Welfare-environmental quality tradeoffs of promoting use of certified seed potato in tropical highlands of Africa: Evidence from central highlands of Kenya

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Abstract

This paper used the propensity score method to assess the effect of using certified seed potato (CSP) on yield, input use, and food security among smallholder farmers. It focused on potato growers in central highlands of Kenya. The study found positive effect using certified seed on both yield and food security. But at the same time users of CSP applied significantly higher amounts of pesticides. This study therefore concludes that while using CSP has positive welfare effects, it can increase the use of inputs, some of which have environmentally degrading effects. It discusses the policy implications of the findings.

Key words: Smallholder farmers, certified seed potato, use and effect, propensity score matching, Kenya

Introduction

Potato (*Solanum tuberosum*) is a major crop in tropical highland regions of Sub Saharan Africa, where it is grown both as a horticultural crop (due to its high value) and food security crop. Globally, it ranks fourth after maize, rice and wheat (Shaaban and Kisetu, 2014). In Kenya, it is the second most important food crop after maize (Muthoni and Nyamongo, 2009; Obare et. al., 2010). It plays an important role as a food staple among producing households, and also contributes to poverty alleviation through income generation in both urban and rural households (Muthoni et al., 2013). An estimated 800,000 farmers grow potato in Kenya (Kaguongo et. al., 2014), while over 2.5 million Kenyans are employed along the potato value chain, either directly or indirectly (Laibuni and Omiti, 2014). As in the rest of the tropical highlands of Africa, potato production in Kenya is dominated by smallholder farmers.

Despite its importance, potato production faces major constraints in much of Africa highlands, a major one being lack of certified seed potato (CSP). Lack of CSP has led to recycling of seed, causing the buildup of pests and diseases among smallholder farms (Muthoni et al., 2013; Laibuni and Omiti, 2014). Consequently, the average potato yields in tropical highlands of Africa fluctuates between 8-10 tons per hectare, compared to 40 tons per hectare obtained in countries in North America and Western Europe , which have more developed potato production systems. (Muthoni and Nyamongo 2009; Were et al., 2013). Low yields, on the other hand, results in low incomes and contributes to food insecurity and poverty among small farm households, and confines smallholder farmers in subsistence agriculture (Barret, 2008; Ogutu et al., 2014), hence limiting growth and development.

Recent efforts to reverse the low yields and fight the pests and diseases by some of the African governments, jointly with the private sector and donors, led to the development of a rapid seed multiplication technique, commonly known as "3G" technique. The technique produces CSP in three generations of field multiplication, as opposed to the conventional 5 to 7 generations (Obado, 2010; CIP, 2011). The seed produced is free from most potato pests and diseases. Kenya, Tanzania, Ethiopia, Malawi and Uganda are among countries that have adopted this technique. To improve access to CSP by smallholder farmers, a private sector partner establishes a seed multiplication farm within the potato producing areas. In Kenya, for instance, Kisima Farm Ltd

(KFL), the private sector partner, established a farm in Nanyuki, close to leading producing potato areas of Meru and Nyandarua counties. The Farm sells its CSP to smallholder farmers within a radius of about 30 kilometers from it, and has retail outlets in other locations that allow smallholder farmers around such outlets to access CSP. KFL has, to date, greatly increased the production and sale of four CSP potato varieties namely Kenya Mpya, Sherekea, Asante, and Tigoni.

The use of CSP is usually intended to improve the welfare of small farm households by specifically increasing yields, food supply and hence food security (given that potato is a staple among producers) and household incomes. It is thus promoted with the aim of reducing rural poverty. However, the use of CSP can result in increased use of pesticides as farmers try to safeguard their investment in the purchase of such seed. Evidence from past studies suggest that farmers rely heavily on pesticides to control pests and diseases in food and cash crops in the highlands due to the tropical climate that generally encourage the outbreak and rapid multiplication of these biotic constraints.

This study uses data collected from a random sample of 408 potato farmers in central highland region of Kenya, stratified by use of CSP from KFL, to assess effect of using CSP on small farm households. The study focused on yield, food security, pesticide (insecticide and fungicide) usage, and fertilizer usage as the outcome variables. The rest of this paper is organized as follows: Section 2 presents the conceptual as well as the analytical framework and the hypotheses tested. Second 3 present the results and discusses the tests of the hypotheses while Section 4 concludes and provides some policy implications of the findings.

2. Study Methods

2.1 Estimation of the effects of using certified seed potato

An individual's or household's decision to adopt or use a new technology or practice is affected by the net benefits of doing so (Ali et al, 2012; Ogutu et al, 2014). Following Ali and Abdulai (2009) and Ogutu et al (2014), this study modeled the effect of using CSP on farm households as a linear function of explanatory variables ($\boldsymbol{X_i}$) and dummy variable ($\boldsymbol{R}_i$) representing the use of CSP. The linear regression model for assessing the effect of CSP can be specified as;

$$Y = \beta X_i + AR_i + \mu_i \quad (1)$$

where Y is the mean outcome variable (input use, yield, and household food insecurity) being impacted by the use of better CSP, R_i = 1 if a farmer purchased and planted CSP, 0 otherwise, and μ_i is the error term.

Whether farmers use CSP or not is dependent on the characteristics of the farmers and farms, and on each farmer's self-selection instead of random assignment. Assuming a risk-neutral[2] farmer, the index function to estimate adoption of CSP is expressed as:

$$R_i^* = \gamma X_i + e_i \quad (2)$$

where R_i^* is a latent variable denoting the difference between utility from using CSP U_{iK} and the utility from using other kinds of seed (U_{iN}). The farmer will thus use CSP if:

$$R_i^* = U_{iK} - U_{iN} > 0. \quad (3)$$

The term γX_i in Equation 3 provides an estimate of the difference in utility from using CSP ($U_{iK} - U_{iN}$), with household and farm-level characteristics, as explanatory variables, while e_i is an error term. Close inspection of equations 1 and 2 will however show that X and Y are interrelated, and that there is presence of selection bias. Selection bias occurs if some unobservable factors influence both the error terms of the outcome equation (μ) and the technology choice equation (e), thus resulting in correlation of the two error terms. Hence estimating Equation 1 using the ordinary least squares regression technique leads to biased estimates.

To control for the self-selection bias, this study used propensity score matching technique. This technique matches the two groups (i.e., users and non-users of CSP) so as to create a plausible counterfactual which will then address the problem of selection bias. Specifically, it matches a treated individual (i.e., the user) with a control individual (i.e., the non-user) that is similar in all

[2] This is a standard assumption in propensity score matching. See Ali and Abdulai (2009) and Becceril and Abdulai (2010) for similar treatment.

observable characteristics except for the treatment, and computes the difference in outcome variable for the two matched individuals. That difference is the effect of treatment (i.e. the use of CSP), measured in terms of average treatment effect on the treated individuals.

The estimation procedure in PSM proceeds as follows: First, propensity scores (defined as the probability of being in a treatment group given the observable characteristics), are obtained by estimating a binary logit or probit regression model. Second, the matching algorithm is selected based on the data at hand after undertaking matching quality test. The common matching algorithms are the Nearest Neighbor Matching (NNM), Radius Matching (RM) and the Kernel Based Matching (KBM). Ali and Abdulai (2009) discuss the differences among these matching strategies and how each works. Third, the control (i.e., non-users of CSP) are matched with the treatment (users of CSP) using the selected matching algorithms. Fourth, tests to assess whether the assumption of common support is satisfied are conducted. Fifth, the treatment effect is estimated in the region of common support based on the matching estimator selected. Finally, sensitivity analysis is undertaken to check if the influence of an unmeasured variable on the selection process is so strong as to undermine the treatment effect. This is achieved by using the Rosenbaum bounds (rbounds) test. Dehejia and Wahba (2002), Kasie and Holden (2006), Caliendo and Kopeinig (2008), and Ali and Abdulai (2010) provide a detailed discussion of the theory and implementation of the matching procedures.

As part of the first step of implementing the PSM, we estimated a binary response model. The functional form of the empirical model estimated was:

cleanseed = f(gender, education, hhsize, lnage, mobiphone, experience, groupmember, lndistkisima, lndistagric, lnassetvalue, creditaccess, landsize) $+ \varepsilon$ (3)

where *cleanseed* is a dummy variable equal to one if the farmer decided to plant/use CSP, zero otherwise; *gender* is a dummy variable equal to 1 if the respondent is male, 0 otherwise; *hhsize* is the number of household members; *lnage* is the natural logarithm of respondent's age measured in years; *mobiphone* is a dummy variable equal to 1 if farmer owns a mobile phone, 0 otherwise; *experience* is number of years of growing potato; *groupmember* is a dummy variable equal to 1 if farmer is a member of a farmer organization, 0 otherwise; *lndistkisima* is the natural logarithm of distance to Kisima Farm in kilometers; *lndistagric* is the natural logarithm of distance to nearest agricultural office in walking minutes; *lnassetvalue* is the natural logarithm of the value of physical assets in Kenya Shillings; *creditaccess* is dummy variable equal to 1 if farmer had access to credit, 0 otherwise; *landsize* is the size of land owned prior to adopting CSP.

The model was estimated using probit regression.

2.3 Sampling procedure and data

The data used in this study were collected from 6 districts of the Mt Kenya region namely, Buuri, Igembe Central, Igembe South, Laikipia East, Meru Central, and Tigania East due to their proximity to the CSP source, i.e., Kisima Farm Ltd. In each of the districts, the study focused on the villages with smallholder potato farmers who had used CSP from Kisima Farm during the any of the four seasons of two years preceding the study (i.e., 2012 and 2013).

The study respondents were selected as follows: First, a list of all the villages with farmers who planted CSP from Kisima Farm was obtained and the villages that had fewer than 12 CSP purchasers were dropped[3]. This procedure resulted in the selection of the 21 villages in Buuri, one in Igembe Central, one in Igembe South, 2 in Laikipia East, 5 in Meru Central, and 4 in Tigania East. A total of 34 villages were therefore selected from the 6 study districts. Second, for each village, a list of all the farmers who had planted CSP from Kisima Farm Ltd during the 2 years prior to the study was drawn with the help of local administrators (village heads) and contact farmers. A second list of potato growers who used other types of seed potato was also drawn. Third, 12 respondents were selected from the two lists, in each village, using probability proportionate to size sampling technique. That is, more farmers were sampled from the list with more names, and vice versa. This procedure resulted in the selection of 408 farmers: 167 CSP and 241 non-users.

[3] This was done mainly to avoid oversampling of respondents in villages with very few purchasers.

Eight trained enumerators collected the data from the selected farmers through personal interviews using a pre-tested questionnaire. The interviews ran from March to May 2014. The data were entered in SPSS and analysed using Stata.

3. RESULTS

3.1 Characterization of study respondents

Table 1 presents the demographic characteristics of users and non-users of CSP stratified by gender of the respondent. The mean age of all the respondents is 49 years, but the average age of male respondents is significantly higher than for the female respondents. On average, the respondents have eight years of education, implying that majority have only attained primary level of schooling.

Table 1: Demographic and households' facility access statistics

	Users[a] (N=167)	**Non-users[b] (N=241)**	
Variable	Mean (SD)	Mean (SD)	**Mean diff[a-b] (t-value)**
Distance to Kisima Farm (kilometers)	27.31	32.7	-5.393*
	(26.51)	(29.24)	(-1.937)
Distance to nearest main road (minutes)	28.42	28.82	-0.40
	(27.85)	(24.95)	(-0.149)
Distance to nearest agric office (minutes)	101.56	79.67	21.891**
	(111.58)	(81.28)	(2.168)
Age (years)	49.08	48.49	0.59
	(12.53)	(13.89)	(0.45)
Gender (1=Male, 0=Female)	0.55	0.47	0.08
	(0.5)	(0.5)	(1.63)
Education (years)	8.92	7.89	1.03***
	(3.86)	(3.76)	(2.69)
Farming experience (years)	19.72	18.62	1.1
	(12.41)	(12.64)	(0.87)
Owns mobile phone (1=Yes, 0=No)	0.96	0.89	0.08***
	(0.19)	(0.32)	(3.05)
Household size (count)	4.34	4.25	0.08
	(1.59)	(1.73)	(0.49)
Dependency ratio[4]	15.30	11.29	4.01
	(46.76)	(44.68)	(0.86)

Standard errors and t-values are in parentheses; *, **, and *** significant at 10%, 5% and 1% respectively

[4] Dependency ratio is calculated following the World Bank (2014) as the ratio of household members below 15 years or above 64years of age to the working age members (15-64 years).

Users of CSP have significantly higher average level of education than the non-users. This finding is in line with the adoption literature which suggests that education is increases the likelihood of uptake of new technologies (Wafullah et al 2015). At the same time, male respondents have significantly higher average level of education than their female counterparts. Users and non-users of CSP also differ in terms of ownership of mobile phones (an important communication tool/asset) and dependency ratio. Results further show that the study respondents have, on average, grown potato for 19 years, and therefore have considerable amount of experience in potato farming. There is however no difference in potato growing experience between purchasers and non-purchasers, and also between male and female farmers.

3.2. Effect of using CSP seed on small farm households

Table 2 presents the results of the statistical tests of difference in the amount (in value terms) of common inputs used in potato production. It shows that users of CSP differ from their counterparts in their usage of some of the key agricultural inputs. Specifically, the results show that the amount of fertilizer and insecticides used by CSP users is significantly higher. Users of CSP spent USD 265/ha and USD10/ha more on fertilizers and insecticides, respectively, than their counterparts. There is, however, no statistically significant difference in fungicide usage between users and non-users of CSP. Fertilizer is often used for soil amendments and is an important input in increasing crop productivity in many African countries (Vanlaume et al, 2014; Larson et al, 2016). However, use of fertilizer has been associated with non-point source pollution hence increase in its use can degrade the environment (Kimwaga et al, 2015; Cheng and Luo, 2015). Results show that there was no significant difference in the value of fertilizer used by the two groups of farmers.

The use of better CSP and increased use of yield-enhancing inputs is expected to influence potato yields among adopters. Hence we examined the differences in yield between users and non-users of CSP. In addition differences in sales of both ware and seed potato, with the latter targeting farmers who sell some of their potato harvest as seed to neighbors, and also incomes were analyzed.

Table 2: Test of differences in input use (in USD), by users and non-users of certified seed potato

Variables	Users (N=167) A		Non-users (N=241) B		Mean diff A-B	(t-value)
	Mean	(SD)	Mean	SD		
Non-labor inputs						
Purchased seed, USD/Ha	535.2	(228.1)	459.1	(217.5)	76.2***	(4.10)
Foliar feed, USD/Ha	10.5	(10.7)	7.2	(10.0)	3.3***	(3.20)
Fertilizer, USD/Ha	265.0	(137.8)	212.8	(117.7)	52.2***	(4.10)
Insecticide, USD/Ha	9.7	(10.1)	5.8	(8.4)	3.9***	(4.30)
Fungicide, USD/Ha	52.1	(30.4)	52.9	(33.4)	-0.8	(0.25)
Purchased manure, USD/HA	91.2	(107.0)	81.0	(94.5)	10.2	(1.02)

*, **, and *** significant at 10%, 5% and 1% respectively

Table 3 presents the results of the results of these analyses. It shows that there is statistically significant difference in all the three outcome variables (i.e., yield, sales and income) between users and non-users of CSP. Specifically, users of CSP produced more potato per acre of land, and hence, sold more thus earning more income from sales than their counterparts.

Table 3: Potato production, utilization and incomes, by full sample, by gender and purchase

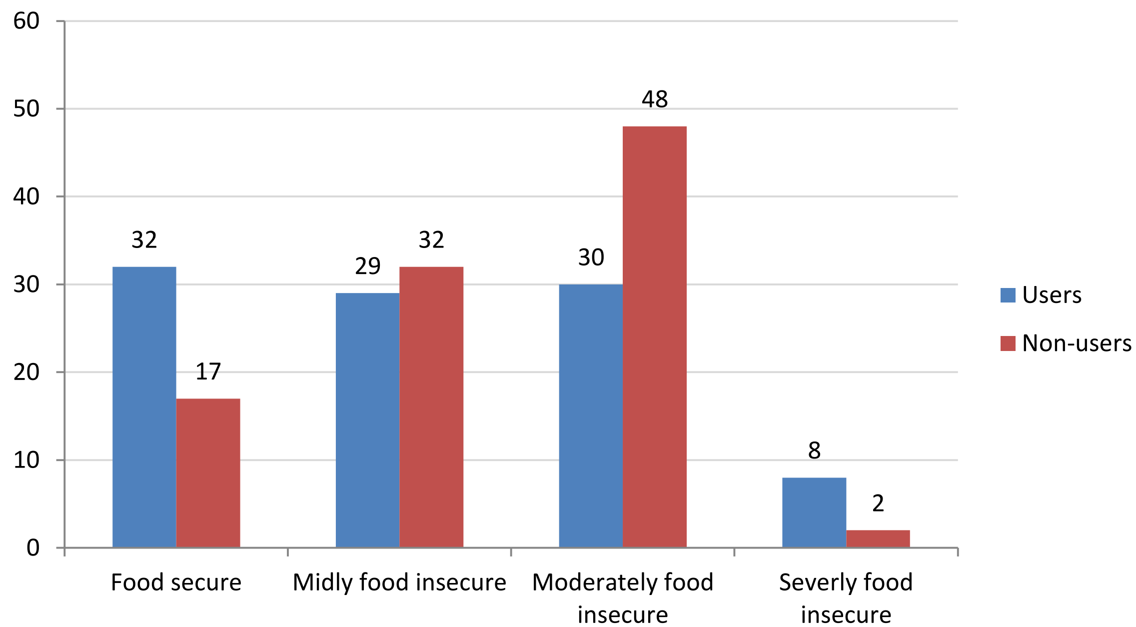
	Purchasers N=167	Non-purchasers N=241	mean diff (t-value)
Variables	Mean (SD)	Mean (SD)	
Potato output per hectare (i.e., yield) (Kgs)	11584.8 (6454.6)	8787.1 (5762.0)	6994.3*** (11.48)
Ware potato sales per hectare (Kg)	19352.0 (5188.2)	5337.3 (4596.2)	14014.7*** (12.33)
Seed potato sales per hectare (Kg)	155.5 (226.2)	115.4 (218.3)	40.10*** (4.50)
Potato income per hectare (USD)	1413.3 (776.9)	1054.8 (804.0)	10.21*** (4.49)

Source: Authors survey (2014)
Note: Standard deviations and t-values are in parentheses
*, **, and *** significant at 10%, 5% and 1% respectively

The results of analysis of the effect of using CSP on household food security (based on household food insecurity access prevalence (HFIAP)) between users and non-users of CSP are presented in Figure 1. The HFIAP is computed following Coates et al (2015), and is a snapshot measure of the degree of food insecurity in a household based on a 30-day period. The figure shows that the higher proportion of non-users experienced food insecurity problems in the 30 days preceding this study. Specifically, 80% of non-users of CSP were either mildly or moderately food insecure as compared to 59% of their counterparts. A chi-square test of differences in the prevalence of food insecurity between users and non-users of CSP yielded a p-value of 0.000 indicating that the observed differences are indeed statistically significant.

The above section has demonstrated that there is some evidence that the use of CSP is associated with increases in the amount of pesticides used, potato yields, and household food security status. Does this evidence persist under the use of the more rigorous econometric techniques? To address this question, we used propensity score matching (PSM) technique to test if purchase of CSP increases pesticide use, potato yield, and household food security status.

Figure 1: Prevalence of food insecurity in the study households: results of HFIAP analysis, % of respondents



The results of the Probit regression model, estimated as the first step of PSM estimation method, are shown in Table 4. They show that households located further from Kisima Farm are less likely to purchase CSP, probably due to the bulky nature of the seed and hence the high transport costs. On the other hand, a higher value of assets and land size owned prior to the purchase of CSP increase the likelihood of adopting CSP. The likelihood of purchasing CSP is also affected by membership of a farmer group, perhaps because such groups organize joint purchase to reduce transport and other transaction costs.

Table 5 presents the measures of impact (i.e., the average treatment effect on the treated – ATT) of using CSP computed using three matching approaches (algorithms) namely Nearest Neighbor method (NNM), Radius method (RM) and Kernel-based method (KBM) to check the robustness of the findings. Results show that using CSP increases the use of insecticides, albeit modestly, and reduces household food insecurity. The results of these two outcome variables are consistent across all the three matching algorithms. Also, as above, the purchase of CSP increases productivity, but has no significant effect on the quantity of fungicides applied. Specifically, on average, the use of CSP increases productivity by 2975-9521 kilograms per hectare, and insecticide use by a modest amount of about USD 6/hectare. However, the effect of purchase of CSP on productivity is significant for only one of the matching methods.

Table 4: Results of the Probit regression model estimated to generate propensity scores for the PSM technique

Variable	Coefficient	P-value
Explanatory variables		
Lnage	-0.326	0.245
Gender	0.107	0.478
Occupation	-0.025	0.850
Education	0.078	0.514
Household size	-0.005	0.904
Ln (distance to ext. office)	0.072	0.375
Ln (distance to Kisima Farm)	-0.233***	0.004
Credit access	-0.147	0.584
Land size prior to adoption	0.226***	0.000
Ln(assets value)	0.295***	0.000
Own mobile phone	0.272	0.399
Group membership	1.404***	0.000
Constant	-2.786	0.032
Model diagnostics		
Observations	408	
Pseudo R^2	0.3005	
P-value	0.000	

*, **, and *** significant at 10%, 5% and 1% respectively

Table 5: Results of propensity score matching analysis

Matching algorithm	Nearest neighbor		Radius		Kernel-based	
Outcome Variables	ATT	T-stat	ATT	T-stat	ATT	T-stat
Value of purchased fungicide (USD/Ha)	13.6	0.78	8.2	0.99	8.16	0.97
Value of purchased insecticide (USD/Ha)	6.6**	2.36	6.2**	2.78	6.53**	2.83
Potato yield (Kg/Ha)	9520.7**	2.24	2975.4**	2.12	3322.7**	2.33
Value of purchased fertilizer (USD/ha)	234.5	0.99	31.2	1.02	43.0	1.40
HFIAP score	- 2.52***	-3.25	- 2.17***	- 2.86	- 2.25***	-3.90

*, **, and *** significant at 10%, 5% and 1% respectively

In order to check the sensitivity of the results to the unobserved variables, the Rosenbaum (rbounds) tests were conducted. The results indicated that these results are quite robust and that no changes in the unmeasured variables can change the results considerably.

4. Summary, conclusion and implications

This study examined the effects of using CSP on farm households and on the use of yield-enhancing inputs with the potential to degrade the environment. Results of descriptive analysis indicate that use of CSP is associated with increased yields, sales and hence income. In addition, users of CSP were less food insecure than their counterparts. These gains are however accompanied by modest increase in the use of inputs, notably pesticides and fertilizer.

The results of the survey probit regression model estimated as the first step of implementing PSM indicated that farmer endowment with physical capital assets and group membership, distance to the source of CSP, and land ownership influence the likelihood of using CSP. Distance to source of CSP reduces the likelihood of its use suggesting the significance of transaction costs in farmers' decision to use of CSP, but may also reflect the bulky nature of the seed potato.

The findings of the PSM estimation are in line with those of descriptive analysis. They confirm that users of CSP obtained higher yields, pesticide usage and household food security. Users of CSP specifically used a slightly higher amount of insecticides than their counterparts. They also increased their usage of fertilizers. Both inputs can have negative effect on environmental quality if not used judiciously.

This study therefore concludes that the use of CSP has positive welfare effects on small farm households in terms of higher productivity (yield), hence incomes. However, these gains can lead to increased use of pesticides as farmers defend their investment in certified seed. These findings imply the need for farmer training safe and judicious use of pesticides and also fertilizers.

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