1860 m above sea level). The site receives rainfall twice per year from October to December, usually referred to as 'short rains' and March to June, referred as 'long rains'. During the study period, short rains recorded an average rainfall of 547 mm with a minimum and maximum temperature of 17 and 29°C, respectively. The long rains received 788 mm of rainfall with an average maximum temperature of 28°C and minimum temperature of 16°C. More detailed site description is available in Gitari et al. (2019).

2.2 Experimental design

In this experiment, we adopted a randomised complete block design with four replicates in 4 by 6 m plots. The treatments consisted of potato intercropped with legumes, namely dolichos (*Lablab purpureus* L.) (P-D), climbing bean (*Phaseolus vulgaris* L.) (P-B) and garden pea (*Pisum sativum* L.) (P-G) and a control (P-S) of pure potato stand. Planting was done at the beginning of each growing season with potato seed planted at an inter-row spacing of 90 cm and inter seed spacing of 30 cm whereas, for legumes, two seeds were planted per hill in a single row between potato rows.

2.3 Crop management

At planting, potato was supplied with 200 kg ha^{-1} of NPK (17:17:17) fertilizer and an equivalent quantity of calcium ammonium nitrate fertilizer 28 days after planting (DAP). Weeding, hilling for potato and staking for bean were carried out manually 28 DAP. Potato was sprayed against late blight with Ridomil Gold MZ 68 WG (Mefenoxam 40 g kg^{-1} + Mancozeb 640 g kg^{-1}) alternated with Daconil 720 SC (Chlorothalonil 720 g L^{-1}) after every 14 days starting at 28 DAP.

2.4 Data collection

Harvesting was carried out manually from 12 m2 central area per plot at 65 and 75 DAP for pea, 84 DAP for potato and bean, and 120 DAP for dolichos. The yield (tuber and grain) was recorded in kg ha-1 then converted into potato equivalent yield (PEY) using Eq. (1) (Gitari et al. 2018).

$$PEY = PY + \frac{LY * LP}{PP} \quad (1)$$

Where PY and LY = potato and legume yield (in kg ha^{-1}), respectively. PP = market price of potato (0.27 US$ kg^{-1}), and LP = market price of legume (1.07, 0.92 and 0.78 US$ kg^{-1} for dolichos, pea, and bean respectively). Gross returns (GR) were computed by multiplying PEY by PP as indicated in Eq. (2) whereas net returns for each cropping systems were calculated as shown in Eq. (3) by subtracting total cost of production from gross returns.

$$\text{Gross returns} = PEY * PP \quad (2)$$

$$\text{Net returns} = GR - CP \quad (3)$$

Where PEY = potato equivalent yield from Eq. (1) and CP = total production costs as given in Table 1. Profitability of cultivating potato under legume intercropping systems was assessed using value/cost ratio (VCR) and benefit/cost ratio (BCR) as shown in Eq. (4) and Eq. (5), respectively.

$$\text{Value/cost ratio} = \frac{\text{Gross Returns}}{(QF_1 * PF_1) + (QF_2 * PF_2)} \quad (4)$$

$$\text{Benefit/cost ratio} = \frac{\text{Net Returns}}{\text{Cost of production}} \quad (5)$$

Where $QF_{1,2}$ = Quantity of fertilizer type 1 (NPK, 17:17:17) and 2 (calcium ammonium nitrate) (CAN) in kg ha^{-1}, $PF_{1,2}$ = cost of fertilizer type 1 and 2 in US$ kg^{-1}. The calculations were based on 2016 market prices, i.e. US$ 0.49 kg^{-1} for NPK (17:17:17) fertilizer and US$ 0.34 kg^{-1} for CAN fertilizer.

2.5 Data analysis

The economic viability of applying fertilizer to potato under legume intercropping systems was assessed by analysing tuber yield, potato equivalent yield (PEY) and value/cost ratio (VCR) using generalized linear models in R software version 2.2.3. Tukey's post hoc test was used to separate means at $p \leq 0.05$. Regression analysis was performed to show relationships between PEY and VCR as well as between PEY and VCR.

3 Results

3.1 Potato tuber yield, potato equivalent yield, gross and net income, value/cost ratio and benefit/cost ratio in response to integration of legumes into potato-based cropping systems

The tuber yield was significantly ($p < 0.05$) influenced by the type of legume integrated into potato-based cropping system, and the differences varied with season. For instance, the tuber yield recorded in P-D (35 t ha^{-1}) was comparable to P-S with a negligible difference of 1 t ha^{-1} (Figure 1). However, intercropping potato with pea and bean resulted in a significantly ($p < 0.05$) yield decrease of 19 and 16%, respectively compared P-S.

Similarly, the type of potato-legume intercrop had significant ($p < 0.05$) effect on potato equivalent yield (PEY), gross and net income, value/cost ratio and benefit/cost ratio, but these differences fluctuated from season to season (Table 2). With respect to seasons, 2015 long and short rains recorded significantly higher yield (42 and 43 t ha^{-1}), respectively) compared to 2014 short rains (36 t ha^{-1}) and 2016 long rains (37 t ha^{-1}). Across the season, the significantly highest and lowest potato equivalent yield values were recorded in P-D (40 t ha^{-1}) and P-S (35 t ha^{-1}), respectively whereas an intermediate value of 38 t ha^{-1} was observed in P-G and P-B.

Integration of legumes into potato cropping systems had a positive impact of economic returns. For instance, across the seasons, P-D had the highest gross and net returns at US$ 10707 and, 8967, respectively compared to US$ 9596 and, 8007 recorded for P-S. Regardless of the cropping systems, significantly higher gross returns was recorded in 2015 long (US$ 7333) and short (7544) rains compared to values of US$ 6233 and 6576 for 2014 short

Table 1: Variable cost for different potato-legume intercropping systems

	Labour	Seed Potatoes	Legume seeds	Fungicides/ Pesticides	Fertilizer	Glad total
Treatment	US$ ha^{-1}					
P-S*	315.25	882	-	85.8	306	1589
P-D	421.95	882	23.4	106.7	306	1740
P-G	397.7	882	19.4	85.8	306	1691
P-B	446.2	882	15.6	85.8	306	1766

*P-S, pure potato stand; P-D, potato intercropped with dolichos; P-G, potato intercropped with pea; P-B, potato intercropped with climbing bean.

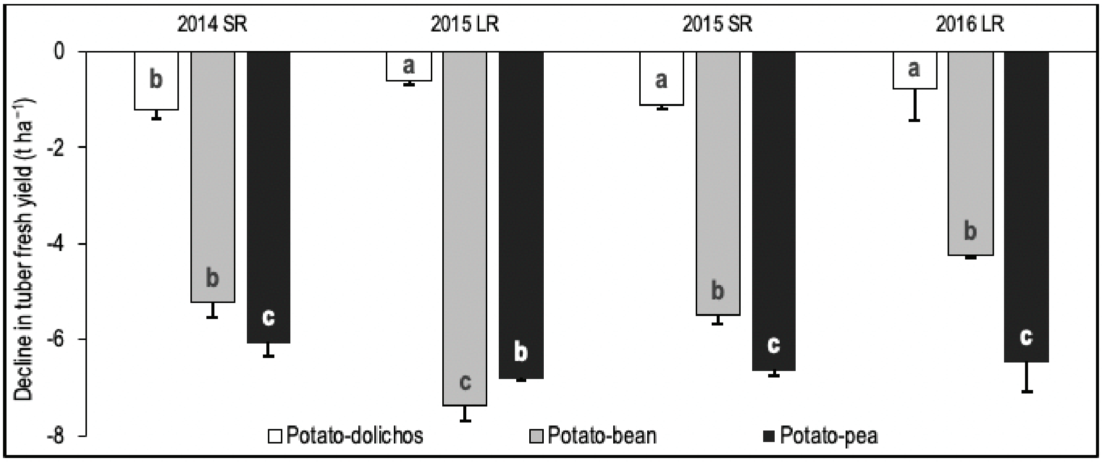

Figure 1: Decline in tuber yield under intercropping relative to monocropping systems. SR and LR signify short and long rains seasons, respectively. Bars bearing different letters across the cropping systems and within the same season denote significant differences among the treatments at p ≤ 0.05. Error bars signify standard error of the mean.

rains and 2016 long rains, respectively). The value/cost ratio values recorded in P-D (35), P-B (34) and P-G (33) were significantly higher than in P-S (31). For value/cost ratio, P-D had significantly the highest value (5.3) compared to an intermediate value of 5.0 recorded in P-G and P-S and the lowest value of 4.8 in P-B.

3.2 Relationship between potato equivalent yield (PEY) and value/cost ratio, and between PEY and benefit/cost ratio.

A regression analysis of VCR against potato equivalent yield indicated a very strong linear dependence of VCR on PEY with R^2 of 0.98 (Figure 2a). This was an indication that when other factors are held constant, a unit increase in VCR would be due to an increase in PEY by about 1.17 Mg ha^{-1}. Similarly, regression of BCR against PEY showed a positive and direct relationship though with a weaker coefficient of 0.82 (Figure 2b), implying that a one-ton increase in PEY would result in 0.14 unit increase in BCR given that all other confounding factors are fixed.

4 Discussion

This study revealed that the viability of using fertilizer under potato legume intercropping systems based on the promising higher returns compared to potato pure stand system. Assessing intercropping systems could be difficult without considering legume yield. However, given that there were different yield types involved, this complicated the issue even more. Gitari et al. (2018) reported that by equating all yield into equivalent values of the main crop (in our case potato); intercropping systems can easily be compared with the monocropping systems. Potato equivalent yield (PEY) has also been applied to potato-radish intercropping systems by Singh et al. (2016) and Gitari et al. (2018). These authors observed higher PEY values under intercropping compared to potato pure stand hence concurring with our findings. The highest PEY recorded under potato-dolichos could be attributed to the high market value of dolichos.

Increase in PEY resulted in increase in value/cost ratio (VCR) values, as denoted by the regression analysis, which revealed a stronger and direct relationship (R^2 = 0.98) with PEY than that of benefit/cost ratio (BCR) (R^2 = 0.82). Generally, VCR is the most commonly employed indicator used to assess the financial incentives for growers to use fertilizer using non-economic means (Niyuhire et al. 2017; IFDC 2017). All the VCRs values reported in this study were > 1, inferring that fertilizer use was profitable. However, we only considered the values greater than 35 to provide satisfactory incentive. In this case, the observed VCRs suggested that fertilizer use is satisfactorily profitable only under potato-legume intercropping systems, especially P-D.

IFDC (2017) recommends that VCR should be at least four to accommodate price and climatic risks and still provide an incentive to the farmers. In the current study, the VCRs recorded in all intercropping systems surpassed this threshold by over eight times indicating adequate risk coverage against investment in use of the fertilizer under potato-legume intercropping. In sub-Saharan Africa, especially Kenya, potato farming is faced with various uncertainties, which include erratic rainfall patterns and fluctuation of ware tuber prices. Hence, covering such

Table 2: Potato equivalent yield (PEY), gross returns, net returns, value/cost ratio and benefit/ cost ratio as influenced by cropping systems at different seasons

Variable	Cropping System	2014 Short Rains	2015 Long Rains	2015 Short Rains	2016 Long Rains
PEY	P-S[1]	31.9[c2]	38.2[d]	39.0[c]	33.1[c]
(Mg ha^{-1})	P-D	35.5[a]	43.1[a]	43.0[a]	37.1[a]
	P-G	33.8[b]	40.2[b]	40.9[b]	35.3[b]
	P-B	35.2[a]	38.1[c]	40.7[b]	37.7[a]
Gross	P-S	8606[d]	10321[c]	10532[d]	8924[c]
Returns	P-D	9585[a]	11627[a]	11600[a]	10018[a]
(US$ ha^{-1})	P-G	9114[c]	10845[b]	11033[b]	9524[b]
	P-B	9498[b]	10285[c]	10997[c]	10169[a]
Net	P-S	7017[d]	8732[c]	8943[c]	7335[c]
Returns	P-D	7845[a]	9887[a]	9860[a]	8278[a]
(US$ ha^{-1})	P-G	7423[c]	9154[b]	9342[b]	7833[b]
	P-B	7731[b]	8519[c]	9231[b]	8402[a]
Value/	P-S	28.1[c]	33.7[c]	34.4[c]	29.2[d]
Cost Ratio	P-D	31.3[a]	38.0[a]	37.9[a]	32.7[a]
	P-G	29.8[b]	34.4[b]	36.1[b]	31.1[c]
	P-B	31.0[a]	33.6[b]	35.9[b]	33.2[b]
Benefit/	P-S	4.4[c]	5.5[c]	5.6[c]	4.6[c]
Cost Ratio	P-D	4.5[a]	5.7[a]	5.7[a]	4.8[a]
	P-G	4.4[b]	5.4[b]	5.5[b]	4.6[b]
	P-B	4.4[b]	4.8[c]	5.2[b]	4.8[a]

Analyses of variance (*p* values)

Variable	Cropping system	Season	System × Season
Potato equivalent yield	< 0.001	< 0.001	0.138
Gross returns	< 0.001	< 0.001	0.006
Net returns	< 0.001	< 0.001	< 0.001
Value/cost ratio	< 0.001	< 0.001	< 0.001
Benefit/cost ratio	< 0.001	< 0.001	< 0.001

[1]P-S, pure potato stand; P-D, potato intercropped with dolichos; P-G, potato intercropped with pea; P-B, potato intercropped with climbing bean.
[2]Means followed by different letters within a column differ significantly at $p \leq 0.05$.

risks assures farmers of high income when investing in potato-legume intercropping systems. In this way, farmers could easily be persuaded to use fertilizers as they can better estimate the returns attainable by using fertilizers particularly under degraded soils (Gitari et al. 2015, 2019; Sharma et al. 2017; Nyawade et al. 2019a and b; Gachene et al. 2019). This can act as a good impetus to smallholder farmers who mainly practise intercropping given that they are assured of higher returns to investment in fertilizer application. Therefore, VCR proofs to be a reliable tool that can be used to show the economic viability of potato-based intercropping systems. It has an advantage over the BCR given that it does not require incorporation of all variable costs involved in crop production.

5 Conclusion

Intercropping is a viable practice for intensification of potato cropping system, particularly *in Kenyan* highlands where farmers have small landholdings of less than a hectare. This study was carried out with the objective of determining the economic viability of potato-legume intercropping systems under tropical field conditions value/cost ratio and benefit/cost ratio in relation to potato

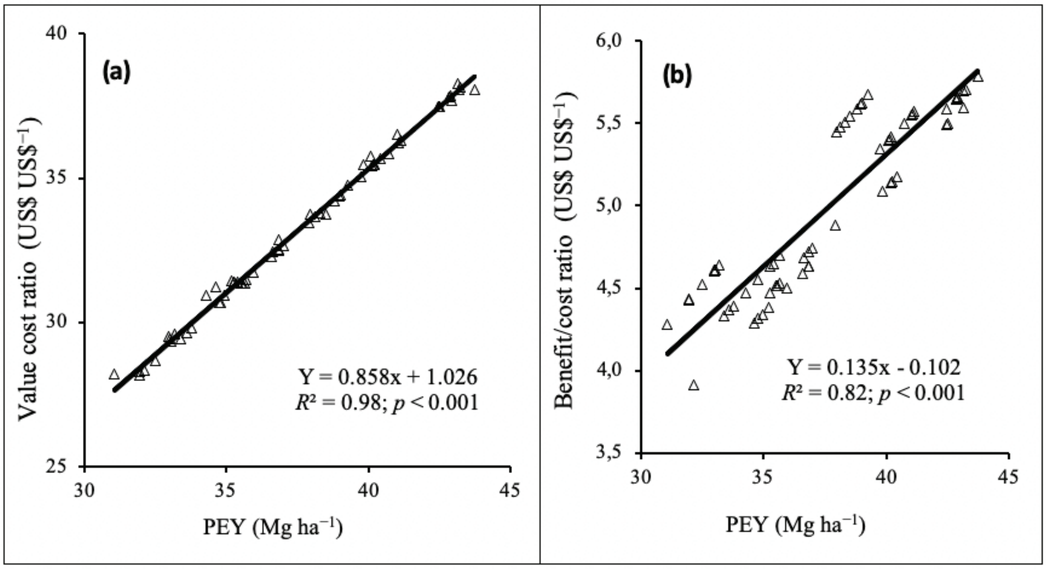

Figure 2: Relationship between potato equivalent yield (PEY) and value/cost ratio (a) and between PEY and benefit/cost ratio (b)

equivalent yield. The results of this study demonstrated that value/cost ratio (VCR) and benefit/cost ratio (BCR) are vital tools for determining the profitability of incorporating legumes into potato-based intercropping systems. The expectation is that smallholder potato farmers in sub-Saharan Africa will be incentivised to use fertilizers due to improved economic returns associated with fertilizer use. In this regard, dolichos was identified as the most qualified candidate for intensification of these cropping systems given that it not only resulted in the highest VCR but also BCR without a significant penalty on tuber yield.

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