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Research Paper

Ex-ante welfare impacts of adopting maize-soybean rotation in eastern Zambia

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ABSTRACT

This paper estimates the welfare impacts of adoption of maize-soybean rotation in eastern Zambia using data from on-farm trials and household survey data collected from over 800 households. The on-farm trials were conducted from 2012 to 2015 while the household survey was conducted in 2012. The study evaluated maize-soybean rotation where soybean was grown with and without inoculants and inorganic fertilizer, whereas continuous maize cropping was used as a control. The paper estimated household level income changes and poverty reduction due to adoption of maize-soybean rotation using market level economic surplus as well as household level analyses to allocate economic surplus changes to individual households. The results showed that several factors influence the adoption of maize-soybean rotation, including land ownership, education, and age of the household head. Results also showed that adoption of maize-soybean rotation reduced per-unit production costs by between 26 and 32% compared to continuous maize. Ex-ante welfare impact analysis showed significant potential income gains and poverty reduction following adoption of maize-legume rotation in eastern Zambia. The paper concludes with implications for policy to promote wider adoption of soil fertility management practices such as maize-soybean rotation for increased maize productivity in Zambia.

1. Introduction

It is widely recognized that broad-based technological change in agriculture is critical for achieving agricultural productivity growth and poverty reduction in Sub-Saharan Africa. In Zambia, agricultural productivity growth is one of the key policy objectives for achieving sustainable economic growth, poverty reduction, and improved nutrition, health, and social well-being (Kalinda et al., 2014; Sitko et al., 2011). Maize is a staple food in Zambia and is mostly grown by smallholder farmers under low soil fertility, limited use of high yielding varieties and inorganic fertilizers (Langyintuo and Mungoma, 2008; Heisey and Mwangi, 1996). As a result, the average maize yields on farmers' fields remain very low.

Increasing and stabilizing the productivity of maize in inherently poor soils is critical for improving food security. The use of soil fertility enhancing legumes in the maize-based systems holds a considerable promise to not only boost productivity but also to provide nutritional and income benefits for the poor. Cereal-legume rotation which is one of the options for the Integrated Soil Fertility Management (ISFM) (Vanlauwe et al., 2015; Sanginga et al., 2003) has a number of benefits for both farmers and the environment, including soil fertility improvement through nitrogen fixation, reduction of diseases and weed and insect populations, and increases in soil-carbon content, which is essential for increasing yields and mitigating the effects of climate change (Govaerts et al., 2007; Hutchinson et al., 2007; Andersson et al., 2014; Garrison et al., 2014; Pretty, 2008; Thierfelder and Wall, 2010). Past research on maize-soybean rotation has shown that under farm conditions maize grown after soybean yields about 1.5 tons/ha, more than the farms with continuous maize (0.5 tons/ha) in Zimbabwe (Kasasa et al., 1999). Other studies in West Africa showed that, on average, maize yields following legumes were higher than that of continuous maize cultivation by between 20 and 38% (Sanginga, 2003; Yusuf et al., 2009).

A number of studies have assessed the ex-post (e.g. Abdulai and Huffman, 2014; Becerril and Abdulai, 2010; Kassie et al., 2011; Shiferaw et al., 2014) as well as the ex-ante (e.g. Akinola et al., 2009; Kostandini et al., 2013, 2016; Alene et al., 2009, 2013) impacts of agricultural technology adoption in Africa. Most of the past ex-ante studies have used the economic surplus model to estimate the aggregate benefits arising from adoption of yield increasing technologies (e.g.

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Akinola et al., 2009) but do not go beyond market level economic surplus to allocate these benefits to individual households. This paper applies a procedure to allocate market-level economic surplus changes to individual households to estimate household level income changes and poverty reduction associated with adoption of maize-soybean rotation in eastern Zambia. To our knowledge, this is the first study to attempt to allocate benefits from an experimental setting to individual households in Zambia. The paper contributes to the growing literature on impacts of technology adoption by estimating the potential impacts of adopting maize-soybean rotation in Zambia. Specifically, we estimate the benefits of maize-soybean research using economic surplus analysis and allocate this surplus to individual households. To achieve this, we combine data from on-farm trials with rich household level data. This ex-ante approach can therefore be a valuable tool for impact evaluation and research priority setting.

The rest of the paper is organized as follows. Section 2 provides an overview of the methodology used in the study. The data description and descriptive statistics are given in Section 3, whereas 4 presents the empirical results and discussion. The last section draws conclusions and policy recommendations.

2. Methodology for ex-ante assessment

2.1. The economic surplus method

To evaluate the benefits of maize-soybean rotation, we draw on the approaches by Alston et al. (1995), Alwang and Siegel (2003) and Moyo et al. (2007). Following Moyo et al. (2007), aggregate economic surplus analysis is combined with household-level data analysis to construct ex-ante estimates of changes in poverty resulting from adoption of maize-soybean rotation. While the surplus analysis provides estimates of changes in economic surplus, the household-level analysis provides estimates of household-specific changes in income by allocating economic surplus changes to individual producers and consumers. The household income changes can then be used to estimate changes in aggregate income and poverty.

The economic surplus method is the most widely used procedure for economic evaluation of benefits and costs of a technological change (Alene et al., 2013). According to Alston et al. (1995), the first step in calculating the benefits is the estimation of the unit cost reduction (*K*-shift) resulting from the new technology. The *K* can either be estimated using information provided by scientists associated with the new technology or calculated from on-farm trials.[1] Second, information on the expected adoption rates, as well as their evolution over time is gathered. Third, information on the market associated supply and demand elasticities and equilibrium prices and quantities is combined with the first two steps. Using these steps, one can estimate the price, quantity and corresponding economic surplus changes associated with technology adoption (Moyo et al., 2007). The difficulty is to allocate these surplus changes to individual households.

Economic surplus changes are usually calculated under various market scenarios, with the most common being either under open or closed market situations. In this study, we adopt the open market situation. The small country assumption is often suitable because most of the agricultural products are tradable and most regions or countries do not influence international prices significantly (Alston et al., 1995). In a small open economy, the country does not affect the world price, hence the economic surplus change is equal to the producer surplus, which implies that the primary beneficiaries from adopting maize-soybean rotation are the maize producers either through sales or consumption at home (Fig. 1). In Fig. 1, *D* represents the demand curve, consumption *C*, and production Q_0, defines the initial equilibrium at the world market price, *Pw* (which is a constant and defines the opportunity cost of resources used in production and consumption), with a traded quantity, QE_0 (representing exports), equal to the size of the difference between consumption and production. Maize-soybean rotation research leads to a shift in the supply curve *So* to S_1 and production increases to Q_1. This action results in an increase in maize exports to QE_1 and since Zambia does not affect the world price of maize, the economic surplus is equal to the change in producer surplus (area J_0abJ_1). The surplus change captures the entire short run benefits of adoption, assuming prices in all other markets are not affected by the supply shift (Moyo et al., 2007).

In the graph, the unit cost reduction (*K*) due to the adoption of the new technology is represented by:

$$K = \frac{\Delta P}{P_w} = \frac{a - e}{P_w} \tag{1}$$

where ΔP depicts the price change and *Pw* is as defined above.

2.2. Welfare effects: allocating surplus to households

In allocating the surplus to households, three steps are involved (Moyo et al., 2007). First, we calculate the total household expenditure[2] per capita (which we use as a proxy for income) using household level data and compare it to the poverty line. Note that household expenditure includes both expenditure on food and non-food items (e.g. expenses on health, education, housing and clothing); second we use the propensity scores to determine which households are most likely to adopt maize-soybean rotation and estimate the household welfare changes and; third we establish the change in the number of poor households resulting from adoption. The most commonly used indices to estimate poverty are the Foster Greer Thorbeck (FGT) indices defined as:

$$P_\alpha = \frac{1}{N}\sum_{i=1}^{q}\left[\frac{z - y_i}{z}\right]^\alpha \tag{2}$$

Where *N* is the total number of people, *q* is the number of poor people, y_i is the household income per capita, *z* is the poverty line and α is a parameter of inequality aversion. It follows that when $\alpha = 0$, the formula reduces to the headcount ratio which shows the proportion of the population that lives below the poverty line. When $\alpha = 1$, P_α is the poverty gap ratio, which measures the depth of poverty and when $\alpha = 2, P_\alpha$ measure the severity of poverty and reflects the degree of inequality among the poor. The FGT class of poverty measures satisfies a convenient decomposability property (Ray, 1998). In our case, the FGT indices are appropriate because they allow us to assess poverty across adopters and non-adopters.

Maize production and household incomes change due to adoption of the maize-legume rotation is related to the value of agricultural production and the per unit cost reduction that results from adoption such that the change in household income in a small open economy for the *i*th household is:

$$d\pi_i \approx K_iP_iQ_i(1 + 0.5K_i\varepsilon) = J_0abJ_1 \tag{3}$$

P_i is the pre-research price, Q_i is the pre-research quantity, ε is the elasticity of supply[3] and K_i is the proportionate shift downwards in the marginal cost curve (supply curve) due to research.

2.3. Adoption of maize-legume rotation at household level

In order to estimate ex-ante changes in poverty, it is important that farmers who are likely to adopt modern agricultural technologies are

[1] We use this method in estimating the *K*-shift.

[2] In the subsequent sections, we use the term "household income" to mean "household expenditure".

[3] Previous studies (e.g. Katepa, 1984; Nakaponda, 1992; Harber, 1992) estimated supply elasticities for maize ranging between 0.21 and 0.8 in Zambia. In this study, we use an average of 0.51 as the elasticity of supply.

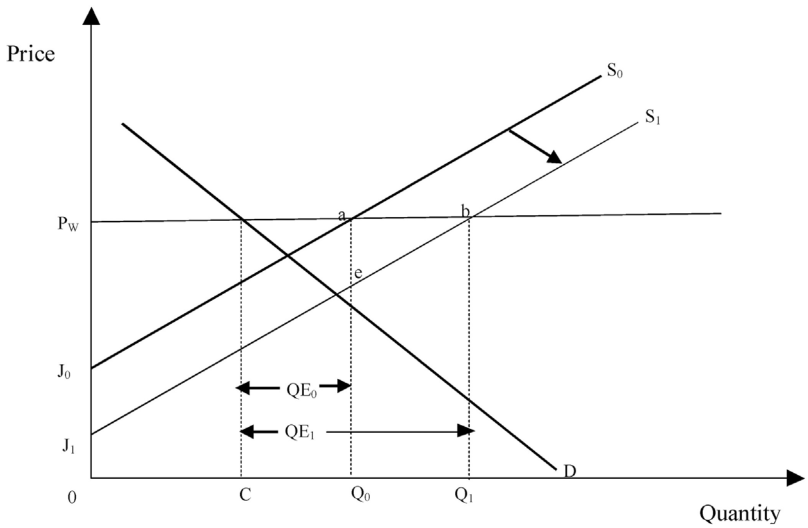

Fig. 1. Effects of technological change in a small open economy.

identified. To identify households most likely to adopt the new technology, a model of production probabilities can be estimated from similar agricultural technologies (Alwang and Siegel, 2003). In Zambia, maize-legume rotation is promoted as one of the components of conservation agriculture (CA). However, crop rotations are not only restricted to CA but are also embodied by other approaches to sustainable intensification, including ISFM (Sanginga et al., 2003; Vanlauwe et al., 2010, 2014). Vanlauwe et al. (2010) defines ISFM as a set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs and improved germplasm, combined with the knowledge of how to adapt these practices to local conditions, aimed at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity. The legumes that are commonly rotated with maize include groundnuts, cowpeas and common beans. For the sake of brevity, we assume that farmers who are likely to adopt maize-legume rotation as part of the ISFM package are also likely to adopt maize-soybean rotation. Let the adoption of a new technology be a binary choice where a farmer decides to adopt the new technology when there is a positive difference between the marginal net benefits of adopting the technology and not adopting the technology. If we denote this difference as I^*, then a farmer will adopt a new technology if $I^* > 0$.

However, I^* is not observed, what is observed is a binary indicator that equals one if a farmer adopts the technology and zero otherwise. More formally, the relationship can be expressed as:

$$\begin{aligned} I^* &= Z'\alpha + \varepsilon_i \\ I^* &= 1 \text{ if} I_i^* > 0, \\ I^* &= 0 \text{ if} I_i^* \leq 0. \end{aligned} \tag{4}$$

Where Z is a vector of observed household and farm characteristics determining adoption; α is the vector of unknown parameters to be estimated; and ε_i the vector of random disturbances related with the adoption of a new technology with mean zero and variance σ_i^2.

Based on similar technologies such maize-legume rotation and variables affecting the probability of adoption, Eq. (4) can be used to predict adoption probabilities for each household. Households can then be ranked in order of decreasing probability of adoption and adopters can be identified as those whose predicted probability of adoption exceeds a threshold prediction probability (Alwang and Siegel, 2003; Moyo et al., 2007; Francisco et al., 2014). For instance, if the assumption is that 15% of households adopt, those households are selected whose predicted probability of adoption exceeds that of the household at the 85th percentile of the ranking.

The probabilities predicted from Eq. (4) were then used to determine the likely adopters of maize-soybean rotation technology. The probabilities were ranked in a descending order and the income changes were applied to the first 75%, 85%, and 100% according to the adoption probability. The income changes were then estimated for each of the adopters and non-adopters under the open economy. Using the FGT indices, poverty indices were calculated by comparing the income per capita for each household before and after technology adoption.

3. Data sources and descriptive statistics

3.1. Survey data

The data used in the analysis mainly come from a household survey conducted in the study area. A survey of 810 sample households was conducted in January and February 2012 in Eastern Province of Zambia. This was a baseline survey conducted by the International Institute of Tropical Agriculture (IITA) and the International Maize and Wheat Improvement Centre (CIMMYT) in collaboration with the Zambia Agricultural Research Institute (ZARI) for the project entitled Sustainable Intensification of Maize-Legume Systems for the Eastern Province of Zambia (SIMLEZA). A survey questionnaire was prepared and administered by trained enumerators who collected data from households through personal interviews. The survey was conducted in the same SIMLEZA project districts in Eastern Zambia—Chipata, Katete, and Lundazi—which were targeted by the project as the major maize and legume growing areas. In the first stage, each district was stratified into agricultural blocks (8 in Chipata, 5 in Katete and 5 in Lundazi) as primary sampling units. In the second stage, 41 agricultural camps were randomly selected, with the camps allocated proportionally to the selected blocks and the camps selected with probability of selection proportional to size. Overall, 17 camps were selected in Chipata, 9 in Katete and 15 in Lundazi. A total sample of 810 households was selected randomly from the three districts with the number of households from each selected camp being proportional to the size of the camp. The data collected included information on socioeconomic characteristics of farmers, production systems, plot-level characteristics such as soil characteristics, and management practices based on the principles of ISFM.

3.2. Experimental data

The farmer managed on-farm trials were carried out in 2012–2015 by IITA in collaboration with ZARI and the Ministry of Agriculture and Livestock (MAL) under the above mentioned SIMLEZA project. The trials were set up in the same baseline survey districts of Chipata, Katete and Lundazi. Fig. 2 shows the location of the on-farm trials. In each of the trials, there were five blocks comprising continuous maize

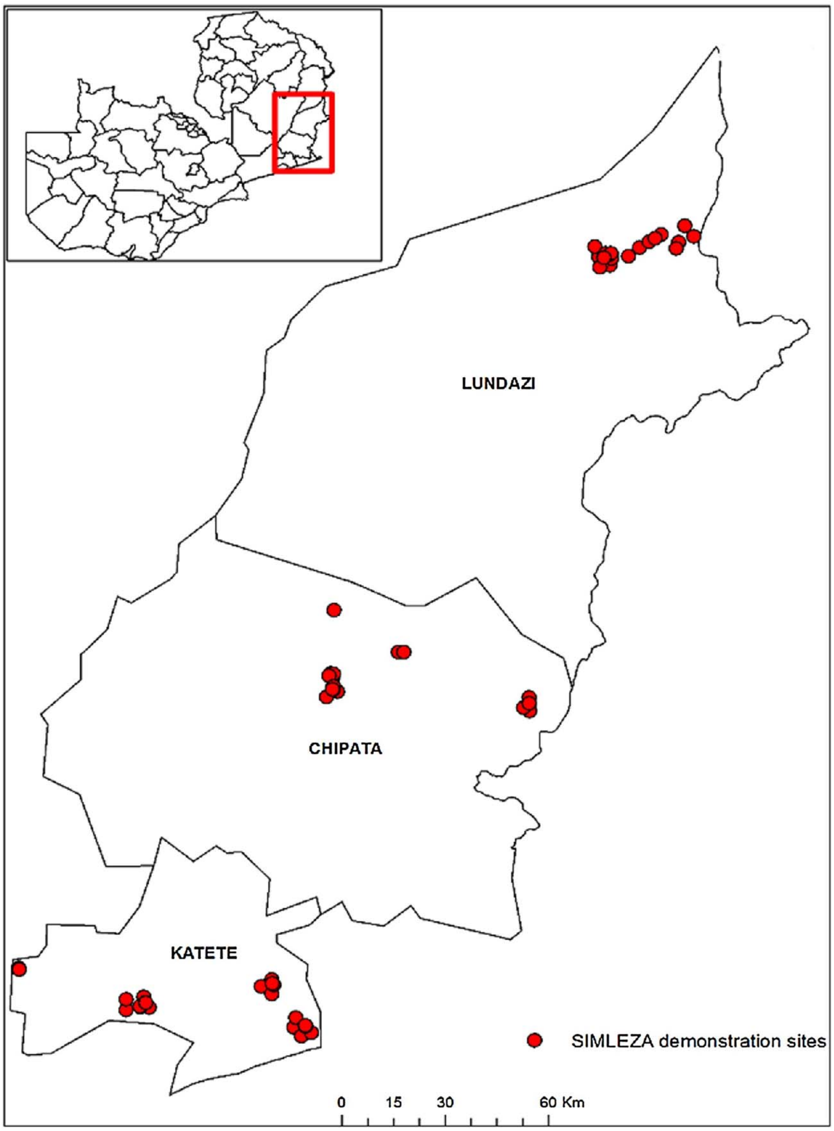

Fig. 2. Location of the on-farm trial plots.

Table 1
Maize-soybean rotation trials in eastern Zambia.

Treatment	Year 1		Year 2	
	Crop	Inputs	Crop	Inputs
Continuous maize (control)	Hybrid maize	200 kg/ha D compound and 200 kg Urea	Hybrid maize	200 kg/ha D compound and 200 kg/ha Urea
Maize-soybean rotation	Soybean	No fertilizer/inoculant	Hybrid maize	100 kg/ha D compound and 100 kg/ha Urea
Maize-soybean rotation	Soybean	100 kg/ha D compound	Hybrid maize	100 kg/ha D compound and 100 kg/ha Urea
Maize-soybean rotation	Soybean	500 g/ha of inoculant	Hybrid maize	100 kg/ha D compound and 100 kg/ha Urea
Maize-soybean rotation	Soybean	100 kg/ha D compound and 500 g/ha of inoculant	Hybrid maize	100 kg/ha D compound and 100 kg/ha Urea

cultivation as the control, maize-soybean rotation (without fertilizer and inoculant), maize-soybean rotation (with inoculant), maize-soybean rotation (with fertilizer) and maize-soybean rotation (with inoculant and fertilizer) (Table 1).

The trials were replicated by a number of different host farmers. The host farmers were selected following community awareness on the SIMLEZA project with the help of the camp extension officers (CEOs)[4] and the community structure represented by the community agriculture committee (CAC). The key points used in the selection of host farmers included: 1) Ability: a farmer should have some experience in growing the crop; 2) Willingness: a farmer should be willing to grow the crop; 3) Easy accessibility: the fields should be accessible throughout the growing season; 4) Adequate land: a farmer should have enough land that will enable crop rotation and isolation; and 5) Literacy: a farmer should be able to read and/or write English or the local language. In 2012 and 2013, 48 and 56 farmers were selected respectively. However, some farmers could not continue to host the trials due to

[4] These are government extension agents.

mismanagement and other reasons such that only 31 and 49 farmers hosted the trials in the 2014 and 2015 cropping seasons. For this reason, we combine soybean data from the first and third seasons (i.e. 2012 and 2014) and do the same for maize for the second and fourth seasons (2013 and 2015) such that we have one cycle of maize-soybean rotation instead of two (i.e. soybean in the first and third cropping seasons and maize in the second and fourth cropping seasons). For the maize grown after soybeans, D compound fertilizer was applied at half the recommended rate (100 kg/ha) (Table 1). The composition of the main nutrients in D Compound fertilizer is NPKS 10-20-10-6. In the control (i.e. continuous maize), the full rate of 200 kg/ha of D Compound and Urea fertilizers was applied in the four seasons. Note that we also averaged the data for the continuous maize such that we had two years (seasons) to enable us to compare with the other treatments.

The hybrid maize variety used in the on-farm trials depended on the community preferred variety and its seed rate was at 0.5 kg/plot (25 kg/ha) with a planting space of 75 cm inter-rows and 30 cm intra-rows. The soybean seed rate was at 2 kg/plot (100 kg/ha) and the variety used was Lukanga (i.e. an improved variety) with a planting space of 75 cm between ridges. Each ridge had two rows of soybean, 20 cm apart and drilled at 5 cm.

4. Results and discussions

4.1. Partial budget analysis and unit cost reductions

Using the experimental data, a partial budget analysis was conducted to assess the potential financial benefits of adopting maize-soybean rotation. The partial budgets were calculated based on the five on-farm trials summarized in Table 1. Some of the costs included in the analysis are associated with the purchased inputs such as seed, inoculants, and fertilizers. In the first year in which soybean was grown under four different treatments, the partial budget analysis results show that the gross margins were higher for soybeans grown when fertilizer and inoculants were applied than the other three soybean treatments (Table 2). This may be attributed to the higher grain yield gains obtained from the application of both the inoculants and fertilizer. Research has shown that soybean grain yield responds to inoculation and application of Phosphorus (Zoundji et al., 2015). However, compared to the benefits from the control (continuous maize), the results show that gross margins were higher for maize than for soybeans even though the variable costs for maize were higher than those for soybean. Again this may be partly attributed to the fact that hybrid maize responds highly to fertilizer application which resulted in higher yields thereby offsetting the high costs of inputs.

The partial budget for the second year in which maize was planted in the plots in which soybean was planted in the previous season shows a different picture. The results show that gross margins were higher for treatments 2 (soybean only) and 3 (soybean with fertilizer) while treatment 1 (continuous maize) was the lowest (Table 3). In terms of maize yields, maize following soybean with fertilizer (i.e. soybean grown with fertilizer) had a marginal advantage (i.e. there was no significant different in yields in treatments 2 to 5) with 3.29 tons/ha as compared to other treatments. There was, however, a clear yield advantage over the continuous maize which had only 2.96 tons/ha and it is evident that across the four soybean treatments, maize benefited greatly from the nitrogen fixed by the soybean as all the treatments had more than 3 tons/ha. Application of fertilizer that has a considerable amount of Phosphorus to legumes has been shown to produce more grain and biomass, thereby reducing the need for external Nitrogen fertilizer for the subsequent maize crop (Sanginga et al., 2003).

The grain yield comparisons for the five treatments presented in Fig. 3 also show the same picture. In general, the cumulative distribution functions (CDFs) for treatments 2 to 5 are generally to the right of the continuous maize yield CDF. The implication is that, in terms of maize yields, treatments 2 to 5 have a first order stochastic dominance over the continuous maize treatment. In other words, the four treatments generated the risk efficient yields compared to the continuous maize cropping system. Among the four soybean treatments, the CDFs did not show which practice generated the highest risk efficient maize yields, implying that the yield gains were not significantly different among the four treatments.

Across the two years, the average gross margins were highest for the treatment which included soybean, fertilizer and inoculant (ZMW1971) and lowest for continuous maize (ZMW1581) (Table 4). Continuous maize, on the other hand had the highest total variable costs followed by soybean, fertilizer and inoculants, soybean and fertilizer, soybean and inoculants and soybean only treatments in that order (Table 4). With regard to the benefit-cost ratios, treatments 2–5 had higher values than continuous maize. Treatment 4 turned out to have the highest benefit/cost ratio (2.56) and this is because inoculants are quite cheap as compared to inorganic fertilizers. A similar result was found by Van Vugt et al. (2016) in Malawi. The implication is that farmers can expect economic benefits of ZMW2.56 for every ZMW1 they invest in maize-soybean rotation.

The maize yield gain and the unit cost reduction effects for all the treatment options were then calculated using the data in Tables 2–4. The results in Table 5 show that the average maize yield following treatments with soybean only was 3.27 tons/ha, representing a yield gain of 15% and a cost reduction of about US$66 (ZMW416)/ton. Similarly, the average maize yield after soybean applied with fertilizer and inoculants was 3.19 tons/ha, representing a yield gain of 14% and cost reduction of US$53(ZMW334)/ton over the continuous maize. For soybean only and soybean, fertilizer and inoculants treatments, the respective proportional unit cost reductions (*K*) were 32% and 26% of the price of maize. The estimation procedure involves allocating this unit cost reduction to individual households by combining the information from the on farm trials—which was used to derive aggregate market level economic surplus changes—with household level data. In the subsequent economic surplus and poverty analyses, we use the *K*

Table 2
Partial budget analysis of on-farm trials conducted in the first year.
Source: Own calculations based on-farm trial data.

	Treatments				
	Continuous maize	Soybean	Soybean and fertilizer	Soybean and inoculants	Soybean, fertilizer and inoculants
	1	2	3	4	5
Crop in first year	Maize	Soybean	Soybean	Soybean	Soybean
Number of Farmers	52	52	52	52	52
Average yield (kg/ha)	2740.82	513.26	787.41	649.57	989.61
Field price (ZMW/kg)	1.30	2.50	2.50	2.50	2.50
Gross field benefits (ZMW/ha)	3563.07	1283.15	1968.53	1623.93	2474.02
Total variable costs (ZMW/ha)	2143	900	1320	960	1380
Gross margin (ZMW/ha)	1420.07	383.15	648.53	663.93	1094.02

Table 3
Partial budget analysis of on-farm trials conducted in the second year.
Source: Own calculations based on-farm trial data.

	Treatment				
	Continuous maize	Soybean	Soybean and fertilizer	Soybean and inoculants	Soybean, fertilizer and inoculants
	1	2	3	4	5
Crop in second year	Maize	Maize	Maize	Maize	Maize
Number of Farmers	52	52	52	52	52
Average yield	2964.81	3272.58	3288.64	3209.20	3193.65
Field price (ZMW/ha	1.30	1.30	1.30	1.30	1.30
Gross field benefits (ZMW/ha)	3854	4254.36	4275.23	4171.96	4151.75
Total variable costs (ZMW/ha)	2143	1303	1303	1303	1303
Gross margin ((ZMW/ha)	1711.26	2951.36	2972.23	2868.96	2848.75

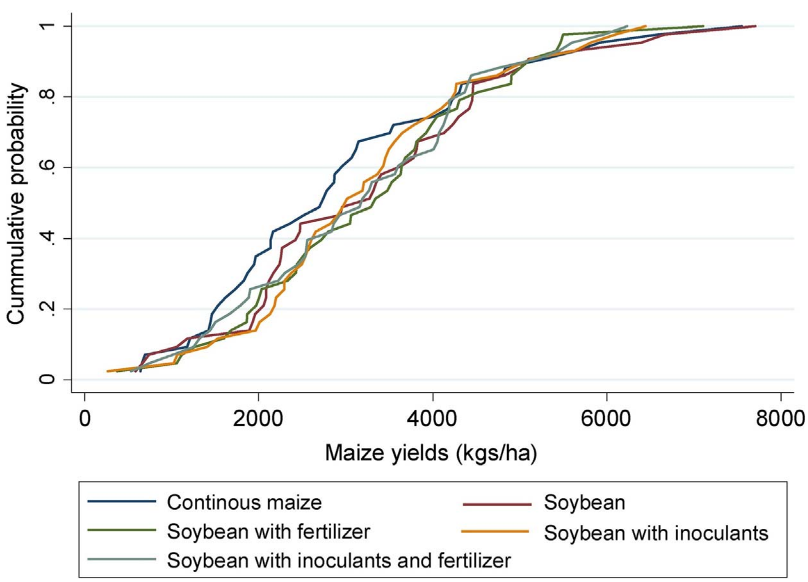

Fig. 3. Cumulative distributions of maize yields for the different on-farm trials.

Table 4
Average gross benefits (first and second year).
Source: Own calculations based on-farm trial data.

	Continuous maize	Soybean	Soybean and fertilizer	Soybean and inoculants	Soybean, fertilizer and inoculants
	1	2	3	4	5
Gross field benefits (ZMW/ha)	3724	2769	3122	2898	3314
Total variable costs (ZMW/ha)	2143	1101.50	1311.5	1131.5	1341.5
Gross margin (ZMW/ha)	1581	1667	1810	1766	1971
Benefit: cost ratio	1.74	2.51	2.38	2.56	2.47

from treatment 5 (soybean, fertilizer and inoculants) because it is the one recommended by researchers as the most optimal.

4.2. Determinants and impacts of technology adoption

4.2.1. Determinants of adoption of maize-legume rotation

An important step in allocating the aggregate market level economic surplus changes to individual households is the creation of household specific predictions of the probability of adoption of new technologies (Alwang and Siegel, 2003). To accomplish this, we first estimated the determinants of adoption of maize-legume rotation using a probit regression model.[5] The adoption model builds on the models used in past studies that include household and farm characteristics as determinants of technology adoption (see Feder et al., 1985 for a review). The results showed that age, education, total cultivated land, and access to credit were important determinants of adoption of maize-legume rotation (Table 6). Older farmers are expected to accumulate more personal capital to enable them to invest in modern technologies and may also have more experience with soil fertility management practices. Adoption of maize-legume rotation also increases with education of the household head and this is probably because educated farmers are in a better position to understand the benefits of new agricultural technologies (Khonje et al., 2015; Alwang and Siegel, 2003). Availability of land on which to grow an improved maize or legume variety can also affect farmer's adoption decisions. This is so because farmers can only allocate a larger area to improved varieties if they have enough land such that those with more land have a comparative advantage to adopt new agricultural technologies. Access to credit is important for a farmer

[5] The descriptive statistics of the variables used in the probit regression are presented in Table A1 in Appendix A

Table 5
Maize yield gains and unit cost reduction under the different treatment options.
Source: Own calculations based on-farm trial data.

Treatment	Yield (t/ha)	Cost (US $/t)	Unit cost (US $/t)	Unit cost reduction (US$/t)	Unit cost reduction (as a proportion of maize price) (K)
Continuous Maize	2.85	340	119	–	–
Soybean	3.27	175	53	66	0.32
Soybean and fertilizer	3.29	208	63	56	0.27
Soybean and inoculants	3.21	180	56	63	0.31
Soybean, fertilizer and inoculants	3.19	213	67	53	0.26

Note: Exchange rate: 1US$ = ZMW6.3.

Table 6
Probit model estimates of the determinants of adoption of maize-legume rotation in eastern Zambia.
Source: Model results.

Variable	Coefficient	*t*-ratio
Age	0.01**	(2.06)
Gender	0.08	(0.78)
Education	0.04**	(2.48)
Household size	0.01	(0.38)
Cultivated land	0.04**	(2.14)
Leadership	0.06	(0.57)
Market information	0.07	(0.70)
Contacts	0.00	(0.85)
Access to off-farm income	−0.12	(1.11)
Credit	0.30**	(2.62)
Ln distance	−0.02	(0.47)
Lundazi district	−0.65***	(5.35)
Katete district	−0.32**	(2.35)
Constant	0.05	(0.17)
N	810	
Pseudo R^2	0.06	

to decide whether or not to adopt a new agricultural technology (Feder et al., 1985). This is so because credit can enable farmers to purchase inputs such as fertilizer, seed, herbicides and inoculants that are in most cases jointly adopted with new agricultural technologies.

Based on the estimated probit model, we predicted the likely adopters of maize-soybean rotation and this was done by ranking the predictions in order of decreasing probability of adoption. Since the survey data showed that 75% of the farmers adopted maize-legume rotation in eastern Zambia in 2012, we simulated the adoption of maize-soybean rotation at 75, 85, and 100%. The benefits (i.e. income changes) arising from adopting maize-soybean rotation were then applied to the first 75, 85 and 100% of the adopters of maize-legume rotation based on the household's adoption probability. In an open economy case, we can include the *K* and elasticity of supply in Eq. (3) to approximate the change in income for adopters such that:

$$\begin{aligned} d\pi_i &= K_i PQ_i(1 + 0.5K_i\varepsilon) \\ &= 0.26PQ_i(1 + (0.5*0.26*0.5)) \\ &= 0.28PQ_i \end{aligned} \quad (5)$$

This is equivalent to a 28% increase over the base value of maize production. Following Moyo et al. (2007) and Francisco et al. (2014) the resulting income changes were then computed for each of the adopting households. The income changes were then added to the initial total household income to derive post adoption income for adopters which was then compared to the poverty line to compute the poverty indices.

Table 7
Number of farmers lifted out of poverty due to adoption of maize-soybean rotation in the Eastern province of Zambia.

Economy	Percentage of households assumed to be adopting	Headcount[1] index	Poverty gap index	Poverty severity index	Number of poor people lifted out of poverty[2]
Baseline		0.690	0.370	0.236	
	75%	0.641	0.311	0.188	65583
	85%	0.632	0.303	0.181	77629
	100%	0.617	0.293	0.173	97706

Notes: [1]We used the international poverty line of US$1.25/capita/day, which was converted to ZMW 1450.
[2]This was calculated by multiplying the total number of maize growers by the percentage reduction in poverty and the average household size in eastern Zambia. Estimated number of maize growers in eastern Zambia and the average household size in 2011 were 257,391 and 5.2 respectively.

4.2.2. Impact of maize-soybean rotation

In the open economy, all the benefits accrue to the producers such that the change in total economic surplus is equal to the change in producer surplus following technology adoption. Table 7 presents the results from the simulation exercise under the three adoption scenarios. The table also shows the FGT indices calculated using the household survey data. The poverty headcount index shows a baseline poverty rate of 69% in eastern Zambia. With 75% adoption of maize-soybean rotation, the poverty rate reduces to 64% (4.9 percentage point reduction), whereas increasing the adoption to 85% results in 5.8 percentage point reduction in the number of maize farmers who are poor. Note that we have only looked at the maize growers, hence our results do not account for the poverty rates for the consumers. The results further show that a 100% adoption of maize-soybean rotation leads to a 7.3 percentage point reduction in poverty in the number of maize farmers who are poor. We also observed a similar trend in the poverty gap index and poverty severity index (Table 7).

Table 7 further shows the number of maize growers who would be lifted out of poverty if we considered maize growers in the entire Eastern province of Zambia. In 2011–2012 season, there were about 265,755 agricultural households and 257,391 (97%) maize growers in the Eastern province of Zambia (Tembo and Sitko, 2013). Extrapolating the poverty results to the total maize growers in the Eastern province, the results in Table 7 show that 75% adoption of maize-soybean rotation would result in 65,583 people being lifted out of poverty. Similarly, assuming that all the households adopt the technology, 97,706 people would be lifted out of poverty. The results show that even though the percentage point reductions in poverty appear to be small in percentage terms, extrapolating it in terms of the number of individuals lifted out poverty is very high, given that we only considered a single and not multiple technologies.

5. Conclusion and policy recommendations

This study estimates the potential impacts of adopting maize-soybean rotation on poverty in eastern Zambia, using data from on-farm trials and a household survey. The paper estimates household level income changes and poverty reduction due to adoption of maize-soybean rotation using market level economic surplus as well as household level analyses to allocate economic surplus changes to individual households. The results show that adopting maize-soybean rotation results in substantial benefits when compared with traditional continuous maize production. For instance, the partial budget analysis results show that rotating maize with soybean with inoculants and fertilizer applied resulted in the highest gross margin per ha of ZMW1971

(US$313), which was about 25% higher compared with continuous maize. The results from the economic surplus model show that if 85% of the famers were to adopt maize-soybean rotation, the incidence of poverty for maize growers would reduce on average by 5.8 percentage points compared to the baseline poverty rate of 69%. Extrapolating this to the whole population of maize growers in eastern Zambia translates into more than 77,629 people being lifted out of poverty. These results underscore the importance of including grain legumes in maize-based systems.

It is indisputable that poor soil fertility is one of the major causes of the reduction in per capita food production not only in Zambia but also in Sub-Saharan Africa as a whole. One of the options to increase smallholder production and productivity is the application of inorganic fertilizers. Unfortunately, most smallholder farmers are resource poor and cannot afford to purchase the expensive inorganic fertilizers. The results from this study show that adopting maize-soybean rotation can substantially reduce the application of the expensive inorganic fertilizers while at the same time increasing maize yields. It is therefore important that policy makers encourage the inclusion of maize-soybean rotation in the extension messages as part of the broader soil fertility management practices being promoted in order to increase maize production in Zambia.

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Appendix A

See Table A1

Table A1
Socioeconomic characteristics of the sample households.
Source: Survey data.

Variables	Mean	Std. Dev.	Min	Max
Adopters of maize-legume rotation (1 = yes)	0.75	0.43	0	1
Household size (number)	6.97	3.12	1	20
Gender of the household head (1 = yes)	0.64	0.48	0	1
Age of the household head (years)	43.01	14.23	0	96
Education of the household head	6.24	3.58	0	17
Market information dummy (1 = yes)	0.65	0.48	0	1
Cultivated land (ha)	3.52	3.39	0	40
Access to off-farm income (1 = yes)	0.62	0.49	0	1
Access to credit (1 = yes)	0.76	0.43	0	1
Household expenditure per capita (ZMW)	6332	5921	0	129,800
Distance to extension agent office (walking min)	65.61	71.57	0	720
Contacts with extension agents (number)	15.95	28.89	0	364
Relatives/friends in leadership positions (1 = yes)	0.60	0.49	0	1
Number of observations	810			

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