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Full Length Research Paper

Management of potato leaf miner in Uganda

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The yield of potato, an important food security and income crop in Uganda is substantially affected by pests. A survey was carried out in south western Uganda, a major potato growing area to assess the distribution and severity of potato pests in June and July 2015. In addition, leaf miner management options such as pesticide use, yellow sticky traps and mulching were evaluated for effectiveness. Trials in leaf miner hot spots in Bukimbiri and Chahi sub-counties of Kisoro district were conducted in three seasons during 2016 to 2017. In each sub-county, two sites were selected per season and trials were established in a completely randomized design with each treatment being replicated three times. From the survey, aphids and leaf miners were the major pests with high incidences in Kabale and Kisoro districts and rarely encountered in Rukungiri and Kanungu. Use of Dudu-acelamectin reduced leaf miner damage on leaves in season 1 (2017; P=0.001) and registered significantly higher yields compared to other treatments. Yellow sticky traps trapped high leaf miner fly populations but leaf miner damage on leaves and yield were not significantly different from control and mulched plots. Judicious use of pesticides in high leaf miner populations together with yellow sticky traps can reduce leaf miner populations and damage on potato.

Key words: Potato, potato leaf miner, pesticides, yellow sticky traps.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is the fourth most important crop after corn, rice and wheat (Schwartzmann, 2010) with world's total production of 376.8 million tonnes (UNSTAT, 2016). The crop plays a significant role in human nutrition by providing essential amino acids, minerals and vitamins (Deußer et al., 2012). Today, over 140 countries engage in potato production with China being the largest producer (Kroschel et al., 2012). In sub-Saharan Africa, potato production has increased from 100 to 290 metric tonnes between 1994 and 2008 with 70% of this growth being concentrated in East Africa (FAO, 2008). In East Africa, Kenya is the leading potato producer with 9.0 tonnes/ha, followed by Rwanda 7.7 tonnes/ha, and lastly Uganda producing 4.3 tonnes/ha (FAOSTAT, 2016).

Potato is Uganda's staple food and main source of income especially in South Western Highlands where 60% of the national crop is produced (FAO, 2008; Aheisibwe et al., 2015). However, yield has remained low compared to the 40 to 50 tonnes/ha produced in well-developed potato production systems (FAOSTAT, 2013). The low potato yield is attributed to various factors which

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include poor quality seed, diseases, limited use of fertilizers, and invasion of the crop by insect pests among others (Wagoire et al., 2005). The most important potato pests constraining potato quality and productivity in Uganda are potato tuber moth, aphids and leaf miners (Okonya and Kroschel, 2016).

Leaf miners (*Liriomyza* species) are polyphagous pests causing severe damage on potatoes and several other crops (Parrella, 1987). Adult flies lay eggs in leaves, the larvae feed within the leaves and at high fly populations feeding can heavily reduce yield and/or lead to plant death (Spencer, 1989). Leaf miner populations vary with season and temperatures for example in Baltistan, Pakistan highest populations are recorded in July with temperatures range between 22 and 27°C (Rizvi et al., 2015).

The common leaf miner species in the world are *Liriomyza trifolii* Burgess, *Liriomyza sativae* (Blanchard) and *Liriomyza huidobrensis* (Blanchard) (Murphy and Lasalle, 1999). *L. huidobrensis*, originally reported in Mexico, and Central and South America, causes serious damage on potato and has rapidly spread to other countries in Africa, Europe and Asia (Mujica and Cisneros, 2001). In Indonesia, leaf miners are reported to cause up to 100% yield loss at high fly populations (Shepard et al., 1998). In Kenya, yield losses are reported to range between 20 and 100% depending on the cultivar, crop species, crop development stage and also on leaf miner fly population (Gitonga et al., 2010). Although farmers have reported damage by leaf miners in Uganda, little is known about its severity and yield losses on potato.

Several leaf miner management strategies have been used in other countries but successful management depends on the development of a reliable and sustainable integrated pest management system. Murphy and LaSalle (1999) and Liu et al. (2009) demonstrated use of hymenopteran parasitoids as biological control agents of the leaf miner and can be complimented by planting flowering plants as sources of natural enemies. Although parasitoids are important control agents, their effective use in practice can be difficult because naturally parasitoid populations lag behind host population development (Weintraub, 2001). In such cases, growers will need to apply insecticides for leaf miner populations to keep below economically damaging levels (Reitz et al., 2013). The uses of trans-laminar insecticides with abamectin and cyromazine as active ingredients significantly reduce Agromyzid larvae with limited effects on the pest parasitoids (Reitz et al., 2013). In some instances, use of pesticides in leaf miner management has not been effective because the pest tends to develop resistance (Suryawan and Reyes, 2016). Additionally, there are potato plants resistant to L. huidobrensis and the mechanism of resistance is attributed to varieties having a high density of glandular trichomes which restrict oviposition sites and reduce feeding (Weintraub and Horowitz, 1995). The effectiveness of the aforementioned leaf miner management strategies have not been tested in Uganda.

In view of the aforementioned, there was need to assess the status of potato pests in the region and the present study assessed the distribution, severity of potato pests and evaluated the effectiveness of different management options for the potato leaf miner in South Western Agro Ecological Zone of Uganda.

MATERIALS AND METHODS

Survey site

A survey on the distribution and severity of potato pests was carried out in south western Uganda in June and July, 2015 in the districts of Kabale, Kisoro, Rukungiri and Kanungu. A total of 12 sub-countries were selected namely Chahi, Bukimbiri, Nyakabande and Kanabi from Kisoro; Muko, Bubare, Rwamucucu and Kamuganguzi from Kabale; Nyakishenyi and Nyarushanje from Rukungiri; Kihihi and Rutenga from Kanungu.

Four farmers were selected from each sub-country for house hold interview and field sampling. A distance of 2 to 6 km was used from one farmer to another depending on the availability of the farmer and the potato garden.

Pest and damage assessment

Thirty plants in each sampled field were selected diagonally and checked for the type of pests present and infestation severity scored.

Damage by leaf miners was scored on a scale of 1 to 5 where 1 represented no symptoms and 5 the most severe symptom (Nukenine et al., 2002). Potato leaves were checked for any signs of leaf miner damage.

Aphids were counted on three leaves of each plant (the top, middle and bottom) and recorded. Aphid severity on plants was scored at a scale of 1-5 where 1 represented no aphid, 2=1-10 aphids, 3=11-50 aphids, 4=51-100 aphids, and 5=≥100 aphids per three leaves

Leaf miner and aphid severity index were calculated using the following formula according to Nelson et al. (1999):

$$[1*P1+2*P2+3*P+4*P4+5*P5/N\ (G-1)]\times 100$$

where P1 to P5 = Total number of observed plants at each site. G = Number of grading = 5 and N = Total number of observations.

Evaluation of leaf miner management options

The study was conducted in Chahi and Bukimbiri sub-counties of Kisoro district for 3 seasons with two sites being planted per sub-county. Trials were planted on 30th March 2016, 18th October 2016 and 27th April 2017. New sites were selected for the following seasons within the same sub-counties. Clean potato seed of variety Rwangume was used because it is the most cultivated variety in the region. Potato was planted at a spacing of 30×75 cm in a 3×3 m plot, each plot separated by 2 m space from the other. N.P.K fertilizer was used to boost soil fertility and Ridomil was used as a fungicide to protect the crop against late blight and other fungal diseases.

Management strategies that were evaluated include: use of pesticides (Dudu acelamectine), use of yellow sticky traps (used locally available mouse traps), use of mulching with bean residues (since the pest pupates in soil, we hypothesized that mulching would hinder the emergence of the adults and reduce pest population) and a combination of yellow sticky traps and mulching.

The pesticide (Dudu acelamectine) was applied as soon as pest damage in the field was observed. All sprays were done in the morning during calm weather conditions to avoid pesticide drifts. Manufacturers' application rates of 15 ml in 15 L of water sprayed after every 7 days were followed. Yellow sticky traps were installed after 3 weeks of crop emergency for population monitoring and control. In a 3 × 3 m plot, five sticky traps were placed and these would be changed in case they were damaged by weather or if they were full of insects. All other strategies were put in place after the pest had appeared. Plots with no treatment were also established for comparison. The experimental design was a completely randomized design with 3 replications per site.

Data collection

Data were collected on leaf damage after 3 weeks of application of a management strategy and yield at maturity. Leaf damage data were collected according to Lopez et al. (2010) where ten plants were randomly selected per plot and on each plant the canopy was divided into three layers, that is, lower leaves (0-20 cm), middle leaves (20-40 cm) and upper leaves (>40 cm). Damage was observed as mines and punctures. Depending on the leaf area damage, a damage score was used according to Lopez et al. (2010) as follows: low (20-40%), moderate (40-60%), high (60-80%) and severe (80-100%).

Data analysis

Genstat 14th edition statistical package was used in data analysis to generate descriptive statistics. ANOVA was used to generate differences in districts, altitude, crop age, treatments and time of planting.

RESULTS

Distribution and severity of potato pests

Leaf miners and aphids were the common pests on potato at 41.7 and 55%, respectively (Table 1). Leaf miners were found in Kisoro district in the sub-counties of Chahi, Bukimbiri and Nyakabande. In Kabale, the pest was found in Muko and Bubare sub-counties and rarely encountered in Kanungu and Rukungiri districts (Figure 1). Leaf miner damage was higher at high altitudes compared to low altitudes (Table 2) and no leaf miner damage was observed at altitudes below 1000 m above sea level (Table 2). There was a significant difference in leaf miner damage on potato plants at different growth stages (P=0.001) with potato at two and three months after planting showing more damage than potato at one month old (Table 2).

Aphids were found in all the districts but more prevalent in Kabale and Kisoro districts (Figure 1). Aphids were encountered at all altitudes but high altitudes had significantly more aphid numbers than low altitudes (P<0.001) (Table 2). Aphid severity was associated with the age of the crop with the highest numbers on potatoes of three months old and the lowest on potatoes of one month old (P=0.001) (Table 2).

Evaluation of management options for potato leaf miner

Analysis of variance (Table 3) shows a significant difference (P=0.001) in yield for time of planting while other evaluated management options (pesticides, yellow sticky traps and mulching) were not significantly different. There was no significant difference on leaf damage for time of planting. Management options were statistically different in terms of leaf damage (P=0.001). The interaction between time of planting and management options had no effect on yield and leaf miner damage (Table 3).

Yield and leaf damage under leaf miner management options

In the first season 2016A, plots treated with pesticide (Dudu acelamectin) were significantly less damaged compared to the ones with yellow sticky traps, mulch and control plots (P=0.03). Leaf damage in plots with yellow sticky traps and mulches was not significantly different from control plots (Table 4). There was no significant difference in yield between managed and control plots (P=0.951) (Table 4).

In season 2016B, leaf miner populations were very low and the pest manifested when the crop was almost mature. Damage data was not collected, but the crop was harvested for yield data. Yield from all treatments was not significantly different (P=0.63) (Table 4).

In 2017A, the pest manifested early on the crop and there was a significant difference in leaf damage (P= 0.006) and yield for management options (P=0.001). In terms of yield, pesticide application gave a higher yield that was significantly different from all other management options. Yield from other management options was not different from control. Plots treated with pesticide had a significant low leaf damage compared to other plots (Table 4).

DISCUSSION

Distribution and severity of potato pests

Aphids and leaf miners were the common pests in potato fields. They are important potato production constraints in east African countries (Were et al., 2013). The higher incidence of pests particularly in the districts of Kisoro and Kabale could be attributed to continuous potato growing throughout the year giving a chance to pests to thrive.

Potato leaf miner damage severity increased with elevation while potatoes planted at elevations below 1000 m being less damaged. Leaf miner abundance at high altitudes could be explained by their natural occurrence in

Table 1. Occurrence of potato pests in south western Uganda in the survey carried out between June and July 2015.

Potato pests	Number	Percentage
Aphids	33	55.0
Leaf miners	25	41.7
Others (Cutworms, potato tuber moth and ants)	2	3.3

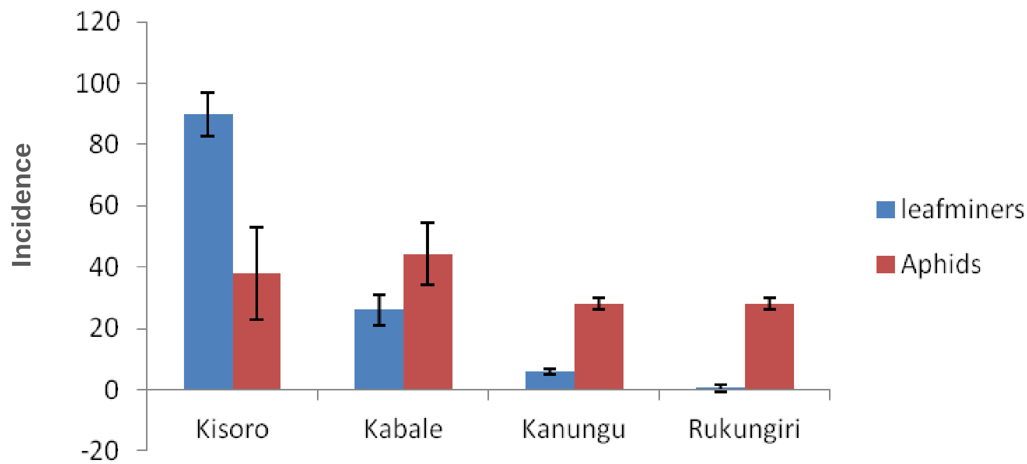

Figure 1. Incidence of leaf miners and aphids in districts of South Western Uganda.

Table 2. Mean severity score and severity index for potato leaf miners and aphids from the districts of south western Uganda.

Variable	Mean severity score for leaf miners damage	Severity index for leaf miners	Mean severity score of aphids	Severity index for aphids
District				
Kabale	1.49	1.0	1.8	2.3
Kanungu	1.08	0.06	1.4	0.08
Kisoro	3.52	8.84	1.6	0.87
Rukungiri	1.01	0.027	1.4	0.18
LSD	0.15	-	0.15	-
F-prob	0.001	-	<0.001	-
Altitude				
≤1000	1.00	1.19	1.06	1.27
1001-1500	1.3	1.59	1.13	1.9
1501-2000	2.16	2.74	1.604	2.15
2001-2500	2.3	3.19	1.58	2.13
LSD	0.3	-	0.3	-
F- prob	0.001	-	<0.001	-
Crop age				
1	1.13	0.1	2.3	0.10
2	2.17	3.84	2.5	2.98
3	3.62	6.49	2.6	4.07
LSD	0.261	-	0.26	-
F-prob	0.001	-	0.001	-

Table 3. Analysis of variance of yield and leaf damage for potato leaf miners management options and planting time in south western Uganda.

Source of variation	Yield			Damage on lower leaves		
	df	F- Statistic	F-Value	Df	F-statistic	F- value
Management option	4	1.19	0.33	4	10.92	0.001
Time of planting	2	39.99	0.001	1	0.56	0.463
Management option* time of planting	8	0.35	0.938	4	1.71	0.182

Table 4. Percentage leaf damage and mean yield for different potato leaf miner management options.

Treatment	Yield (kg/ha)			Damage on lower leaves (%)			Damage on middle leaves (%)		
	2016A	2016B	2017A	2016A	2016B	2017A	2016A	2016B	2017A
Control	43259	39111	6167.5	51.0	-	73.2	36.8	-	56.0
Mulching	51852	57556	7653.4	51.7	-	60.5	35.3	-	42.5
Pesticide (Dudu acelamectin)	57963	52111	10694.4	26.7	-	20.2	20.0	-	22.5
Yellow sticky traps	50185	56000	8093.3	58.0	-	65	30.3	-	40.0
Yellow sticky trap+ Mulch	52074	41556	8491.3	50.5	-	54	26.7	-	48.3
LSD	NS	NS	2368.9	24.57	-	20.17	NS	-	10.56
F-prob	0.952	0.634	0.006	0.030	-	0.001	0.498	-	<0.001

temperate regions and cooler highlands (Specer, 1973; Parrella, 1987). For instance, *L. huidobrensis* is reported to have first invaded higher and cooler altitudes of Indonesia and Costa Rica (Weintraub, 2001). In addition, Rodriguez-Castaneda et al. (2017) noticed a physiological restriction for *L. huidobrensis* at 28 to 29°C above which adult flies failed to emerge. Lanzon et al. (2002) noticed that *L. huidobrensis* developed faster at lower temperature of 15°C and much slower at 30°C. This temperature ranges are the same for Kabale and Kisoro. Moreover, potato production in Kanungu and Rukungiri is still very low and the area has a relatively long dry spell without the host crop, most likely does not allow the pest population to increase. Chavez and Raman (1987) reported a significant negative correlation between the activity of adult female leaf miners and temperature explaining their limited occurrence in the warmer areas of Kanungu and Rukungiri. Significant differences in leaf miner damage in older plants than young plants are supported by findings of Mujica and Kroschel (2011) who reported increased crop injury by leaf miners with crop development.

Evaluation of management options for potato leaf miner

In the first season of 2016 where planting was done in March, leaf damage on insecticide treated plants was significantly lower compared to other management options but yield was not different from control plots and other treatments. This could have been as result of lower leaf miner populations in that season or because of early planting, which could have made the crop vigorous and overpowered the effects of leaf miner damage. Similar findings were reported in Israel whereby the arrival of *L. huidobrensis* and its conspicuous damage on leaves did not result in any yield loss (Weintraub, 2001). However, in 2017A when leaf miner attack was pronounced, significantly high leaf damage was observed on control plots compared with pesticide treatments and insecticide treated plots yielded higher. Similar trends were reported by Guantai et al. (2015) where pesticide use in the management of the pea leaf miner reduced crop damage. Dudu acelamectin is an insecticide having abamectine as an active ingredient. Abamectin has systemic and translaminer properties and has been found to be effective against leaf miner larval stages (Weintraub and Horowitz, 1995; Reitz et al., 2013). Yellow sticky traps were observed to trap leaf miner populations but plots with traps were not significantly different in yield and leaf damage with control plots. The same trends were reported by Kroschel et al. (2012) where trapping reduced leaf miner flies but would not effectively prevent yield reductions and larval mining and development. Therefore, in such cases judicious use of insecticides with yellow sticky traps would be more effective.

Planting in March and October increased yields and reduced pest damage on potato compared to planting late in April. In Uganda, crops planted in March experience enough rainfall suitable for crop growth.

Planting late April is off season meaning the crop will meet drought in June and chances of performing well are minimal. Barros et al. (2017) noted that environmental and cultural conditions including off season cultivation, monocultures and occurrence of drought periods increase pest attacks and limit crop yields.

Conclusion

Aphids and leaf miners were the major potato pests in south western highland agro-ecological zone of Uganda. Use of Dudu-acelamectin in high leaf miner populations resulted in reduced leaf miner damage and increased yield. Yellow sticky traps are good for population monitoring and reduction. Planting clean seed at the beginning of rains results in healthy and vigorous plants with high yields. Therefore early planting is the best practice as it reduces costs involved in leaf miner management. Further research should focus on the effect of planting dates on leaf miner management.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Determinants of the extent of adoption of maize production technologies in Northern Ghana

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In spite of substantial investments in developing and disseminating improved maize production technologies by successive governments and several development partners, technology adoption in Ghana remains low. The purpose of this study was to identify the factors that influence the extent of adoption of improved maize production technologies among farmers in northern Ghana. A Tobit regression model was used to analyse the determinants of the extent of technology adoption. Results of the study revealed that formal education, farming experience, extension contact, access to credit, and membership of a farmer-based organisation are significant determinants of the extent of adoption of all three technologies considered. Moreover, sex of household head did not influence the extent of adoption of improved seeds but was rather significant in the case of fertiliser application and row planting. The study recommends that projects/programmes and policies related to the introduction and dissemination of improved maize production technologies in northern Ghana should draw lessons from studies like this to ensure improved technology uptake.

Key words: Adoption, improved technologies, maize, Tobit regression.

INTRODUCTION

Background

Agriculture has been the backbone of Ghana's economy throughout its post-independence history and the sector remains one of the most competitive in the Ghanaian economy contributing about 19.1% to the country's GDP (GSS, 2017). Though it has been described as the foundation of the country's socio-economic development, the agricultural sector is characterized by low productivity due to the dominance of the sector by smallholder farmers who heavily depend on rain-fed conditions, limited use of improved seeds, inorganic fertiliser, mechanization, and high post-harvest losses (Chamberlin, 2007). There is the opportunity for farmers to realise high yields and improve farm incomes using the best agricultural practices and technologies. It is evident worldwide that agricultural productivity has been driven by improved farm technologies (Gabre-Madhin and

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Johnston, 2002). Adoption of agricultural technologies has been associated with multiple benefits to farm households, including higher earnings and reducing poverty (Kassie et al., 2011), improved nutritional status and lower food price (Kumar and Quisumbing, 2010). Thus, the adoption of improved agricultural technologies is essential to the attainment of the Sustainable Development Goals (SDGs) one and two of ending poverty and hunger.

Maize is recognised as the most important cereal crop produced in Ghana and an essential part of the food and feed system and of high commercial value (FAO, 2008). In northern Ghana, it facilitates food security and serves as a source of generating income for many households (Wiredu et al., 2010). Owing to this, maize is among the few crops in northern Ghana which have received much attention from the government and other development agencies (ACDI/VOCA, 2012; Ragasa et al., 2013). Also, the importance of maize to the livelihoods of most farming households has made it a target crop for the government's flagship 'Planting for Food and Jobs' policy. However, due to the dependence on traditional farming practices, the use of low yielding varieties, limited use of fertiliser and low plant population, among others, maize production in Ghana has relatively remained stagnant in terms of volumes harvested and area under cultivation (MiDA, 2009). There have been average shortfalls of about 12% in maize supplies since the country is not self-sufficient in the production of this important staple crop (MiDA, 2009). Available estimates indicate an average national yield of 1.9 metric tonnes per hectare. However, with the adoption of appropriate production technologies, yields of 5.0 to 5.5 metric tonnes per hectare have been reported (MoFA, 2016). Growth in the maize sector has mostly been through the expansion of cultivated area rather than productivity increase on existing farms (Fuglie, 2012). However, population growth with its associated competition for land is limiting the land expansion potential of farms in most agro-ecological zones of which northern Ghana is not an exception (Diao, 2010). There is the need to improve the country's production of maize particularly in the three northern regions, with the adoption of improved technologies to ensure adequate supply and improve food security.

This paper specifically ascertains the extent to which farmers have adopted improved varieties, fertiliser application and row planting in maize production and evaluates the key factors that influence the extent of adoption of these improved maize production technologies in northern Ghana.

LITERATURE REVIEW

As highlighted by Roger's adoption and diffusion of innovations theory, the adoption of agricultural technologies is influenced by individual characteristics, perceived characteristics of the technology, and the institutional environment within which the adoption process occurs (Rogers, 2003). Traditionally, an array of personal characteristics, information flow, risk, institutional and input constraints have been considered as the prevailing factors influencing the adoption of agricultural technologies. For instance, some personal and household characteristics such as sex of household head, number of years in school, farming experience, household size, farm size and ownership of farm plots have been recognised as factors that influence technology adoption. Male-headed households are believed to have improved access to education, productive resources (such as land) and information on new technologies than female-headed households who are faced with social, cultural and religious constraints (Mignouna et al., 2011). This is a likely constraint to the adoption of improved technologies by female-headed households. Household size of farmers represents the pool of labour available to farm households, and this is believed to have a positive relationship with technology adoption, especially technologies that are labour-intensive. Bonabana-Wabbi (2002) asserts that families with large size are less limited by labour constraints in adopting some labour-intensive technologies. Failure of the labour market to provide on-farm labour for the adoption of labour-intensive technologies might deny smaller households the incentive to extensively adopt an improved technology. In such cases, households with larger sizes resort to the family for labour, hence speeding up the adoption of the technology.

It is often believed that land ownership has a positive influence on technology adoption. Doss (2005) argues that landowners are more likely to adopt innovations than tenants as tenants are faced with the insecurity of tenure that deprives them of adopting fixed input technologies such as irrigation system, mulching among others. Similarly, it is believed that farmers with larger farm sizes are more likely to adopt improved technologies as they can dedicate part of their lands to test the technology unlike those with smaller land sizes (Uaiene et al., 2009). On the contrary, Mwangi and Kariuki (2015) asserts that small land size will encourage technology adoption as an incentive for increased productivity. Education has been identified to positively and significantly influence technology adoption (Mignouna et al., 2011). Farmers with relatively high education are assumed to better comprehend and interpret new technologies much faster than farmers without formal education. Also, several studies have found a positive relation between farming experience and adoption. It is believed that due to their long stay in farming, they might have retrieved all their capital investments and are financially well off and can bear the cost of innovation unlike a starter in the industry (Uaiene et al., 2009). However, the converse has also been reported (Mwangi and Kariuki, 2015).

In addition, some institutional variables such as extension visits and training, access to credit, membership of a farmer-based organisation and the distance to input market have been identified as significant factors that influence the adoption decision and extent of adoption of improved technologies. For instance, Doss (2005) cites access to extension service as one of the critical avenues to acquire information about new technology. Regular contacts with extension agents help in the transmission of message about the existence of new technology, its usage and benefits from the producers to the adopters (Mwangi and Kariuki, 2015). Similarly, participation in extension training programmes has been identified to influence technology adoption positively (Monfared, 2011). Access to credit facilities offers a greater chance of adopting new technology. Farmers with access to credit facilities, either in cash or kind (inputs) are more likely to adopt improved technologies than those with limited access. Mwangi and Kariuki (2015) asserts that lack of credit opportunities relax the adoption decision of farmers and this is likely to influence the extent to which farmers can adopt improved technologies on their farms. Assurance of financial stability would imply that the farmer would be able to bear the cost of adopting the technology. According to Doss (2005), access to the input market makes farmers less restrained in purchasing inputs. Distance as a measure of technology adoption increases the cost of adoption and the time of adoption. When cost increase with limited financial reliability, farmers are less willing to and less capable of investing in the technology. Uaiene et al. (2009) notes that there exists a negative relationship between distance and adoption of improved technology. Social networks gained from social groups among farmers help in agricultural technology adoption as farmers can share information and learn from one another. According to Salifu et al. (2012), farmers with membership in a farmer-based organisation can get easy access to extension services, credit facilities as well as information on new technologies unlike those outside such farmer-based organisations. Contrary to this assertion, Doss (2005) argued that acquiring information about new technology through farmer groups and extension services are not necessarily a guarantee for technology adoption.

The effects of the factors identified as possible determinants of adoption were tested in this study.

METHODOLOGY

Study area

The study was conducted in the northern part of Ghana, covering Upper East, Upper West and Northern Regions. The area has a single rainy season which mostly begins in April/May and ends in September/October. This is followed by a continuous dry season from early November to the end of March. The maximum temperature within this season occurs towards the end of March whereas minimum temperature occurs in December and January (GSS, 2013). The population of Northern Ghana is predominantly rural (72%) with agriculture as the main economic activity (GSS, 2010). It is the most significant contributor to the local economy and employs more than 70% of the economically active population in the three regions (MoFA/SRID, 2011). Northern Ghana plays an essential role in agriculture in Ghana; accounts for about 40% of the country's agricultural land and is commonly referred to as the grain basket of the country (MoFA, 2010). Major staple crops cultivated in the area include maize, rice, sorghum, millet, groundnut and cowpea grown on a subsistence basis. The choice of the study area was based on the importance of maize in the farming system in northern Ghana and the availability of many interventions in the area disseminating and promoting the adoption of improved maize production technologies. However, the study area is considered among the poorest in the country in spite of the existence of enormous potential to achieve food security due to the area's comparative advantage in tubers (yam), grains and legume production (SRID-MoFA, 2012). In the Comprehensive Food Security and Vulnerability Analysis by the World Food Programme (WFP) in Ghana, the three regions were ranked as the most food insecure in the country (WFP, 2012). The underlying factors of food insecurity in the study area have been generally attributed to low yields of produce which are due to unfavourable weather, limited use of improved technologies, lack of agricultural inputs, storage and processing facilities, poor market linkages and poor road networks (WFP, 2012).

Sampling, data collection and data analysis

The study population included maize producing households in the three northern regions. A multi-stage sampling approach was utilised in selecting districts, communities and ultimately farmers for the survey. At the first stage, each region was considered as a cluster within which districts were purposively selected to include beneficiary districts of the USAID's Agriculture Development and Value Chain Enhancement (ADVANCE) project. A comprehensive list of maize producing communities in each district was obtained, and this served as the basis for the next stage of sampling. Communities were selected from each district through a simple random sample approach based on the list of communities obtained. In each community, farming households were listed with the help of ADVANCE field officers and households were randomly selected to reflect the number of households in the community. A total of 1,302 households were selected for the survey. Table 1 presents the distribution of sampled respondents across the study regions. The study employed a structured questionnaire to collect data from maize producing households in the study area in a cross-sectional survey. Trained enumerators conducted the household survey through a face-to-face interview.

Descriptive tools such as frequency tables, proportions and arithmetic mean were employed to summarise and describe the characteristics of respondents. For the continuous variables, student's t-test was used to ascertain statistical differences between adopter and non-adopter categories. The study adopted the Multivariate Tobit regression model in identifying factors that influence the extent of technology adoption.

At best, adoption studies based on dichotomous regression models such as the probit and logit models only explain the probability of adoption and non-adoption and not the extent to which farmers apply the improved technologies on their fields. A farmer adopting an improved technology may be doing so in part or all of his/her field. Therefore, a dichotomous definition of adoption will not be adequate in explaining the extent of technology adoption (Feder et al., 1985). The Tobit model, which is an extension of the probit and logit model, is one of the models that have discrete and continuous parts and mostly used in dealing with the problem of censored data (Johnston and Dinardo, 1997). Indeed, a number of studies have employed the Tobit model in estimating the extent of

Table 1. Sample size.

Region	Number Districts	Households	
		N	%
Northern	20	646	49.60
Upper East	9	228	17.50
Upper West	9	428	32.90
Total	38	1302	100.00

Table 2. Description of variables used in the model and their *a priori* expectations.

Variable	Description/Definition	Expected sign
HHsex	Sex of household head (1=Male; 0=female)	+
Farmexp	Number of years in maize production (Years)	+/-
HHsize	Number of family members in a household (Number)	+/ -
Educ	Number of years in school (Years)	+
Ownland	Ownership of maize plots (1=owner; 0=otherwise)	+
Extcontact	Farmer's access to extension visits (1=Yes; 0=otherwise)	+
Accredit	Access to credit for farming (1=yes; 0=otherwise)	+
Dist	Distance from house to the nearest input market (Kilometers)	-
Acctrain	Participation in extension training programmes (1=yes; 0=otherwise)	+
FBO	Belonging to a farmer-based organisation (1=yes; 0=otherwise)	+

technology adoption (Nkonya et al., 1997; Mafuru et al., 1999; Wiredu et al., 2012; Rahman and Chima, 2016).

A Tobit regression model was employed to investigate the factors that influence the proportion of maize field farmers allocate to improved technologies. For each of the three technologies considered in this study (improved seeds, row planting and fertiliser application), the dependent variable takes the value of the percentage of maize field allocated to that improved technology. The Tobit model is most suitable in dealing with this kind of data because it makes use of both observations at the limit, usually zero (those who did not adopt an improved technology) and those with positive values. Considering the multiple technologies under consideration, three Tobit equations are required. Since a number of farmers may be adopting different combinations of the three technologies, a multivariate Tobit model was developed to capture the joint outcome. According to Belderbos et al. (2004), the multivariate model estimates the influence of the explanatory variables on each of the technologies and the correlation between the adoption of the different technologies.

Let the outcome function for adopting a particular technology be represented by:

$$i^* = xi + ui \quad (1)$$

Where, X_i represents the vector of regressands/explanatory variables; ɣ represents the vector of parameters to be estimated, and u_i represents the error term.

Unlike the probit model which only provides information on the decision to adopt, the Tobit model captures the decision and the outcome. The three equations in this case are specified as:

$$Y_{1i}^{*} = \gamma_i x_{1i} + \upsilon_{1i} Y_{1i}^{*} = \text{maximum}\ (Y_{1i}^{*}, 0) \quad (2)$$

$$Y_{2i}^{*} = \gamma_i x_{2i} + \upsilon_{2i} Y_{2i}^{*} = \text{maximum}\ (Y_{2i}^{*}, 0) \quad (3)$$

$$Y_{3i}^{*} = \gamma_i x_{3i} + \upsilon_{3i} Y_{3i}^{*} = \text{maximum}\ (Y_{3i}^{*}, 0) \quad (4)$$

Where, Y_{1i}^{*}= extent of adoption of the i[th] farmer who adopted improved seed; Y_{2i}^{*}= extent of adoption of the i[th] farmer who adopted row planting and Y_{3i}^{*}= extent of adoption of the i[th] farmer who adopted fertiliser application.

The empirical model used was specified as:

EXT_Adopt = β0 + β1SEX_HHH + β2FARMEXP + β3HHSIZE + β4EDUC + β5LANDOWN + β6EXT + β7ACCREDIT + β8DIST + β9ACCTRAIN + β10MFBO + ui

Where, EXT_Adopt represents the extent of adoption of improved seed, row planting and fertiliser and µ is independent normally distributed error term. The meaning of the covariates, their definitions, and expected *a priori* signs are presented in Table 2.

RESULTS AND DISCUSSION

Descriptive results

Table 3 presents characteristics of the surveyed farmers by their adoption status of the selected improved technologies. As shown by the t-test for all the technologies, there is no significant difference between adopters and non-adopters in terms of age and land ownership. However, there was a statistically significant difference between adopters and non-adopters of the technologies in terms of education, farming experience, extension contact, credit access, distance to input market, access to training, and membership in farmer-

Table 3. Characteristics of adopters and non-adopters of different maize production technologies.

Variable	Improved seed			Row planting			Fertiliser			All farmers (N=1302)
	Adopters (N=295)	Non-adopters (N=1007)	t-value	Adopters (N=535)	Non adopters (N=767)	t-value	Adopters (N=415)	Non dopters (N=887)	t-value	
Sex of household head (1=Male)	0.67 (0.47)	0.71 (0.45)	1.56	0.65 (0.48)	0.74 (0.44)	3.41***	0.67 (0.47)	0.72 (0.45)	1.60	0.70 (0.46)
Age (Years)	42.18 (11.97)	42.78 (12.29)	0.75	42.10 (12.41)	43.03 (12.07)	1.36	41.86 12.18)	43.02 (12.22)	1.60	42.65 (12.22)
Education (Years)	5.42 (4.86)	3.06 (4.23)	8.14***	5.37 (4.84)	2.37 (3.77)	12.56***	5.18 (4.91)	2.86 (4.08)	8.95***	3.60 (4.49)
Household size (Number)	9.28 (4.11)	9.85 (4.12)	2.10**	9.68 (4.09)	9.74 (4.14)	0.24	9.67 (4.20)	9.74 (4.09)	0.30	9.72 (4.12)
Farming experience (Years)	19.28 (8.01)	16.41 (8.38)	5.23***	19.22 (8.67)	15.55 (7.83)	7.94***	19.17 (8.72)	16.07 (8.03)	6.31***	17.06 (8.38)
Farm size (Hectares)	1.88 (1.81)	1.82 (1.54)	0.62	1.94 (1.89)	1.76 (1.37)	1.98*	1.98 (1.93)	1.76 (1.43)	2.29**	1.83 (161)
Land ownership 1=Yes)	0.94 (0.23)	0.94 (0.24)	0.01	0.94 (0.24)	0.94 (0.23)	0.29	0.93 (0.25)	0.95 (0.22)	1.05	0.94 (0.23)
Extension contact (1=Yes)	0.51 (0.50)	0.23 (0.42)	9.48***	0.52 (0.50)	0.14 (0.35)	16.12***	0.55 (0.50)	0.17 (0.38)	14.86***	0.29 (0.46)
Access to credit (1=Yes)	0.53 (0.54)	0.30 (0.46)	7.70***	0.58 (0.49)	0.19 (0.39)	15.95***	0.58 (0.49)	0.24 (0.23)	12.48***	0.35 (0.48)
Distance to market km)	8.61 (10.52)	10.10 (11.78)	1.97**	8.3 (10.23)	10.78 (10.78)	3.85***	8.98 (11.37)	10.13 (11.58)	1.68*	9.76 (11.52)
Training (1=Yes)	0.57 (0.50)	0.34 (0.48)	7.12***	0.58 (0.49)	0.27 (0.44)	12.14***	0.55	0.32	8.03***	0.4 (0.49)
FBO member-ship (1=Yes)	0.66 (0.47)	0.39 (0.49)	8.50***	0.66 (0.48)	0.31 (0.46)	13.17***	0.64	0.36	9.85***	0.45 (0.50)

*, **, *** Indicates significance at 10%, 5% and 1% respectively. Values in parenthesis are standard deviations.

based organisations. There was a significant difference in the household sizes of adopters and adopters of improved seeds only. Also, there was a significant difference in the percentage of adopters and non-adopters of row planting in terms of the sex of household head. The results also show a significant difference in the average maize farm size of adopters and non-adopters of row planting and fertiliser.

Extent of adoption

Following Feder et al. (1985), the study measured the extent of adoption as the proportion of farmers' maize farm allocated to the adoption of improved technology. Table 4 presents the difference between adopters and non-adopters of the selected maize production technologies across the three regions in terms of maize farm sizes. Across the study area, the average maize farm size under cultivation was estimated at 1.83 hectares. Among the regions, the northern region recorded the highest average maize farm size (1.90 ha), followed by Upper East (1.83 ha), and the lowest was recorded in the Upper West region (1.73 ha). An ANOVA test (F-value = 1.384, p=0.251) showed that the difference between the regions was not significant. Among all farmers, the difference in maize farm size for adopters and non-adopters was significant only for row planting and fertiliser (Table 4). Further analysis of the proportion of farmers' field allocated to the adoption of improved technologies revealed that, adopters of improved seeds allocated about 54% of total maize farm to that technology. Similarly, farmers who planted in rows and those who applied fertiliser did soon about 59 and 56% of total maize farm respectively (Table 5). It can be observed from Table 5 that technologies which required relatively higher level of investments recorded a comparatively lower extent of adoption. Thus, the relatively low extent of adoption of fertiliser and improved seeds may be attributed to the financial requirement in the adoption of these purchased inputs. Indeed, capital-intensive technologies are only affordable to farmers who are well-to-do and thus their adoption and extent of application are usually limited farmers who have the means to meet the capital requirements it comes with (Khanna, 2001).

Determinants of the extent of technology adoption

Table 6 shows the results of the estimated Tobit regression model. Results of the Tobit regression model show that the log likelihood is -18849.818

Table 4. Average maize farm size under cultivation.

Region	Improved seeds			Row planting			Fertiliser			All farmers
	Adopters	Non-adopters	t-alue	Adopters	Non-adopters	t-value	Adopters	Non-adopters	t-value	
Northern	2.06(1.56)	1.87 (1.51)	1.14	2.02 (1.82)	1.84 (1.35)	1.47	2.12 (1.94)	1.82 (1.34)	2.19 **	1.90(1.52)
Upper East	1.91 (1.74)	1.8 (1.51)	0.45	1.9(1.65)	1.77 (1.50)	0.60	1.95 (1.78)	1.76 (1.44)	0.83	1.83(1.57)
Upper West	1.74 (1.99)	1.73 (1.62)	0.09	1.87 (2.08)	1.59 (1.32)	1.63	1.86 (1.98)	1.65 (1.56)	1.24	1.73(1.75)
All farmers	1.88 (1.81)	1.82 (1.54)	0.62	1.94 (1.89)	1.76 (1.37)	1.98 **	1.98 (1.93)	1.76 (1.43)	2.29 **	1.83(1.61)

Values in parenthesis are standard deviations

Table 5. Extent of adoption/proportion of land allocated to improved technologies.

Technology	Northern (%)	Upper East (%)	Upper West (%)	All farmers (%)
Improved seed	56	52	52	54
Row planting	59	56	60	59
Fertiliser	60	51	53	56

and is significant at 1% level. This indicates that the model adequately represents the data. There were positive relationships between the extent of adoption of all the three selected improved technologies and education, farming experience, extension contact, access to credit, participation in training programmes, and membership in a farmer-based organisation. Meanwhile, sex of household head had a significant positive relationship with the extent of adoption of row planting and fertiliser only. On the other hand, there was a negative relationship between household size and the extent of adoption of improved seeds and fertiliser. Land ownership and distance to the nearest input shop were however not significant determinants of the extent of adoption of all the selected technologies.

In this study, years of formal education was hypothesised to have a positive association with the extent of adoption of improved maize technologies. As expected, the coefficient of formal education was positively significant for all three technologies. Farmers with some level of formal education are more likely to better understand and interpret the consequence of adopting a new technology much faster than farmers without formal education. It is therefore not surprising that years of formal education has a positive influence on land allocated to the adoption of improved maize technologies. This finding is comparable to that of Mafuru et al. (1999) who reported education as a significant factor affecting the proportion of land allocated to improved maize technologies in Tanzania. This implies that the relevance of human capital development cannot be underestimated. A similar finding on the effect of education on the allocation of land to improved wheat variety has been reported by Gebresilassie and Bekele (2015) in Ethiopia. Sex of household is significant and positively influences the extent of adoption of improved seed, row planting, and fertiliser. This implies that holding all other variables in the model constant, male-headed households are more likely to allocate a greater part of their maize plots to improved technologies than their female-headed counterparts. This finding conforms to our *a priori* expectation and is consistent with earlier results of Omonona et al. (2006) and Asante et al. (2011). Farmers experience was measured as the number of years engaged in maize farming, and this was hypothesised to have a positive effect on the extent of adoption. As expected, farming experience has a significantly positive effect on the extent of adoption of improved seeds, row planting and fertiliser at 1% level.

With adequate experience, farmers are expected to improve their skills in production and be able to evaluate the advantages of improved technologies (Mignouna et al., 2011). Contrary to this finding,

Table 6. Tobit regression estimates of factors influencing the extent of adoption.

Independent variables	Seed		Row Planting		Fertiliser	
	Coefficient (Standard Error)	Z-score	Coefficient (Standard Error)	Z-score	Coefficient (Standard Error)	Z-score
Sex of household head	2.3845 (1.9134)	1.25	8.4257 (2.0390)	4.13***	4.3828 (2.0498)	2.14**
Years of Education	0.8214 (0.2020)	4.07***	1.6727 (0.2152)	7.77***	0.7876 (0.2164)	3.64***
Household Size	-0.5095 (0.2126)	-2.40**	0.0860 (0.2265)	0.38	-0.3110 (0.2277)	-1.87*
Farming Experience	0.3547 (0.1044)	3.40***	0.6276 (0.1112)	5.64***	0.3448 (0.1118)	3.08***
Land ownership	-0.3212 (3.7142)	-0.09	-0.9725 (3.9581)	-0.25	-1.1193 (3.9789)	-0.28
Extension contact	11.6444 (1.9686)	5.92***	20.7032 (2.0978)	9.87***	23.2090(2.1089)	11.01***
Access to credit	9.2711 (1.8753)	4.94***	19.5832 (1.9984)	9.80***	15.9091 (2.0089)	7.92***
Distance to market	-0.1214 (0.0749)	-1.62	-0.1907 (0.0799)	-1.39	-0.0210 (0.0803)	-0.26
Training	6.7996 (1.8379)	3.70***	12.9052 (1.9586)	6.59***	5.8565 (1.9689)	2.97***
FBO Membership	7.5861 (1.8102)	4.19***	14.3877 (1.9291)	7.46***	8.2615 (1.9392)	4.26***
Constant	8.7961 (4.6203)	1.90*	6.1743 (4.9236)	1.25	10.0566 (4.9495)	2.03**
σ^2	30.9301 (0.6061)	51.03***	32.9608 (0.6459)	51.03***	33.1342 (0.6493)	51.03***
Wald chi2 (33) = 700.38***						
Log Likelihood = -18849.818						
No. Obs = 1302						

Dependent variable = percentage of maize farm allocated to improved technology adoption.
Values in parentheses are standard errors. *, **, *** indicates significance at 10%, 5% and 1% respectively.

Gebresilassie and Bekele (2015) observed no significant effect of farming experience on the extent to which smallholder farmers adopted improved wheat varieties on their farms. Results from Table 6 also show that household size is significant and negatively affects the extent to which farmers adopt improved maize seeds and fertiliser. The implication is that increasing household size reduces the area allocated to improved maize seeds and inorganic fertiliser. A plausible explanation to this finding may be the fact that households with larger household members may be burdened with additional cost in meeting other household needs and as such may be reluctant in allocating financial resources to improved technologies, particularly those that are cost intensive. Consistent with this finding, Simtowe and Manfred (2006), observed that while larger households may have abundant labour required for maize production, the extent of adoption will depend on the household's financial ability to purchase the improved seed and fertiliser. Similarly, Samuel and Wondaferahu (2015), identified a negative relationship between household size and the area allocated to planting improved soybean seed. On the contrary, other studies (Danso-Abbeam et al., 2017; Mignouna et al., 2011) have reported a significant positive effect of household size on technology adoption.

This study hypothesized extension contact to have a positive influence on the extent of adoption. As expected, results in Table 6 show that the coefficient of extension contact is significant and associated positively with the extent of adoption of all three technologies. This implies that regular contact with extension agents is necessary to enhance the extent of adoption of improved maize technologies. Other studies (such as Mafuru et al., 1999; Namwata et al., 2010; Ayinde et al., 2010) have reported comparable results. For instance, Mafuru et al., (1999) identified extension access as a significant factor that influences the proportion of land allocated to the adoption of improved maize varieties. Contrary to this finding, Salifu et al. (2015) reported that having access to extension services did not show a significant influence on the adoption of improved maize varieties. Similarly, the results also show that attending a training programme has a significant effect on the extent of adoption of improved seeds, row planting, and fertiliser. Farmers' participation in training programmes exposes them to information about new technologies, and thus training participants (farmers) are more likely to allocate a greater proportion of their farms to improved technologies than non-training participants. This finding is in agreement with that of Hall and Khan (2002). The authors reported that training programmes in Ethiopia produced a positive influence on the adoption of improved seeds, fertiliser and herbicides. Similar findings have been reported by other adoption studies on different technologies and crops (Baffoe-Asare et al., 2013; Namwata et al., 2010). Access to credit for agricultural purposes had a positive and significant effect on the extent of adoption of all the three selected improved technologies. This suggests that improved technologies are more likely to be adopted extensively on farmers' field if there is adequate access to credit. Farmers with access to credit will have the purchasing power to purchase agricultural inputs such as improved seeds and fertiliser, and also to pay for extra labour for labour- intensive activities like row planting on the farm. With the rising production cost resulting from the rising input price, credit access becomes important in promoting extensive adoption of improved technology adoption. Similar to this finding, Wiredu et al. (2012) identified lack of credit access as a constraint to the adoption of the mini-sett technology by yam producing farmers in northern Ghana. The results also show a significant positive effect of having membership in a farmer-based organisation on the extent of adoption of all the three selected technologies. Membership in a farmer-based organisation facilitates farmers' access to credit, land, and labour resources. Such farmers are more likely to have information regarding new technologies, improved seeds and inputs. In northern Ghana, information on new technologies and agronomic practices are mostly disseminated through farmer groups. These social ties increase the awareness of farmers on the importance of adopting improved production technologies. It is therefore not surprising that having membership in a farmer-based organisation has a positive and significant effect on the proportion of farmers' field allocated to the adoption of improved technologies. The result of this study is comparable to other adoption studies (Baffoe-Asare et al., 2013; Godtland et al., 2004). This finding is however at variance with Wiredu et al. (2012) who observed no significant effect of group membership on the extent of adoption of the yam mini-sett technology in northern Ghana.

CONCLUSIONS AND RECOMMENDATIONS

This study sought to identify the factors that influence the extent of adoption of improved maize seeds, row planting and fertilizer in northern Ghana. The empirical results showed that among the socio-economic and institutional variables considered, years of formal education, household size, farming experience, access to credit, extension contact, membership in a farmer-based organisation, and participation in training programmes are variables that significantly influence the extent of adoption of all the three selected technologies. Having a male-headed household only influenced the extent of adoption of row planting and fertiliser.

The study recommends that projects/programmes, as well as policies related to maize technology introduction and dissemination, should consider giving much prominence to these identified socio-economic variables. This will enhance the extensive adoption of improved maize production technologies which will help to increase productivity, enhance households' income and improve food security, particularly in northern Ghana. The importance of farmers' access to credit for farming cannot be overemphasized. Government and development partners should explore innovative avenues that will ensure sustainable credit access by farmers to fill the current demand and supply gap. This could include group credit and a nucleus farmer out-grower model. Farmers should be encouraged to have better savings culture to improve their credit access. Also, there is the need to increase the frequency of extension visits to farmers by increasing the number of extension agents in various agricultural districts as they have the potential to influence adoption. Finally, extension programmes should include periodic training through field demonstrations to enhance farmer learning.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Market production and productivity: The effects of cash cropping on technical efficiency in staple crop production

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To meet increasing food demand, most developing countries cannot rely on expanding the crop area, but will need to stimulate yield growth arising from increased factor productivity. This can be achieved through more efficient utilization of inputs to produce maximum output given existing technologies. Low productivity arising from technical inefficiency negatively impacts on household income and food security by reducing food availability as well as economic access. It has been hypothesized that market-oriented production enhances productivity of staple crops through increased use of quality inputs and management technologies. This hypothesis was tested using household survey data from western Uganda. Using a stochastic production frontier model, technical efficiency of the major cash crop and staple crops was estimated. A propensity score matching approach was used to compare the technical efficiency of market-oriented and subsistence households in production of selected staple crops. Results show higher technical inefficiency in staple crops compared to the cash crop among the market-oriented households. A significant negative relationship was also found between cash crop production and technical efficiency in staple crops production. The negative association was attributed to withdrawal of critical resources particularly labor from staple crops to cash crops during peak periods of labor demand.

Key words: Crop productivity, food security, market production, stochastic production frontier.

INTRODUCTION

Developing countries face the challenge of feeding their rapidly increasing population on limited productive land. To meet increasing food demand most countries cannot rely on expanding the crop area, but will need to stimulate yield growth arising from increased factor productivity. This can be achieved in different ways. First, through increased access to and use of non-land inputs such as fertilizers and better technologies, for example high

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yielding varieties to boost crop yields thus shifting to a higher production frontier (Mekonnen et al., 2015). Second, through more efficient utilization of inputs to produce maximum output given existing technologies. The latter approach is known as increasing technical efficiency. Technical efficiency is a prerequisite for economic efficiency, which in turn may be necessary for economic viability and sustainability of farms. Recent studies, however, show that technical efficiency is typically not achieved in African agriculture, as most households do not operate along the best practice frontier (Mugera and Ojede, 2014). Most farms produce at levels below potential for their biophysical environment, implying that more agricultural output can be produced using existing resources (Thiam et al., 2001).

Important to policy makers and farmers is that inefficiencies in agricultural production undermines poverty reduction and food security. Technical inefficiency directly decreases food availability by reducing supply. Indirectly it creates a demand problem by denying producers sufficient income to access what they do not produce themselves. Persistent technical inefficiency in sub-Saharan Africa is often attributed to limited access to information, extension services (Asante et al., 2014) and high-quality inputs especially clean seed (Poulton et al., 2010). A study by Mekonnen et al. (2015) reveals that developing countries have a sizable potential of improving agricultural production from the same level of inputs if they invest in efficiency enhancing technologies including knowledge and information transfer technologies (e.g. radios).

In recent years, most African countries have made an effort to invest in transforming agriculture from subsistence farming (often characterized by low productivity) to market-oriented farming in order to overcome poverty and food insecurity (Carletto et al., 2016). Farmers have received support from governments and non-governmental organizations in form of extension services, training and inputs such as high-quality seeds to produce highly marketable crops such as rice. Prospects of getting high crop income induced farmers to invest in the production of marketable crops and adopt the recommended technologies.

This paper seeks to better understand the changes in technical efficiency in food crop production as farmers increasingly become more market-oriented. How market-oriented crop production affects technical efficiency in the production of staple crops was investigated. Promoting market production in a farming system dominated by subsistence production may positively or negatively affect technical efficiency of staple crops. Positive effects may arise through income generation that can facilitate households' timely access to quality inputs, information, extension services and improved technologies. For instance, access to technologies such as radio programs and mobile phone subscriptions facilitates the transfer of knowledge and information expected to influence technical efficiency in agricultural production (Mekonnen et al., 2015). Farmers may also easily access improved technologies and information by participating in market-oriented government-supported programs. For instance, in Uganda market-oriented households have benefited from government support through the commodity-based extension services approach aimed to transform low input subsistence agriculture into commercial market-oriented agriculture (Mwaura, 2014). In Zimbabwe, Govereh and Jayne (2003) found that cash crop production enhances food crop productivity as food crops benefit from extension services that households obtain through cash crop production programs. Similarly, semi-subsistence farms are found to have a higher technical efficiency in rice production than subsistence farmers in Thailand as a result of extension programs (Athipanyakul et al., 2014).

Moreover, income from production may facilitate market-oriented households to carry out timely field operations, the key to achieving technical efficiency. For example, they can supplement family labor with hired labor-reducing competition for labor between cash and staple crops during peak periods. Evidence from rice farmers in Nigeria shows that hired labor can have a positive impact on technical efficiency (Ogundele and Okoruwa, 2006). This positive path, however, requires households to invest income from the cash crop into efficiency enhancing technologies and inputs for the food crop.

In contrast, if poor households choose not to invest their income in production of staple crops, introduction of a cash crop may have a negative impact on technical efficiency of staple crops. This may come as a result of seasonal competition for critical inputs especially labor. Households that mainly depend on family labor are likely to prioritize the cash crop in terms of labor allocation and management such that activities in staple crops may be affected later in the cropping season hence affecting technical efficiency. Further, for households with different plots of land there is likely to be competition for good quality plots between the cash crop and staples, which may result in low yields of staple crops on low quality plots (Binam et al., 2004).

This study contributes to existing literature, by answering the questions whether market-oriented production enhances technical efficiency of staple crops, and whether market-oriented households are more technically efficient in cash crops than in staples. It is important that we understand how market production affects efficiency in staple crop production in order to inform policy interventions designed to enhance resource use to support market production as well as household food security. While a few studies have assessed the impact of cash cropping on food crop productivity (Govereh and Jayne, 2003; Strasberg et al., 1999), both studies focus on the effect of commercialization on food crop yields which may be due to technological change or technical efficiency. To the best of our knowledge none has explicitly studied the effect of market-oriented production on technical efficiency in staple crop production. Other related studies have assessed the effect of market interventions such as agricultural cooperatives (typically formed to aggregate small holders and link them to input and output markets) on technical efficiency in crop production. Using a stochastic frontier model and propensity score matching, Abate et al. (2014) for example found that farmers in cooperatives are more technically efficient than non-members in Ethiopia. They attribute this to increased access to productive inputs and extension linkages provided by agricultural cooperatives.

To answer these questions, we analyze technical efficiency in production of a major food cash crop (food crop grown for sale) and staples among market-oriented and subsistence households. The case of rice market production in western Uganda was used and resource use efficiency in production of staple crops among two groups of farmers-farmers benefitting from an intervention that aimed to promote market production and farmers from control areas that did not were compared. Rice was chosen because it is a crop that has been extensively promoted for market production with the aim of increasing household income and food security. Overall, low technical efficiency in production of both the food cash crop and the staple crops was found. Technical inefficiency for market-oriented households is higher in staple crops compared to the food cash crop. In addition, evidence was found for significant higher technical inefficiency in staple crops production for market-oriented households compared to subsistence households. It was conjectured that this result is associated with competition for critical resources in peak periods between the staple and cash crops.

Market-oriented food crop production in Southwestern Uganda

Market-based crop production in Uganda has increased remarkably in the past years. This is partly the result of the government's efforts to promote selected food crops as cash crops. Market production is motivated by market liberalization and urbanization which have resulted in increased demand for food both in the domestic and international market, especially in the neighboring countries of Rwanda, Kenya and South Sudan. FAO statistics for example, indicate that cereal exports increased from 7.6 tons in 2000 to 299.4 tons in 2013, this is more than a ten-fold increase. Equally, pulses exports have increased by 988.5% from 3.5 tons in 2000 to 38.1 tons in 2013. For this study we consider the case of rice production in Southwestern Uganda, where rice has been highly promoted as a cash crop. Rice is interesting in that it is a marketable crop traded both domestically and internationally.

Through the commodity-based agricultural extension approach under the National Agricultural Advisory Services (NAADS) program, rice is one of the few food crops that has received a lot of support from the government and other agencies, such as the Japan International Cooperation Agency (JICA). Market-oriented rice production in Kanungu district, Southwestern Uganda, started with the introduction of upland rice varieties commonly known as NERICA by IFAD in 2003 (CARD, 2014). The aim of the project was to increase income and food security for small holder households (IFAD, 2012). The project started in two sub counties of Nyamirama and Kihihi, considered to be relatively fertile as they lie along the Rift Valley. Subsequently, with government support under the National Agricultural Advisory Services (NAADS) program, upland rice production has been extended to other sub counties. It is now a major food cash crop in five out of twelve sub counties in the study area, and one of the priority commodities at national level (MAAIF, 2010). Rice production has increased significantly from 150,000 tons on 80,000 ha in 2004 to 280,000 tons on 140,000 ha in 2012 (MAAIF, 2010; Reda et al., 2012). This reflects the results of training programs providing farmers with information on modern farming technologies and marketing. Farmers' capacity to access the market has been enhanced through training in business development, creating market linkages and providing support to value addition initiatives. Twelve rice hulling machines have been established in the study area, including one that does sort and packaging.

METHODOLOGY

Data

The data used are extracted from a household survey on market production and food security conducted in Kanungu district in 2014. The survey used a multi-stage sampling procedure to select households. A total of 1137 households were sampled; 592 were randomly selected from five sub counties exposed to promotion of commercial rice production and the associated extension services-(treatment). These are considered as market-oriented households. Moreover, we surveyed 545 households randomly selected from two sub counties that did not receive this project. These households consequently do not grow rice. The sub counties were purposively selected considering factors that may drive selection of the area for implementing a market-oriented crop production program. In the present case, sub counties with similar socio-economic and agro ecological conditions were considered. Negligible 'contamination'/ spillover effects in the sub counties used as control were observed. This could reflect an information gap, because farmers in our control area lack the capacity or enthusiasm to search for information on rice production for commercial markets by themselves. It is believed that if a similar program would be introduced in the non-rice growing area, households would equally participate in market production, as subsequently discussed. This study uses data on household demographics and socioeconomic characteristics, inputs and outputs for production of key crops; rice as a cash crop; and beans and sweet potatoes as major staples.

Inputs and output for the food-cash crop (rice) and the staple crops (beans and sweet potatoes) were considered during the main

Table 1. Descriptive statistics for variables included in the study.

Variable	Mean			t-test
	Pooled sample (N = 967)	Market-oriented households (N = 342)	Subsistence households (N= 625)	
Bean output (kg)	112.0	97.0	120.0	4.33***
Labour (man-days)	46.4	44.1	47.6	1.619*
Seed (kg)	16.8	16.1	17.3	1.748**
Area (acres)	0.21	0.19	0.22	1.328*
Sweet potato output (kg)	407.0	356.7	421.3	1.79**
Labour (man-days)	27.1	33.0	25.3	-3.462***
Seed (kg)	318.9	400.8	295	-4.872***
Area (acres)	0.2	0.2	0.2	0.844
Rice output (kg)	-	517.3	-	-
Labour (man-days)	-	160.4	-	-
Seed (Kgs)	-	55.8	-	-
Area (acres)	-	0.43	-	-
Age of household head	42.7	42.5	42.7	-0.27
Education of household head (years)	6.2	6.3	6.1	0.79
Education of heads spouse (years)	4.3	4.5	4.1	1.49
Household size	6.3	6.8	6.0	4.21**
Size of land owned (acres)	1.9	2.4	1.5	4.15**
Distance to main road (km)	2.4	1.8	1.3	3.64**
Distance to main market (km)	5.6	4.6	2.6	13.86***
Distance to sub county headquarters (km)	4.7	5.2	4.5	4.2**
Main occupation agriculture = 1	0.9	1.0	0.9	2.76**
No secondary occupation = 1	0.5	0.5	0 .6	-2.00**
Member of farmer group =1	0.5	0.7	0.4	6.71***
Member of savings and credit group =1	0.8	0.8	0.8	-1.61
Market Production Index (MPI)	46.3	54.1	41.0	8.72***
Rice growing households (%)	40.8	-	-	-

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

cropping season (August-February). Output for rice and beans is the measure of threshed dry crop. Three inputs: land, labor and seed were used. Land is the total area covered by the crop during the main season including own and rented land. Labor is the total number of person days, both from the family and hired, spent on all activities for a particular crop. Seed is the quantity of seed used (both retained from the previous harvest and purchased in the market). Only three inputs were considered because fertilizers and pesticides are not used on the crops in this study, and the use of other inputs such as herbicides is negligible. Capital items such as machinery and buildings were not included in the production function as all households use hand hoes and store the produce in residential houses.

Earlier caveat was mentioned that the measurement error is an issue. Crops such as sweet potatoes are harvested in piece meal, which makes it difficult to estimate accurate output levels. We therefore, rely on estimates of participants regarding harvest levels as if the entire garden were harvested at once. The planting material for sweet potatoes is not tradable in the study area and therefore it is difficult to estimate the quantity of seed used. Another limitation is that land is not adjusted for quality differences at plot level as such data is not available. In case a farmer knowingly allocates a better plot to either of the crops (cash or staple), this could bias our comparative analysis of technical efficiency in cash and staple crop production. One could argue that perhaps the farmer gets the potential optimal output from the low productive plot. However, it is important to note that 'poor' land quality may be partly as a result of poor soil management practices which reflect technical inefficiency (Ahmed et al., 2015; Binam et al., 2004).

Descriptive analysis

Table 1 presents a summary of household and farm characteristics. Our sample reduced from 1,137 to 967 after households were dropped with missing observations on variables of interest. Not surprisingly, but important to note, is a significantly higher market production index for the market-oriented households. This indicates that these households are indeed more market-oriented, as they sell on average 54% of their output value compared to only 41% for the control households. A majority of household heads and their spouses have only primary level education. A larger land size was observed for market-oriented households. However, an average farm size of 2.4 acres (with a standard deviation of 1.9) suggests that a majority of the households are still to be considered small holders.

Empirical approach

Stochastic frontier model

Technical efficiency is a measure of the ability to obtain maximum output from a set of inputs given the best available technology. Different approaches are used to estimate technical efficiency. These include stochastic frontier models, parametric deterministic frontier models and non-parametric deterministic models (Bravo-Ureta et al., 2007). The choice for a specific model depends on the data and the context of the study. A stochastic production frontier model was used to estimate technical efficiency in rice production and two major staple crops; sweet potatoes and beans. The stochastic frontier model has an advantage over the deterministic model in that it incorporates a composed error structure with a two-sided symmetric error term that captures the random effects outside the control of the famer and a one-sided component reflecting inefficiency (Bravo-Ureta et al., 2007).

Following Wang and Schmidt (2002), we estimate a 'one-step' model that specifies the stochastic frontier for each crop j (rice, beans and sweet potatoes) on farm i and estimates how technical inefficiency depends on farm characteristics. A Cobb-Douglas functional form was assumed. The model is specified as follows:

$$lny_{ij} = \beta_0 + \beta_1 lnx_{ij} + v_{ij} - u_{ij}, \quad (1)$$

where; y is output and x_{ij} denotes a vector of inputs (seed, labour and land). β is the parameter vector associated with x variables for the stochastic frontier; *v* is a two-sided normally distributed random error - $v \sim N(0,\sigma_V^2)$ that captures the stochastic effects outside the farmer's control (e.g., weather, natural disasters, and luck), measurement errors, and other statistical noise. The term *u* is a one-sided ($u \geq 0$) efficiency component that captures the technical inefficiency of the farmer. In other words, *u* measures the shortfall in output y from its maximum value given by the stochastic frontier $f(x_i;\beta)+v$. This one-sided term can follow such distributions as half-normal, exponential, and gamma (Greene, 2008). This study assumes that *u* follows a truncated normal distribution $[u \sim N(\mu, \sigma_u^2)]$ which allows the inefficiency distribution to have a non-zero mean μ. The two components *v* and *u* are assumed to be statistically independent of each other.

To analyze the effects of exogenous variables (z_m) on farms' levels of technical efficiency, we defined the technical inefficiency model as follows:

$$\mu_{ij} = \delta_0 + \delta_1(\, cashcrop_i) + \delta_m z_{mij} + \varepsilon_{ij} \quad (2)$$

where μ_i is the mean of the inefficiency term assumed to follow a truncated normal distribution. $cashcrop_i$ represents a dummy for market-oriented rice production (the key variable), and δ_m is a vector of unknown parameters to be estimated.

The control variables used in the efficiency model include: sex, age and education of household head, household size, size of land owned, access to extension services, type of seed, secondary occupation, source of labor (takes the value of 1 if the household mainly uses family labor, zero otherwise), distance to market and sub-county headquarters, membership to farmer groups and savings and credit associations. These factors are often reported to explain variation in technical inefficiency in agricultural production. Sex of household head is likely to affect technical efficiency as it influences access to productive resources such as land and inputs (Peterman et al., 2011). Age reflects experience, as most farmers have grown up in agricultural households. Education and access to extension services are likely to influence uptake of technologies which in turn affect technical efficiency (Kitila and Alemu, 2014). In Ethiopia, engagement in non-farm activities and, land holding are reported to influence technical efficiency of small holder maize farmers (Kitila and Alemu, 2014). There is mixed evidence on the relationship between farm size and productivity, while some studies report a positive relationship (Chirwa, 2007; Tan et al., 2010), others show an inverse relationship (Carletto et al., 2013). Membership of farmer associations and extension services facilitate timely access to inputs, information and technical assistance which are critical for technical efficiency (Chepng'etich et al., 2015). Access to credit facilitates timely usage of inputs including hired labor thus minimizing inefficiency.

Estimating market production effects on technical efficiency

Comparing technical efficiency between the market-oriented and subsistence households presents some methodological challenges. First, market-oriented rice production is a government supported program and such programs are typically not offered at random. It is therefore important to consider the factors that are likely to drive the selection of the area (sub county) in which the program is promoted. In this case for example, rice production may have been first promoted in sub counties that have more favorable weather and geographical conditions for the crop, or in sub counties with few other development programs. Regrettably sub-county specific data is lacking so we are unable to provide statistical information. The available information, however, indicates that sub counties are simply demarcated for administrative purposes and not geographical differences (Kanungu District Local Government, 2013). Arguably we may not completely rule out regional differences that may cause biased estimates. We therefore, include regional dummies in the inefficiency model to control for potential regional variation.

Second, participating in market production is not randomly assigned, but voluntary. Households self-select into market production. It is reasonable therefore, to expect that individual households who participate in market production are different from those that do not. While any household can engage in market production to increase its income, those with more resources such as capital and land are perhaps more likely to engage in it. Moreover, other factors such as entrepreneurship capability are not observable but may influence participation in market production (as well as efficiency in farming). We therefore, face a common problem of selection bias due to un-observables. To overcome the problem of self-selection requires a counterfactual or control group that has the same characteristics as the treated group. Common approaches are instrumental variables, difference in differences and matching methods (Blundell and Costa, 2000). This study employs propensity score matching to construct an appropriate control group.

Matching tries to eliminate selection bias due to observable factors by comparing treated households with control households that have similar observable characteristics. The propensity score is the conditional probability of receiving treatment; in the present case, the conditional probability that a household participates in market-oriented rice production given its geographic location, demographic and household characteristics. Propensity score matching provides unbiased estimates in case self-selection can be explained by observables and reduce dimensionality of the matching problem (Becker and Ichino, 2002). Within subpopulations with the same value for the propensity score, covariates are independent of the treatment indicator and thus cannot lead to biases (Imbens and Wooldridge, 2008). The weakness of propensity score matching is its inability to deal with hidden bias due to unobserved heterogeneity between the treated and control groups which my lead to overestimation of market production effects. This problem was addressed by using Rosenbaum bounds approach to determine how strongly the unobservable must affect selection into treatment in order to undermine our conclusion on market production effects (DiPrete and Gangl, 2004).

In the present analysis, the effect of market-oriented production on technical efficiency in staple crops production is determined by the difference in technical efficiency levels for the market-oriented (rice growing) households and the comparison group (non-rice growing).

It was assumed that participation in market-oriented rice production is a function of a range of observable characteristics at household and individual level. Formally it is expressed as follows:

$$d_i = \beta(w_i) + \tau_i \quad (3)$$

where; $d = 1$ for households growing rice and $d = 0$ for the comparison group, w_i is a set of observed variables that influence the decision to participate in market-oriented production. Other unobserved household-specific factors are summarized by the random variable τ_i.

A logit regression model was used to estimate the propensity scores for the treated and control groups. In a counterfactual framework, our interest is to estimate the average treatment effect on the treated (ATT)[1] (Heckman et al., 1997; Smith and Todd, 2005), where the treatment is participation in market production (in this case rice production) and the outcome variable is technical efficiency. Propensity score matching balances distribution of observed covariates between treatment and control group based on similarity of their predicted probabilities of participating in market production. Thus, using different matching methods (kernel and radius) we are able to estimate the effect of market-oriented production on technical efficiency.

RESULTS

Stochastic frontier analysis

The production frontier and technical inefficiency models for beans, sweet potatoes and rice were estimated using the maximum likelihood estimator. Results are presented in Table 2. In the models for beans and sweet potatoes, we assume that both market-oriented and subsistence households have the same production technology. We then predict technical efficiency levels which we use as our outcome variable in the propensity score matching analysis.

As expected, parameter estimates of the stochastic frontier models indicate that inputs elasticities apart from sweet-potato seed are positive and statistically significant. This implies that households can achieve higher levels of output by increasing input use. The insignificant effect of sweet potato seed is not surprising since the seed is vegetative and the optimum plant density depends on the cultivar. Land input has the largest elasticities ranging from 0.32 for sweet potato to 1.2 for rice. This suggests land is the most critical input in crop production, which is logical given that agrochemicals and fertilizers are hardly used. Increasing cultivated land by 1% will increase sweet potato and rice output by more than 1%. The sum of the coefficients on discretionary inputs in the models for beans and rice is greater than one, signifying increasing returns to scale. This means that the farmers are still operating in the first stage of the production process. This is contrary to the general impression that smallholder agriculture is characterized by decreasing returns to scale. Similar findings have been reported elsewhere, for example in small scale rice production in Nigeria (Oniah et al., 2008). While output is highly responsive to changes in land size cultivated, further increasing productive land is presumably not sustainable given that 71.9% of arable land is under cultivation and arable land per person has declined from 0.45 in 1961 to 0.19 ha per person in 2013 (data.wordbank.org/indicators). The likelihood-ratio test for all models indicates presence of significant technical inefficiency at the 1% level. The value of gamma indicates that about 86% of the variation in beans output; 99% of the variation in sweet potatoes output and 77% of the variation in rice output is due to differences in their technical efficiency. These estimates compare well with those in other studies such as Binam et al. (2004) and Anang et al. (2017) reported in literature.

Does market production enhance technical efficiency of staple crops?

Generally, there are high levels of technical inefficiency in food crop production for farmers in both market-oriented and subsistence production. Table 3 presents a summary of technical efficiency scores.

On average, subsistence households have relatively higher technical efficiency in staple crops than market-oriented households. Compared to subsistence households, a larger proportion of market-oriented households have a technical efficiency below the pooled sample's mean. The highest inefficiency is observed in sweet potato production with a mean technical efficiency of 53%. Considering the pooled sample, there is potential for households to increase their beans and sweet potato output by 37 and 36%, respectively, through efficient use of the present technology. A similar message is presented in Figures 1 and 2, where we observe higher technical efficiency (in beans and sweet potato production), for the non-rice growing households. The mean comparison t-test of no difference in technical efficiency for both crops is rejected at 1% significance level. The inefficiency regression results confirm these differences (Table 2). Estimates of the technical inefficiency models show a positive significant relationship between the dummy for rice production and technical inefficiency in staple crop production even after controlling for regional, social economic and farm characteristics. The coefficients for both the beans (0.667) and sweet potatoes (0.679) models are relatively high suggesting that market-oriented production has a strong efficiency decreasing effect on staple crop production. High coefficients could also mean that inefficiency effects are overestimated due

[1] Details on ATT estimation see Heckman, Becker and Ichino (2002), Smith and Todd (2005)

Table 2. Estimates of the stochastic production frontier function and determinants of technical inefficiency.

Variable	Pooled sample		Market-oriented households
	Beans	Sweet potatoes	Rice
Lnoutput	Coefficients (Std. errors)	Coefficients (Std. errors)	Coefficients (Std. errors)
Production frontier			
Constant	3.056*** (0.164)	6.321*** (0.121)	4.293*** (0.382)
Lnlabour (person days)	0.259*** (0.034)	0.036* (0.020)	0.297*** (0.071)
Lnseed (kg)	0.326*** (0.041)	0.014 (0.010)	0.169*** (0.051)
Lnfieldsize (Acres)	0.544** (0.210)	0.324** (0.131)	1.216*** (0.288)
Technical inefficiency model			
Constant	0.539 (0.977)	1.867*** (0.686)	-0.874 (1.13)
Household grows rice =1, 0 otherwise	0.667** (0.262)	0.679*** (0.139)	-
Sex of household head	0.177 (0.192)	-0.052 (0.140)	0.136 (0.219)
Ln age of household head	-0.146 (0.234)	-0.295* (0.173)	0.855*** (0.282)
Ln education of household head (years)	0.005* (0.086)	0.055 (0.070)	0.030 (0.090)
Ln education of heads spouse (years)	-0.170 (0.096)	-0.007 (0.065)	0.012 (0.085)
Ln size of land owned (Acres)	-0.612** (0.242)	-0.323*** (0.121)	-0.246* (0.132)
Ln Distance to main market (km)	-0.181 (0.199)	0.153 (0.135)	-0.549*** (0.193)
Ln Distance to sub county headquarters (km)	0.105 (0.199)	-0.138 (0.145)	0.036 (0.163)
Seed type; improved seed =1; 0 otherwise	-	-	-0.094 (0.133)
Access to extension services	0.084 (0.153)	0.019 (0.116)	0.134 (0.155)
Source of labour; family =1: 0 otherwise	0.553** (0.220)	-0.130 (0.106)	0.478*** (0.143)
Household has no secondary occupation	-0.047 (0.124)	0.052 (0.092)	-0.035 (0.1259)
Member of farmer group =1; otherwise =0	-0.020 (0.150)	-0.192 (0.120)	0.074 (0.143)
Member of saving & credit group = 1; otherwise = 0	-0.073 (0.148)	-0.203* (0.119)	-0.041 (0.150)
Area dummy 1 (Kihihi)	0.027 (0.167)	-0.501** (0.177)	-0.167 (0.142)
Area dummy 2 (Nyamirama)	-0.487* (0.266)	-0.547** (0.168)	-0.523*** (0.188)
Area dummy 3 (Kambuga)	-0.454** (0.220)	-0.240** (0.119)	-
No. of observations	883	518	359
Diagnostic statistics			
$\sigma_s^2 = \sigma_v^2 + \sigma_u^2$	0.75	0.77	0.63
Gamma ($\gamma = \sigma_u^2/\sigma_s^2$)	0.86	0.99	0.77
Log-likelihood	-683.321	-269.64	-356.501
LR statistic	254.86***	7.33*	25.54***
Prob > chi2	0.000	0.000	0.000

*, ** and ***, significant at 10, 5 and 1%. Ln denotes logarithm; pooled sample comprises all market-oriented and subsistence households that grow beans and sweet potatoes.

to endogeneity of participating in rice production. Propensity score matching was used to derive the effects of market-oriented production on technical efficiency in staple crop production.

Propensity score matching analysis

Propensity scores were estimated using the logistic regression and the results are presented in Table 4. Large households, with large size land, distant from the market and are members in farmer groups are more likely to participate in market-oriented production. This is logical in that a household requires a rather large farm to produce for the market and such land is likely to be distant from the market. Farmer groups are likely to be a source of information and inputs which are important for market production.

Market production effects on technical efficiency (ATT) were estimated using kernel and radius matching methods. We impose a common support condition and Chi^2 test results (Table 1 Appendix) show very low pseudo

Table 3. A summary of technical efficiency scores for staple crops.

Efficiency level	Market-oriented households		Subsistence households		Pooled sample		t-values	
	Beans	**Sweet potatoes**	**Beans**	**Sweet potatoes**	**Beans**	**Sweet potatoes**	**Beans**	**Sweet potatoes**
Mean	0.58	0.53	0.65	0.67	0.63	0.64	4.9667***	6.0206***
Minimum	0.11	0.11	0.13	0.05	0.07	0.05	-	-
Maximum	0.87	0.90	0.91	0.94	0.91	0.94	-	-
Proportion of households < mean	41.6	50.7	36.1	38.2	41.9	44.1	-	-
Number of observations	336	138	493	390	829	626	-	-

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

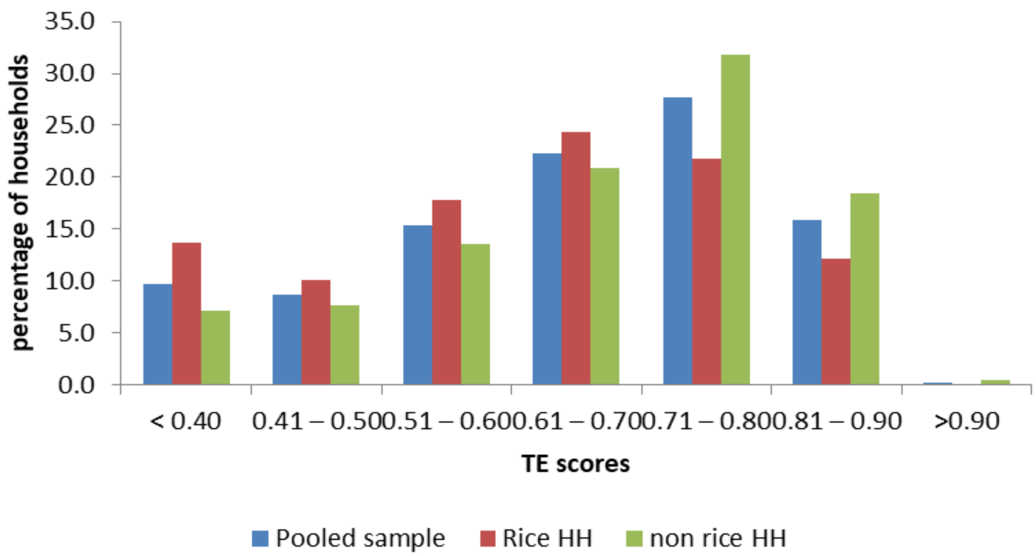

Figure 1. Distribution of technical efficiency scores in beans production.
Source: Survey conducted by the authors.

R2 not statistically significant after matching, and the covariate balancing test results show that all covariates are balanced (Table 2 Appendix). The distribution of propensity scores using kernel and radius matching are shown in Appendix Figure 1. The results are presented in Table 5. Consistent with descriptive statistics and the inefficiency coefficients we find that technical efficiency in staple crops is significantly lower for market-oriented households than for subsistence households. Results reveal that technical inefficiency in bean production is higher by 8.3%

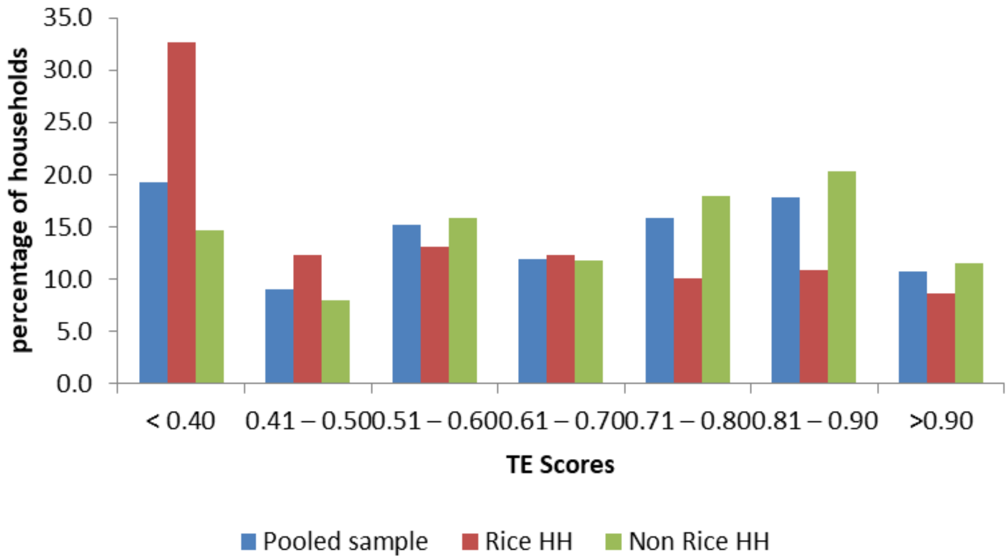

Figure 2. Distribution of technical efficiency scores for sweet potatoes.
Source: Survey conducted by the authors.

Table 4. Logistic regression for participating in rice market production.

Variable	Coefficient	Std. Err.	z
Age of household head	0.0416	0.0422	0.98
Age of household head^2	-0.001*	0.0005	-1.76
Education of household head (years)	-0.0370	0.0258	-1.43
Education of heads spouse (years)	-0.0122	0.0302	-0.4
Household size (no. Persons)	0.0525*	0.0316	1.66
size of land owned (ha)	0.4814***	0.0827	5.82
Size of land owned^2 (ha)	-0.0195***	0.0042	-4.65
Distance to road (km)	-0.0356	0.0519	-0.68
Distance to main market (km)	0.6089***	0.0600	10.14
Agriculture as main occupation=1, otherwise =0	0.5514	0.3876	1.42
Household has no secondary occupation	-0.2878	0.1855	-1.55
Member of farmer group =1; otherwise =0	1.0181***	0.1890	5.39
Constant	-4.2335***	0.9649	-4.39
Number of observations	816	-	-
Prob>chi^2	0.000	-	-
Pseudo R^2	0.268	-	-

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

for market-oriented households compared to subsistence households. Similarly, in sweet potato production, technical inefficiency for market- oriented households is higher by 14.0%. The results are consistent for both kernel and radius matching. Sensitivity analysis using Rosenbaum bounds (Table 3 Appendix) shows that doubts on statistical significance of estimated results can occur if confounding factors cause the odds ratio of participating in market production to differ by a factor above 3.0 (DiPrete and Gangl, 2004). Thus, our results are robust.

The negative significant effects on technical efficiency may supposedly be attributed to withdrawal of critical labor inputs from staple foods when a household is producing a cash crop. A majority (61.2%) of households rely heavily on family labor for production of both staple and cash crop. This means that during peak periods of labor demand, family labor is constrained thus affecting timely field operations and consequently technical efficiency. This is affirmed by the significant positive

Table 5. Effects of market production on technical efficiency in production of staple crops.

Outcome	Matching algorithm	Number of treated	Number of controls	Mean TE treated	ATT (Std. error)	Critical level of hidden bias (Γ)
TE scores for beans	Kernel matching (band width = 0.05)	304	484	0.58	-0.083*** (0.0207)	Above 3
	Radius matching (caliper =0.05)	304	484	0.58	-0.082*** (0.0200)	Above 3
TE scores for sweet potatoes	Kernel matching (band width = 0.05)	134	463	0.54	-0.139*** (0.0247)	Above 3
	Radius matching (caliper =0.05)	134	463	0.54	-0.141*** (0.0258)	Above 3

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

relationship of family as the main source of labor with technical inefficiency. Given the seasonality of the food crops combined with constant changes in weather conditions (e.g. sudden rainfall), management decisions on resource allocation hinge on priorities and the risks effects of timing actions (land preparation, planting, weeding and harvesting) on output of a particular crop. In such situations market-oriented households are more likely to prioritize the cash crop. It is also important to note that subsistence crops are mainly managed by women who are already burdened with other activities (Nakazi et al., 2017). Moreover, market-oriented households are likely to allocate the most productive land to the cash crop leaving marginal land for the staple crops hence affecting their technical efficiency. This argument is in line with the findings of Savadogo et al. (1998) in Burkina Faso. As pointed out by Neumann et al. (2010) inefficiency due to soil fertility constraints can be reduced by an effective land management. In situations where the farmer cannot improve the land quality through better soil management practices, allocating high quality land to the cash crop may seem to be a rational decision if the farmer gets higher utility from the cash crop. However, we are not able to establish whether market-oriented households are economically efficient, as this study did not measure allocative efficiency.

Are market-oriented households more technically efficient in cash crops than staples?

Considering the subsample of market-oriented households, we predict technical efficiency of their major food cash crop and staples. Table 6 presents a summary of the frequency distribution of technical efficiency scores.

Results show that on average market-oriented households could raise output of rice their main cash crop by 40% using the same inputs. However, it is possible that this would imply further delaying operations in staple crops and compromising technical efficiency in these crops. The estimated technical efficiency in rice production ranges from 0.25 to 0.87 and about 42.5% of the households have their technical efficiency score below the mean. Figure 3 shows that in the short run, over 70% of market-oriented households can increase their output in rice and bean production by adopting existing technologies and farming practices used by the best practice producers. While the highest technical efficiency score is recorded in sweet potato production, over 30% of market-oriented households scored less than 40% technical efficiency. A comparison of mean technical efficiency of the cash crop (rice) and the staple crops using a t-test reveals that market-oriented households are more technically efficient (p-value = 0.001) in production of rice compared to the staple crops. The result is consistent with our conjecture that market-oriented households may concentrate their management on production of the cash crop. This result contrasts the findings by Binam et al. (2004) who found no significant differences in technical efficiency among maize and groundnut cropping system.

Other factors influencing technical inefficiency

Other factors that influence technical inefficiency in food crops production include age of household head, education of the spouse of household head, the size of land owned and source of labor. The age of household head has a mixed relationship with technical inefficiency. While it decreases technical inefficiency in sweet potatoes, it increases technical inefficiency in rice production. This might be explained by the fact that older

Table 6. A summary of technical efficiency scores for the cash and staple crops.

Efficiency level	Market-oriented household		
	Rice	Beans	Sweet potatoes
Mean	0.60	0.58	0.53
Minimum	0.25	0.11	0.11
Maximum	0.87	0.87	0.90
Proportion of households < mean (%)	42.5	41.6	50.7
Number of observations	345	336	138

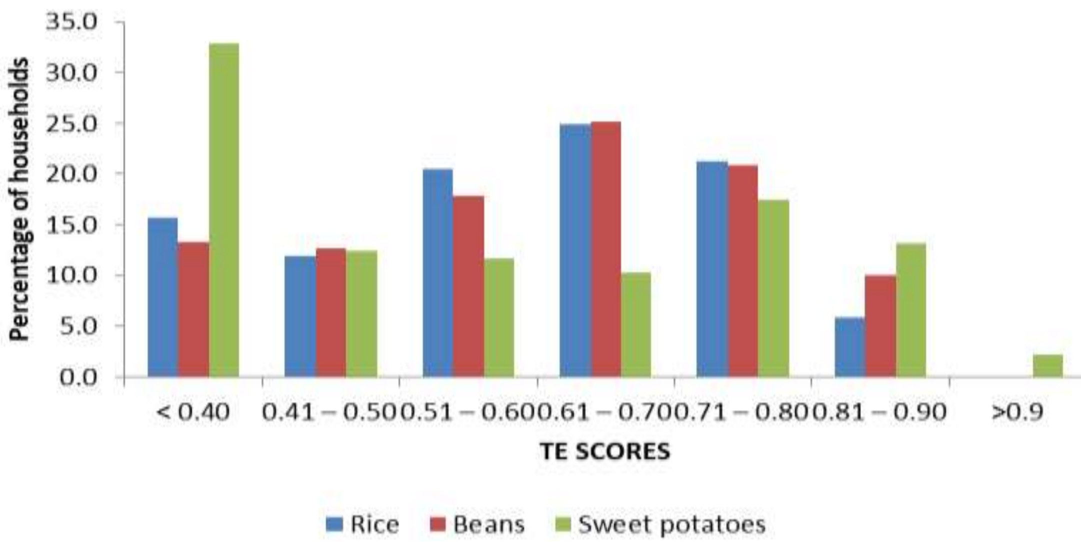

Figure 3. Distribution of technical efficiency scores for market-oriented households.
Source: Survey conducted by the authors.

household heads care more about the ‘food security’ staple crop (as sweet potato is commonly referred to) than the cash crop. It is likely that older household heads have bigger families to feed and therefore will tend to be efficient in staple crop production. A positive correlation between age and technical inefficiency in rice production seems to suggest that younger farmers are likely to be more technically efficient in production of a cash crop. This is perhaps due to physiological changes that affect managerial capability as well as strength and in turn labor productivity. Given that cash crops are usually managed by household heads, the aged are relatively less active, they may not easily source for information and therefore, they are likely to be inefficient in management of the cash crop hence increased technical inefficiency. The result is consistent with findings of Coelli and Fleming (2004) that age of household head increases technical inefficiency in the small holder mixed food and cash cropping system in Papua New Guinea due to increased difficulty in managing multiple tasks.

Technical inefficiency in beans production decreases with education of the household head’s spouse. This result underscores the importance of formal education in agriculture (Reimers and Klasen, 2013). Farmers who are educated are more likely to access, process and use information relevant to crop production including ease of access to inputs and adoption of best practices/ technologies that increase technical efficiency. Moreover, education helps farmers become better managers of limited resources by enhancing their decision-making skills.

Contrary to what is commonly reported, that smaller farms tend to be more efficient, our results show a negative association between land size and technical inefficiency. This might be explained by the possibility that, households with bigger farms could be practicing land management practices such as crop rotation and fallowing that improve land productivity. Similar findings have been reported in Bangladesh (Wadud and White, 2000). It is also probable that some of the plots used by households owning very small land are rented. Such plots may not be very productive as many households will not rent out their best plots. Households who use mainly family labor are less technically efficient, presumably because they have limited time to manage all activities of their different crops at the same time. A negative relationship between membership in a savings and credit group and technical inefficiency may be associated with easy access to credit that may enable households timely access to inputs particularly seed and labor. A negative coefficient of distance to the market in rice production implies that efficiency increases as market-oriented farmers are further away from the market. This can be attributed to relatively easy access to labor and perhaps better plots as average land holdings tend to increase with distance from the market. Further, we observe significant effects on technical inefficiency associated with spatial dummy variables and this could be related to different soils.

Conclusion

The association between market production and technical efficiency in food crop production was explored empirically based on the hypothesis that market-oriented production increases technical efficiency in staple crop production. Technical efficiency of one major food cash crop and two staple crops was estimated and attempt was made to isolate the effects of the cash crop on technical efficiency of the staple crops using propensity score matching approach. We find high technical inefficiency in the selected crops across the household categories. We also find that technical inefficiency in staple crops is significantly higher in market-oriented households compared to subsistence households. We argue that market-oriented households are more likely to withdraw resources from staples to cash crop production and seem not to invest their income in crop production. We offer two possible explanations. The first relates to the timing of operations and therefore the effectiveness of labor. Market-oriented households may give precedence to their commercial crops, which in combination with seasonality of operations, would delay operations in staple crops, thereby compromising staple output. The second explanation is that, market-oriented households may allocate marginal land to staple crops, which would also lower output for staples. The implication is that, they may be getting optimal output from such land and therefore, the model overestimates market production effects. Including data on quality of plots allocated to the different crops in the frontier estimates would allow us to test for land quality effects. Regrettably we did not have the data. The present results should be interpreted with caution; we do not claim that market production causes inefficiency but rather, we show evidence that income from production may not be spent for efficiency enhancement in production of staple crops.

Despite the limitations, the findings show that, there is significant potential for households to increase output in both cash and staple crops by increasing technical efficiency. However, for market-oriented households, increasing staple crop production may partly require withdrawing some inputs from the cash crop. This decision can be driven by the utility the household gains from production of either the food or the cash crop. Extending this study to establish the allocative and economic efficiency of market-oriented households may be necessary. The results suggest that public policies aimed at enhancing market production should support innovations that increase technical efficiency. Supporting formal education for example in form of tailored adult literacy programs particularly for women who provide the bulk of agricultural labor might help farmers improve their management skills and hence improve technical efficiency of food crops. Accelerating the pace of adoption of better farming practices and labor-saving technologies may be necessary to facilitate timely operations and subsequently improve technical efficiency in the long run. Given the increasing demand for critical inputs, the agricultural economy in Uganda and generally sub-Saharan Africa will rely on the growth of total factor productivity other than growth of inputs. Considering the African agrarian economies, this study raises new questions for further research: Does farmer specialization in production of one or two crops increase technical efficiency? What are the risks and benefits?

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest.

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Appendix

Table 1. Chi-square test for significance of variable before and after matching.

Outcome	Matching algorithm	Pseudo R2 Before matching	Pseudo R2 after matching	p>Chi^2 Before matching	p>Chi^2 after matching
TE scores for beans	Kernel matching (band width = 0.05)	0.262	0.010	0.000	0.719
	Radius matching (caliper =0.05)	0.269	0.010	0.000	0.724
TE scores for sweet potatoes	Kernel matching (band width = 0.05)	0.218	0.007	0.000	0.997
	Radius matching (caliper =0.05)	0.218	0.007	0.000	0.996

Table 2. Propensity score matching and covariate balancing test.

Variable		Mean		t-test	p>t
		Treated	Control		
Age of household head	Unmatched	42.461	42.715	-0.27	0.789
	Matched	42.424	43.98	-1.51	0.130
Square of age of household head	Unmatched	1951.8	2022.1	-0.80	0.426
	Matched	1953	2100.7	-1.51	0.131
Education of household head (years)	Unmatched	6.2952	6.0702	0.79	0.430
	Matched	6.3257	6.5617	-0.74	0.459
Education of heads spouse (years)	Unmatched	4.494	4.124	1.49	0.136
	Matched	4.5099	4.4231	0.32	0.752
Household size	Unmatched	6.8464	5.9731	4.21	0.000
	Matched	6.8059	6.7717	0.14	0.888
Size of land owned (ha)	Unmatched	2.3769	1.5366	4.15	0.000
	Matched	2.2309	2.6948	-1.94	0.052
Square of land size owned (ha)	Unmatched	13.074	11.609	0.28	0.783
	Matched	12.092	17.013	-1.31	0.190
Household distance to main road	Unmatched	1.7937	1.2684	3.64	0.000
	Matched	1.668	1.685	-0.11	0.916
Household distance to main market	Unmatched	4.6233	2.5513	13.86	0.000
	Matched	4.0877	3.8922	1.30	0.193
Main occupation agriculture = 1	Unmatched	0.95482	0.90289	2.76	0.006
	Matched	0.95724	0 .96833	-0.72	0.471
No secondary occupation = 1	Unmatched	0.49096	0 .56198	-2.00	0.046
	Matched	0.49671	0.53107	-0.85	0.397
Member of farmer group =1	Unmatched	0.66867	0.43595	6.71	0.000
	Matched	0.66118	0.70169	-1.07	0.285

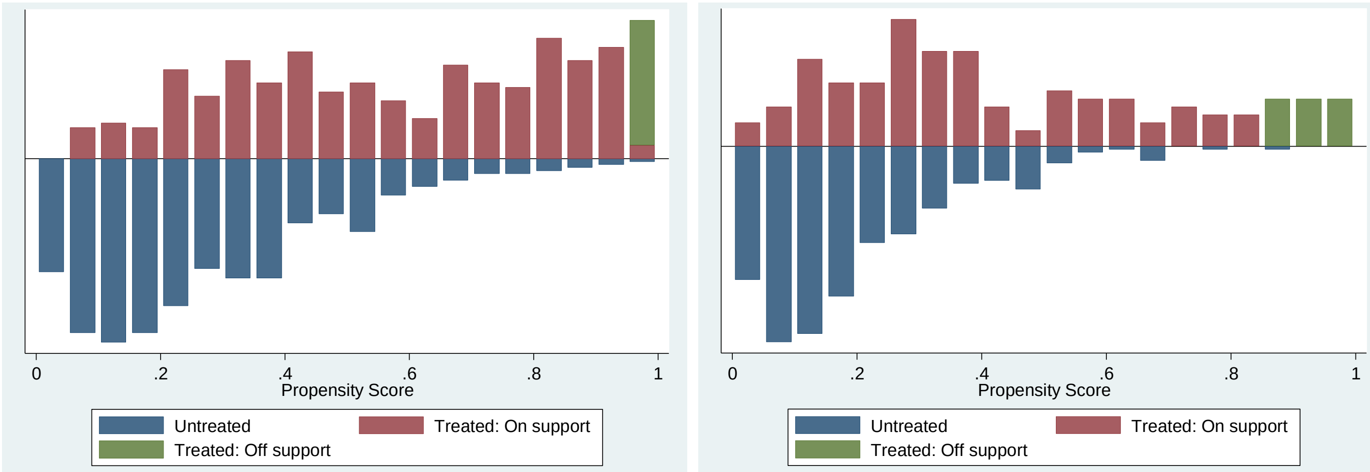

Figure 1. Distribution of propensity scores and the region of common support for beans and sweet potatoes (kernel matching).

Table 3. Sensitivity analysis: Rosenbaum bounds.

Gamma	sig+	sig-	t-hat+	t-hat-	CI+	CI-
1	3.80E-11	3.80E-11	-0.0672	-0.0672	-0.08881	-0.04674
1.1	2.30E-13	3.40E-09	-0.07513	-0.05985	-0.09715	-0.03937
1.2	1.20E-15	1.30E-07	-0.08222	-0.05277	-0.10473	-0.03292
1.3	0	2.40E-06	-0.0889	-0.04661	-0.11201	-0.02707
1.4	0	0.000026	-0.09531	-0.04088	-0.11856	-0.02145
1.5	0	0.000187	-0.10119	-0.03585	-0.12482	-0.01649
1.6	0	0.000952	-0.10675	-0.03126	-0.13068	-0.01162
1.7	0	0.003658	-0.11207	-0.02704	-0.1365	-0.00751
1.8	0	0.01113	-0.11703	-0.02285	-0.1416	-0.00322
1.9	0	0.027883	-0.12161	-0.01897	-0.14651	0.00057
2	0	0.059352	-0.12606	-0.01545	-0.15127	0.004174
2.1	0	0.110141	-0.13039	-0.01195	-0.15581	0.007337
2.2	0	0.182054	-0.13442	-0.00878	-0.16016	0.010609
2.3	0	0.272935	-0.1383	-0.0059	-0.16471	0.013546
2.4	0	0.376928	-0.14201	-0.00293	-0.1686	0.016227
2.5	0	0.48598	-0.14553	-0.00032	-0.17229	0.01868
2.6	0	0.591856	-0.14894	0.002365	-0.17608	0.021614
2.7	0	0.687856	-0.15213	0.004793	-0.17992	0.024032
2.8	0	0.769755	-0.15528	0.00701	-0.18334	0.02653
2.9	0	0.835918	-0.15808	0.009207	-0.18688	0.028908
3	0	0.886813	-0.16134	0.011392	-0.19013	0.031171

gamma - log odds of differential assignment due to unobserved factors; sig+ - upper bound significance level; sig- - lower bound significance level; t-hat+ - upper bound Hodges-Lehmann point estimate; t-hat- - lower bound Hodges-Lehmann point estimate; CI+ - upper bound confidence interval (a= 0.95); CI- - lower bound confidence interval (a= 0.95).

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Full Length Research Paper

Allure of insect pest and diseases among three solanaceous crops viz. tomato, chilli and brinjal in Hamelmalo Agricultural College

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The experiment was conducted in the Hamelmalo Agricultural College, Eritrea, from January 2017 to May 2017. This was done to study the attraction of major insect pest and diseases in three solanaceous crops (tomato, chilli and brinjal) grown singly and with mix cropping pattern. In Eritrea, solanaceous crops are important vegetables grown in different areas of the country. Insect pest and diseases are the major biotic factors that limit the production of these vegetables in the country, these are recorded at the vegetative, flowering and fruiting stages for all three crops. The major insects pest, that is white fly, African boll worm, tomato fruit borer and leaf miner, were recorded on tomato followed by chilli and brinjal; whereas lace wing bug, leafhopper was attracted more on brinjal crops. Tomato and chilli were more susceptible for leaf curl virus and collar rot, while intensity of powdery mildew was maximum on tomato and minimum on chilli, whereas brinjal was least susceptible to any kind of diseases.

Key words: Tomato, Chilli, brinjal, incidence, severity, insect pest, diseases.

INTRODUCTION

Solanaceous crops, comprising tomato, chilli and brinjal, are important vegetables in Eritrea, grown in both high and lowland areas within the year. It has been reported in Eritrea that these solanaceous vegetables are highly susceptible to different kinds of pests and diseases, which limit the production, as crop losses 30 to 40%. With changes in the cropping systems and climate and by introduction of highly yielding varieties, different insects attack the solanaceous crops. The farmers use pesticides in cocktail form. Apart from direct damage, many insect pests are vectors for several viral diseases. Major insect pests of solanaceous crops, especially tomato, chilli and brinjal, are tomato fruit borer *Helicoverpa armigera,* tomato leaf miner and fruit borer *Tuta absoluta*, tobacco caterpillar *Spodoptera litura*, serpentine leaf miner *Liriomyza trifolii*, cotton whitefly *Bemisia tabaci*, Brinjal shoot and fruit borer *Leucinodes orbonalis*, Hadda beetle *Epilachna vigintioctopunctata*, Brinjal leaf roller *Eublemma olivacea*, Brinjal stem borer *Euzophera perticella*, Lacewing bug *Urentius hystericellus*, Chilli thrips *Scirtothrips dorsalis*, White grub *Holotrichia consanguinea*, and Red spider mite/yellow mite

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Polyphagotarsonemus latus. The major diseases of the solanaceous are Powdery mildew, Leaf curl virus, *Begomovirus* species, phomopsis collar rot *Phomopsis vexans*, blight and root knot nematode *Meloidogyne* species.

The estimated world production of tomato is about 89.8 million tons from an area of 3.17 million (Anon, 1998). Tomato is one of the most widely grown vegetables in the world, and in 2005, the European Union was the second largest producer after China (FAOSTAT, 2007). Tomato crops are particularly susceptible to more than 50 different species of the Begomovirus genus. Tomato yellow leaf curl disease and viral disease rout tomato in warm temperate regions of the world (Aron et al., 2008). Chilli is one of the vegetable and condiment crop in the world. India is the largest consumer and exporter of chilli in the world with a production of 1492 MT from an area of 775 thousand ha and productivity of 1.9 MT per ha. Brinjal, *Solanum melongena* L. is the most common, popular and principal vegetable crops grown in India and other parts of the world. The brinjal is mostly important in warm areas of Far East and grown extensively in India, Bangladesh, Pakistan and China.

The host selection of insects and diseases is based on the attractiveness of volatile chemicals emitted by plants. Particularly, female insects use olfactory stimuli to choose plants for ovipositon to ensure their food for the next generation. Proffit et al. (2011) found that the host plant odour elicited in mated tomato leaf miner *T. absoluta* females' upwind orientation flight as well as for egg laying. Gravid *T. absoluta* females discriminated between cultivated and wild tomato and among tomato cultivars according to their volatile profiles. Insects' pest and diseases are common among tomato, chilli and brinjal; while one of the solanaceous crop is more susceptible, others are resistant to the same insects and diseases. The present study was aimed to find out the most susceptible host among three solanaceous crops (tomato, chilli and brinjal) for insects and diseases in monoculture and mix culture. The aim was to determine when and how these crops could be grown in an integrated pest management (IPM) system, for sustainable crop protection to avoid excessive use of pesticides and residues that can be deleterious to humans, animals and the environment.

MATERIALS AND METHODS

Cultivation preparatory

Prior to sowing and transplantations of the crops, the land was ploughed using a tractor once and twice with oxen, in order to make the soil tilt and to remove the different kind of weeds. Levelling was done with human labour and the field was laid out as per the design. All three solanaceous crops, chilli (Treatment 1), tomato (Treatment 2), and brinjal (Treatment 7) were grown separately as well as mixing with tomato+chilli (Treatment 3), tomato+chilli+brinjal (Treatment 4), tomato+brinjal (Treatment 5), and chilli+brinjal (Treatment 6) with three replications.

Seed sowing and transplantation

The popular variety of tomato was Segravati and local variety of chilli and brinjal were selected. Sowing seeds were taken up by adopting standard seedbed 2×2 m^2 for tomato, chilli and brinjal in the college nursery on 25 January 2017. The raised seedlings were transplanted in 3×3 m^2 experimental plots on 1st March, 2017.

Agronomic practices and irrigation

The all-agronomic practices were adopted to grow the good and healthy crops. The farmyard manure and other required fertilizers were applied per standard recommendation. Frequent irrigations were given to the crop during the season. First irrigation was done after transplant. Manual weeding was done at 15, 30, 45 and 60 days after transplantation.

Sampling of insect and diseases

While sampling the specimen, factors such as host condition, growth stage, insect pest, disease development, etc., were taken into consideration. Representative samples, based on visual symptoms of the disease were drawn from each crop at random per methods described by Sukhatme (1954) and Yates (1960). At least five plants per plot were covered for sampling. Sampling was done along the diagonals of the fields at regular intervals (fortnightly). The sampling sites were approximately equidistant from each other along the sampling pathway. At each site, a specified number of plants at specified distance on the row were carefully examined and sampled.

The parameters, which were given particular emphasis, were the intensity and prevalence of insect pest and diseases. For survey, methodologies given by James (1971, 1974) and Weeks et al. (2000) were followed.

The formula used for calculation of the disease incidence and severity are as follows:

Incidence (%) = (No. Of infected plant/Total plant assessed) × 100

Severity (%) = (Sum of all disease rating / Number of plants assesed × Maximum grade) × 100

Statistical data analyses

The collected data were subjected to statistical analysis, using the GENSTAT software.

RESULTS AND DISCUSSION

Report on common insect pest in three solanaceous crops: Tomato, chilli and brinjal

The tomato, chilli and brinjal are highly susceptible for different kinds of insect pest and diseases. Observations were made from germination to harvesting stage of the crops. Observations were made for occurrence of insect pest and diseases on all three crops. There were different

Table 1. Common insect pest on different three solanaceous crop.

S/N	Common name	Scientific name	Host plant	Status
1	White fly	*Bemisa tabaci*	Tomato ,chili and brinjal	Major
2	Jassid	*Empoasca denastans*	Tomato, chili, and brinjal	Major for brinjal
3	African boll worm	*Helicoverpa armigera*	Chili and tomato	Tomato
4	Tomato fruit borer	*Tuta absoluta*	Tomato	Major
5	Lace wing bug	*Urenticus orbonelis*	Brinjal	Minor
6	Aphid	*Myzus persicae*	Chili	Minor
7	Thrips	*Thrips tabaci*	Chili	Minor
8	Grasshopper	*Hieroglyphus haman*	Brinjal	Minor
9	Leaf minor	Leaf minor	Brinjal	Minor
10	Red spider mite	*Liriomyza trifolii*	Brinjal	Minor

Table 2. Insect pest population on different host.

Treatment/population/observation	***Tuta absoluta***			**African bollworm**			**Whitefly**			**Jassids**		
	1st	**2nd**	**3rd**	**1st**	**2nd**	**3rd**	**1st**	**2nd**	**3rd**	**1st**	**2nd**	**3rd**
Chili	0.00	0.00	0.00	7.00	6.67	3.00	0.33	0.67	0.67	4.00	2.67	0.00
Tomato	3.00	6.00	2.33	9.00	14.33	4.00	3.00	6.00	2.33	4.00	2.33	5.67
Tomato+Chili	1.33	3.33	1.00	6.00	4.00	3.00	2.33	3.33	1.00	3.00	1.67	0.00
Tomato+Chilli+Brinjal	1.00	1.33	0.33	5.33	4.33	5.00	1.00	1.33	1.33	3.67	2.00	2.00
Tomato+Brinjal	1.00	1.00	0.33	7.00	6.00	3.33	1.00	0.33	0.33	2.00	2.33	3.00
Chili+Brinjal	0.00	0.00	0.00	7.00	4.00	6.00	0.00	0.00	0.00	4.33	2.00	1.00
Brinjal	0.00	0.00	0.00	0.00	8.00	8.00	0.00	0.00	0.00	4.33	2.00	4.00
L.S.D at 5%	1.29	1.33	0.67	1.78	2.40	1.53	1.33	1.26	1.03	4.12	2.88	6.15

insects and diseases reported during the observation. The major insect and diseases were documented and reported in Tables 1 and 3. During the cropping process, the major insect pest was recorded, which are, white fly, *Helicoverpa armigera*, *T. absoluta*, and jassid; whereas minor insect pest were lacewing bug, grasshopper, thrips, red spider mite and aphids. The major insect pest that causes significant damage in crops, their population after regular interval and further studies, were recorded in the present study.

Population of tomato leaf miner and fruit borer (*T. absoluta*)

T. absoluta tomato leaf miner and fruit borer is one of the most recently invasive pests in African countries. *T. absoluta* was observed in different treatments and found that the population of the *T. absoluta* were significantly on tomato crop, whereas on chilli and brinjal the population was either very low or zero (Table 2). In the first observation, it was found that the highest population was 0.3 larvae/plant on treatment two, while the zero population was on treatments one and six. In the present experiment, pest appeared throughout the observation. However, maximum numbers were recorded on treatment two at time of second observation and lowest in third observation in treatments 1, 6, and 7, respectively. In the third observation, the populations of *T. absoluta* decrease in all treatment even with maximum number on treatment two. Sheata et al. (2016) also reported *T. absoluta* on other cultivated solanaceous plants such as eggplant (*S. melongena*), potato (*S. tuberosum*), pepper (*C. annuum*), sweet pepper (*Solanum muricatum* L.), tobacco (*Nicotiana tabacum*) and other non-cultivated Solanaceae (*Solanum nigrum, Solanum elaeagnifolium*). The present result shows that tomato is highly preferable for *T. absoluta* compared to other solanaceous crops, such as, chilli and brinjal. Shehata et al. (2016), opine that the rate of infestation of different host plants and the biology of *T. absoluta* showed that the insect can discriminate between different host plants and it is more preferential to tomato followed by eggplant, potato and pepper (chilli); this is in line with the present study.

Population of whitefly at different host

Whitefly is one of the major insect pests of solanaceous crops, which damage the crop by direct sucking of

Table 3. Incidence of diseases on different hosts.

S/N	Name of diseases	Symptom	Host plant	Major/minor
1	Powdery mildew	Powder like structure on leaf surface holding conidia	Tomato and Chili	Major
2	Collar rot	Rotting of stem at collar region	Tomato and Chili	Major
3	Leaf curl virus	Curling of leaves and chlorosis, white fly present as a vector	Tomato and Chili	Major
4	Early blight	Concentric ring on leaves	Tomato, Brinjal and Chili	Minor
5	Late blight	Curling of leaves from margins and faded are on centre of the leaves	Tomato and Chili	Minor

phloem juice and transmitting number of viral diseases; leading to the death of plants. In the present study, population of whitefly was monitored and it was found that the population of white flies significantly affected all treatments (Table 2). In the first and second observation treatments, the second has maximum population; however in brinjal crop, infestation level was zero in the first observation but it was minimum on treatments three and six in the second observation. According to Fekri et al. (2013), whitefly *Bemisia tabaci* is one of the most important pests of tomato and this insect exists as an economic pest in most places of the world (Byrne and Houk, 1990; Gerling, 1990). Third observation was made after 45 days and it was found that the population of whitefly in all three crops decreases and maximum population was recorded on brinjal treatment seven; whereas the lowest was on treatments one and two. In the first observation, population of whitefly is maximum on tomato crops, which indicate that they prefer tomato at the vegetative stage than other solanaceous. However, in the third observation, population of whitefly decreases in all the treatments, indicating they prefer the seedling and vegetative stages of crops. Thrips, whiteflies, aphids and mites are the major sucking pests that contributes to decrease in crop yield (Hosmani, 1993), but in the present study all the pest was significantly low in population. Whiteflies are series vector of different viral diseases; they transfer virus from infected plants to healthy plants; leading to high infestation of diseases in a short time. The whitefly sucks the plant sap (Schuster et al., 1996), reducing the quality and quantity of the sap (Mound, 1965b). This pest also transmits various viral diseases (Dickson et al., 1956; Duffus, 1987; Bedford et al., 1994).

Population of African bollworm (Helicoverpa armigera)

The population of African bollworm (ABW) was recorded in all treatments; indicating they are not attracted on brinjal and chilli. At the vegetative stage, very few number of ABW were recorded as pests as more flowers and fruits were bore into, and later on the population increased to 6.0 larvae/plant on treatment two; meanwhile, the population was non-significant on the other crops. At the first observation, the pests damaged the leaves and flowers but at the fruiting stage, the fruits of tomato were scratched and damaged, while larvae were found in matured fruits. Tomato crop is prone to many insect pest infestations (Mailafiya et al., 2014), particularly, the devastating fruit borer *(H. armigera*), which is a major tomato pest, both in rainy and dry season in Nigeria and other tomato growing countries (Trenbath, 1993; Pino et al., 1994; Degri and Mailafiya, 2013).

Population of **jassid (leafhopper)**

The green leafhopper are jassids, belonging to Hemiptera order, Cicadelidae family. They are serious pests for solanaceous crop and commonly damage crops, from seedling to harvesting stage. In the present study, the population of jassids was recorded on every treatment and it was found that the population of jassid was significantly susceptible in all the treatments. In the first observation, the maximum population was found on treatments six and seven, 4.33 hopper/plant; whereas the maximum population in the second and third observations was 2.67 and 5.67 hopper/plant recorded on the first and second treatments, respectively.

Bharadiya and Patel (2005) found that the activity of the jassid, *Amrasca biguttula biguttula* was the maximum as at the third week of November, on brinjal crop (Jadhav et al., 2004). Jassids, *Amrasca biguttula* (Ishida) are some of the major insect pests of chilli. Adult jassids are slow flyers, while the nymphs suck the sap by moving from the down side of the leaf, resulting in wrinkles that appear on dorsal side of the leaf.

Table 4. Intensity of different disease at different host.

Treatment/population	*Collar rot*			Leaf curl virus			Powdery mildew		
	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Chili	26.31	55.50	55.50	0.00	58.90	73.33	58.90	56.66	0.00
Tomato	11.59	14.60	19.40	0.00	70.00	86.66	70.00	65.55	0.00
Tomato+ chili	9.70	18.90	20.10	0.00	66.70	84.44	63.37	58.89	0.00
Tomato+chilli+brinjal	13.00	24.60	24.70	0.00	54.40	70.00	70.00	55.55	0.00
Tomato+brinjal	17.96	13.90	13.90	0.00	65.50	66.66	73.30	51.11	0.00
Chili+brinjal	2.78	0.00	0.00	0.00	56.70	56.66	70.00	51.11	0.00
Brinjal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L.S.D at 5%	7.75	9.69	9.90	0.00	8.17	6.27	8.43	7.28	0.00

The present results indicated that all the treatments are susceptible to jassids.

Occurrence of diseases on different host

Some diseases were found as major and minor as shown in Table 3. Syed et al. (2016a) and Rao et al. (2016) also reported similar diseases as the present field trial, namely, leaf curl virus, powdery mildew, and collar rot. The major disease incidence of leaf curl and powdery mildew of tomato and chilli is caused by leaf curl virus and *Erysiphe* species, respectively. Whitefly, aphids and jassids were observed as the major vector for viral diseases. Wherever the insect pests occurred, there was also incidence of leaf curl disease because of the transmitted viruses. Hence, the present results are also in agreement with Syed et al. (2016). Syed et al. (2016a) found that *Alternaria* blights reported on potato, tomato, okra and chillies from Hamelmalo, Hagaz and Adiatiklezan sub regions; powdery mildews in chillies and okra were noticed from medium to high intensity as well as mosaic viral disease in tomato, cucumber and okra. Rao et al. (2016) found that different diseases such as early blight, late blight, powdery mildew, wilt affected chilli crops and tomatoes; blossom end rot and leaf curl in tomato; and damping off, leaf curl, bacterial leaf spot in chillies.

Disease intensity of collar rot on different hosts

The data collected and analyzed for the parameters shows the host preference of collar rot on different crops and their combinations. From Table 4, it has been noted that there were significant differences in the collar rot incidence on different treatments at 15 days interval of data collection. Data has been collected for collar rot after 25 days of transplant. In all three observations, the maximum collar rot incidence was recorded in chilli (T3), that is, 26.31, 55.50 and 55.50, respectively and the lowest in Brinjal (T_7), that is, 0.00 (Table 4). The order of treatments for 1st observation of collar rot incidence was T1 > T_5 > T_4 > T2 > T3 > T6 > T7; while the order of treatments for the second and third observations was T1 > T_4 > T_3 > T2 > T5 > T6 > T7.

Disease intensity of leaf curl virus on different host

There was high percentage of disease incidence and severity of leaf curl virus during the second and third observations in different treatments due to white fly populations, which is high during this period. However, the first observation incidence and severity were zero in all treatments. Incidence and severity for leaf curl virus have significant difference among the treatments at second and third observations. The highest incidence was found in Tomato + Chilli (T3), which is 70.00 and 86.66 in the second and third observations, respectively; followed by T3, T5, and T6. In treatment seven (Brinjal), incidence and severity were recorded as zero. Same trends were observed in severity of leaf curl virus; the highest in Tomato+Chilli (T3) and lowest in T7 (brinjal). Rao et al. (2016) have reported similar results and Syed et al. (2016b) reported that tomato and chilli are susceptible for leaf curl virus in Hemalemalo region. The leaf curl virus was high due to whitefly populations during the peak seasons of the crop (Table 2).

Disease intensity of powdery mildew on different host

The disease incidence of powdery mildew observed during the experiment was highly severe at the first observation, which is 73.30 in treatment five; but during the second observation, the disease incidence was decreased. During the final observation, there was no incidence and severity. Powdery mildew was severe in all treatments except in T7 where there was significant difference among the treatments for intensity of powdery mildew. At the maturing stage of the crop it was heavy rainfall due to this powdery mildew incidence and severity

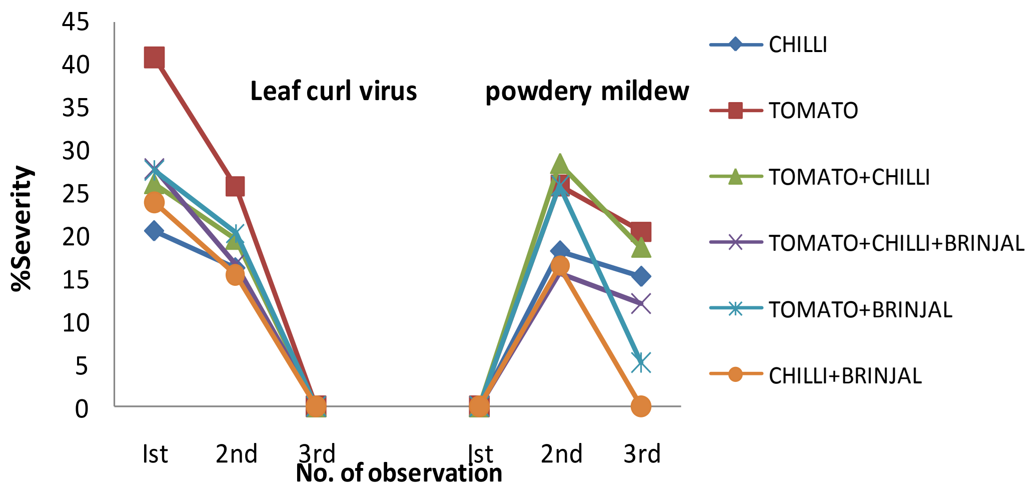

Figure 1. % severities of leaf curl virus and powdery mildew on different host.

recorded zero. Powdery mildew incidence was the highest in T5, 73.30, followed by T2, T4, T6, T3 and T1; in the first observation and second observation the highest incidence was recorded in T2, 65.55, and the lowest in T7. Severity of powdery mildew was higher in T2 as 40.74 and 25.65 in first and second observations, respectively; followed by T4, T5, T3, T6, T1 and T7. Syed et al. (2016b) also reported the same findings that powdery mildew is severe on chilli and tomato, while there is no powdery mildew on brinjal. This has been reported in Anseba region. Powdery mildew was severe before rainfall because it is considered as dry land area disease. This is because this spore do not only require high humidity like other fungus, but holds more than 52% water content as well as high lipid content coating on spore (Figure 1).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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