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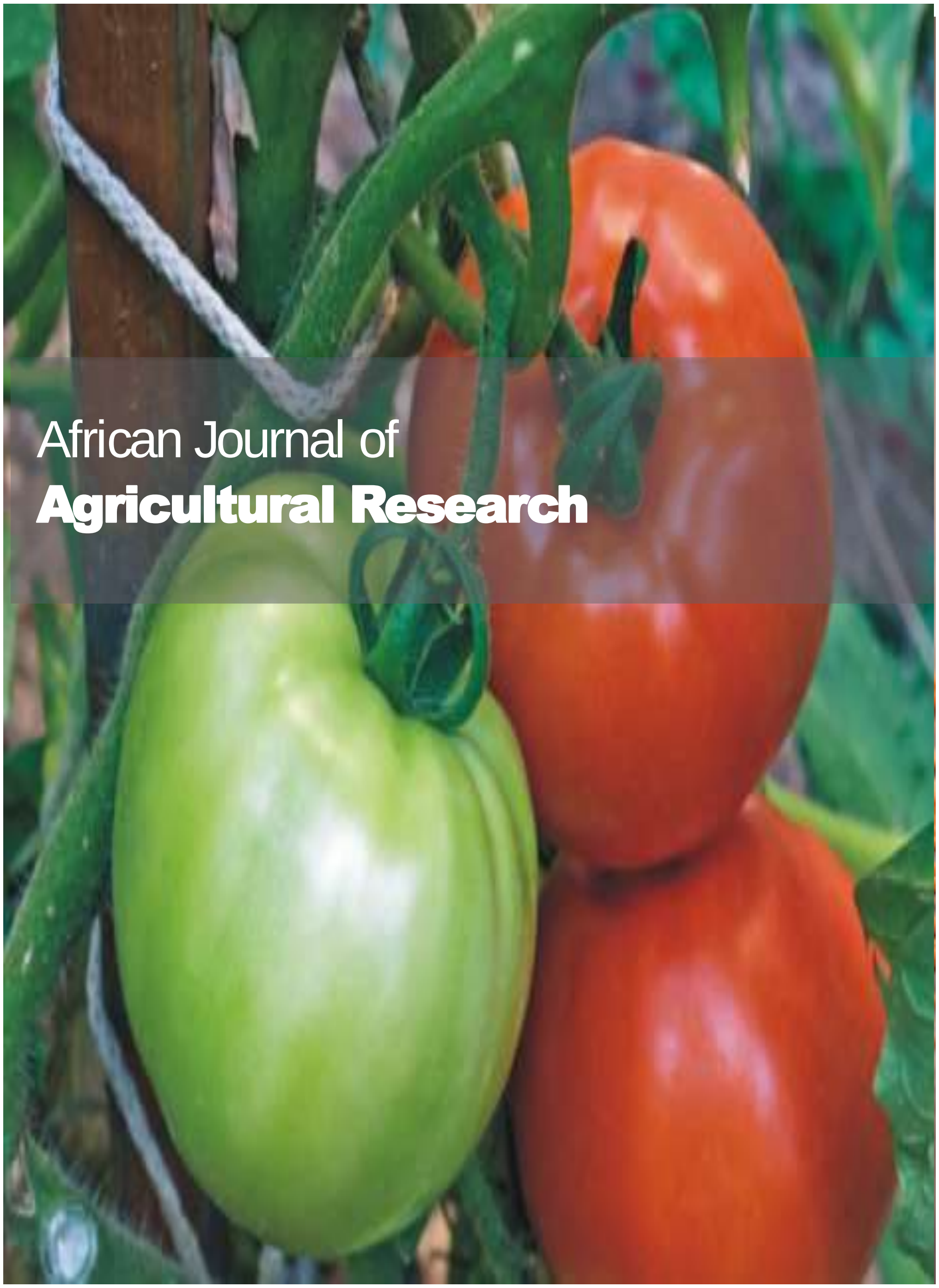

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Full Length Research Paper

Effect of on-farm water management practices and irrigation water source on soil quality in Central Ethiopia

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Soil salinity is the major factor that limits agricultural productivity in arid and semi-arid regions. The use of improved farm management practices in such areas is becoming a highly concerning issue to sustain agricultural productivity. This study, therefore, was conducted to evaluate the effect of on-farm water management practices and irrigation water sources on soil quality. The experiment was conducted on 16 farmer's fields in the area for two consecutive years. Soil and water sampling were done at the beginning and end of each growing season. Both samples were analyzed for selected parameters following standard laboratory procedures. A general linear model of two ways analysis of variance was used to evaluate the variations among treatments. Results indicated that about 64.3% of studied soil properties are showed significant variation at P<5% across treatments. This implies that management practice and sources of irrigation water have an impact on soil productivity. Salinity and alkalinity values showed an increasing trend over time and higher values for both parameters were observed in groundwater irrigated fields. This suggested that irrigation water sources have also pronounced effects on soil quality. The higher value for soil fertility indicators such as organic carbon, nitrogen, and phosphorous was also observed under managed fields. This also suggests management practices positively influenced soil productivity. Therefore, paying attention to management practices and water quality is very important to maintain soil productivity.

Key words: Agriculture, ANOVA, irrigation management, soil salinity, water quality.

INTRODUCTION

Agriculture is the mainstay of the Ethiopian economy contributing almost half of the GDP (43%) and 85% of the total export revenue (CSA, 2018; FAO, 2017). It also supplies a significant proportion of the industrial raw

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materials and employs more than 85% of the labor force in the country (CSA, 2018). However, agricultural productivity remains meager due to declining of soil fertility, increasing soil salinity, and lack of quality irrigation water. Soil salinity is one of the major land degradation problems in dry regions and highly threatens irrigated agriculture in such environments (Al-Ghobari, 2011; Husien et al., 2017). Moreover, salinity problems have aggravated under poorly managed fields and account for the deterioration of soil productivity. As a consequence, the effective use of irrigation water has become an indispensable component of irrigated agriculture (Edossa et al., 2014; Kefyalew and Kibebew, 2016; Hadera, 2018).

In the past, soil salinity and sodicity problems were developed as a result of the accumulation of salts due to natural causes (Heluf, 1987; Abrol et al., 1988; Michael, 1992; Hillel, 2000, 2004). But, in recent decades, vast areas of salt-affected soils have developed from man-made causes (Seid and Genanew, 2013; Edossa et al., 2014; Mesfin, 2015; Abay et al., 2016; Husien et al., 2017; Qureshi et al., 2018; Hadera, 2018). The main possible factor that triggers salinity problems in irrigated fields is poor irrigation management practices (Tessema et al., 2014; Kefyalew and Kibebew, 2016). Edossa et al. (2014) and Mesfin (2015) noted that the problem of salinity is more serious under poorly managed irrigated fields. Consequently, such situations, in turn, could reduce soil fertility and productivity. Furthermore, the area is highly prone to salinization due to the very low and erratic nature of rainfall the area experienced. As Edossa et al. (2014) and Alemayehu et al. (2016) reported smallholder farmers in the area widely used furrow irrigation methods which could increase the possibility of over flooding. This situation in turn could elevate groundwater levels which favors the movement of more solutes to the soil surface. Besides, the very low and erratic nature of rainfall that is experienced in the area can aggravate the salinization process.

The previous studies have demonstrated the effect of managing irrigated fields on soil productivity in the area. For instance, a study by Hadera (2018) revealed that the use of improved farm management practices considerably reduces the salinity problem in irrigated fields. Kefyalew and Kibebew (2016) investigated the effects of different farm management practices on soil property in the area. The result showed that soil productivity was significantly improved under managed fields compared to unmanaged fields. These studies provided a better understanding of farm managing issues as mitigation strategies for improving soil quality. However, these studies more focused on-farm management practices and did not pay attention to irrigation water quality issues in the area (Seid and Genanaw, 2013; Edossa et al., 2014; Husien et al., 2017). Water quality, in this regard, is a highly concerning issue as long as irrigation is planned to be used for crop production. Al-Ghobari (2011) and Husien et al. (2017) suggested that poor water quality from undesired sources can significantly influence soil productivity. The frequent use of farmland for irrigation purposes without monitoring the quantity of water supplied to the crops leads to a higher probability of making the field saline during cropping seasons (Edossa et al., 2014; Hadera, 2018). This also implies that more studies are required to understand the interactions between management practices and water quality used and their combined effects on soil quality.

Productive use of farmlands requires periodical evaluation of salinity build-up in soils and water quality that supposed to be used for irrigation purposes (Legesse and Ayenew, 2006; Al-Ghobari, 2011; Husien et al., 2017; Qureshi et al., 2018). Because the results will provide reliable information with regard to the effectiveness of management practices implemented to improve soil productivity. Moreover, it also helps the users to design strategies for practicing irrigated agriculture in a sustainable manner. In the present study area, so far some researchers have conducted some researches that are related with on-farm water management practices (Mesfin, 2001; Halcrow, 2008; Seid and Genanaw, 2013; Edossa et al., 2014; Alemayehu et al., 2016; Kefyalew and Kibebew, 2016; Hadera, 2018). However, the conducted researches were given more emphasis on irrigated filed management, but not considered irrigation water source effects on soil quality. The purpose of this study was to test the effects of on-farm water management practices and irrigation water sources on soil quality as measured by the concentration of salinity related soil properties. Therefore, the specific objectives of this study were to (i) evaluate the effect of on-farm water management practices on soil salinity; (ii) evaluate the effect of source of irrigation water on soil salinity; (iii) determine the depth-wise effect of irrigation on soil salinity; and (iv) suggest possible management practices that would help the farmers to avoid soil salinity in their farmlands.

MATERIALS AND METHODS

Descriptions of the study area

Location

The study site is located in Adamitulu district in the South Western Shewa zone of the Oromiya Regional State of Ethiopia (Figure 1). It is geographical location extends from 7° 50' 00'' to 7° 53' 57'' N latitude and from 38° 42' 00'' to 38° 46' 00'' E longitude. It is located in the central rift valley region at about 160 km South of Addis Ababa in the vicinity of Lake Ziway.

The study village has occupied with more than 1000 households who are dependent on mixed crop-livestock production systems with irrigation playing an important role. The altitude of the study area is ranged from 1600 to 1900 masl in the tropical semi-arid zone in the middle part of the Ethiopian rift valley system. Since

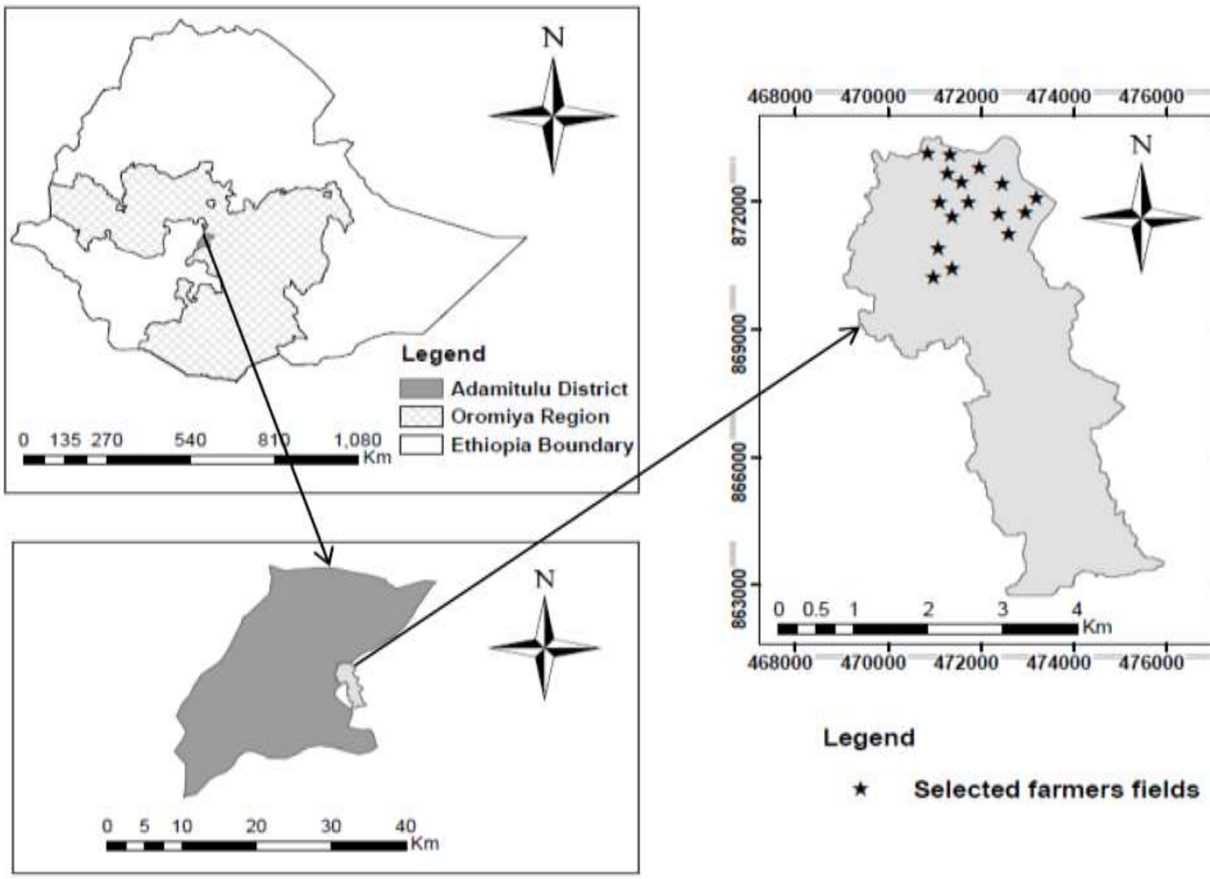

Figure 1. Location map and sampling fields.

Ethiopia lies between latitudes 4°N and 18°N, there is only a small variation in day length both between season and latitudes and the area is suitable for short-day plants.

Climate and land use

The metrological data obtained from an automatic weather station installed in the study area indicated that an average relative humidity is 46.5% during the dry season and 75.5% during the wet season. The average minimum temperature is 19.2°C and the average maximum temperature is 27.5°C. The mean annual rainfall in the area ranges from 600 to 850 mm and the rainfall pattern is erratic and unreliable (Figure 2). However, annual average potential evapotranspiration is approximately 1200 mm which signifies the importance of irrigated agriculture to fill the gap. Geology of the area is characterized by tertiary and quaternary age rhyolite and basalt volcanic materials (FAO, 1984; Giday et al., 1990; Legesse and Ayenew, 2006).

The major soil type exhibited in the area is Solonchacks (Alemayehu et al., 2016), mainly developed from evaporates and salt-rich parent materials (Brady and Well, 2002; Halcrow, 2008). According to Wendemeneh et al. (2020), the properties of the soil in the area ranges from slightly alkaline to strongly alkaline in reaction and dominantly sandy loam in texture. The topography is characterized by plain to undulated hills located adjacent to the escarpment of the central part of the Ethiopian mountain channels. The major land-use types that are practiced in the area are cultivated land which is concentrated in flat areas and grazing land that is mainly located in the hilly area and lakeshores. Cropping practices are dominated by horticultural crop production during the irrigation seasons and cereal production during rainy seasons. The major cash crops grown in the area are tomato, cabbage, onion, and beans whereas maize, teff, and wheat are considered as main food crops (Wendemeneh et al., 2020). The natural vegetation is situated nearby lake and river banks and composed of bushes and *Acacia* species.

Experimental setup and treatments

The experiment was carried out on 16 selected farmer's fields in the area for two consecutive years (2016 - 2017) during dry seasons. The farmers were further categorized into two groups based on water sources used and irrigation water management practice employed. Irrigation water monitoring tool, wetting front detector (WFD) was installed under four farmers' fields from each group. WFD is a funnel-shaped tool buried in the soil within the root zone of the crops to monitor the soil water status during cropping seasons. When a wetting front reaches optimum depth, the detector indicator pops up and irrigators should stop watering their fields. Detectors are usually placed in pairs, about one third and two thirds down the active root zone. While on the other eight farmers field (four from each group) farmers' usual practice (FP) was employed as a means of on-farm agricultural water management practices.

The treatments comprised two water sources and on-farm water management practices (Table 1). The experiment aimed to

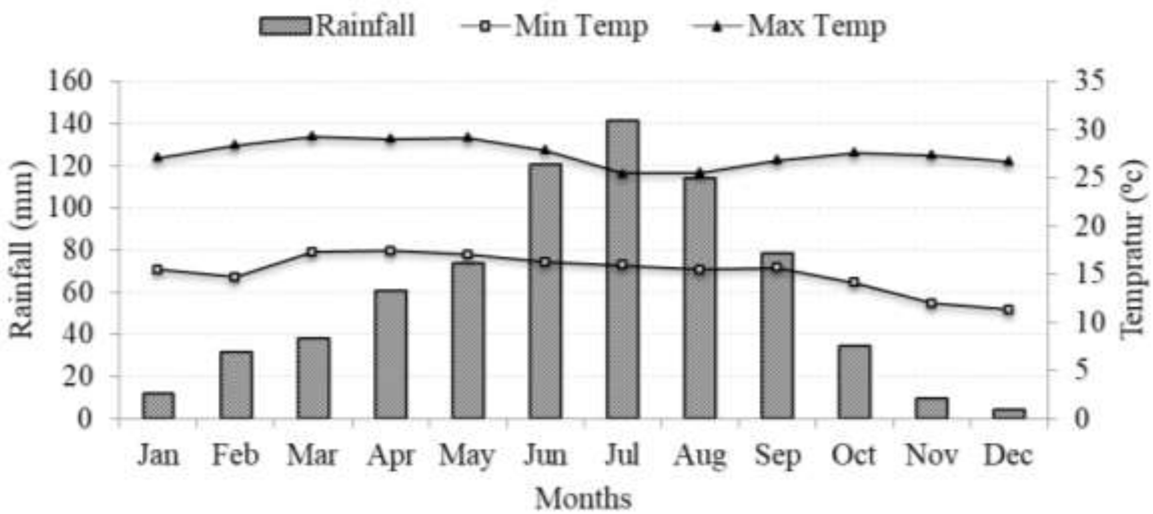

Figure 2. Mean monthly rainfall and temperature of the study area (1997 - 2017).

Table 1. The treatments and experimental setup of the study in the area (2016 - 2017).

Treatment code	Irrigation water source	Irrigation management practices	No. of farmers involved	Remark
Tr-1	SW	WFD	4	All of the farmer's grown leafy cabbage
Tr-2	SW	FP	4	
Tr-3	GW	WFD	4	
Tr-4	GW	FP	4	

Tr; Treatments, SW; Surface water, GW; Groundwater, WFD; Wetting front detector, FP; Farmers practice.

evaluate the effect of on-farm water management practices and the source of irrigation water used on soil quality in the area. The area of each experimental plot was 250 m^2 (25 m × 10 m). The spacing between rows was 60 cm and between plants was 35 cm. The seedling of leafy cabbage was prepared in a common place for all involved farmers. The transplanting of seedlings was done similarly at the beginning of February for each growing season under all farmers' fields. All post-planting field management practices were performed just after planting up to the end of cropping seasons. All important field data were collected in an organized manner from day one up to the end of cropping seasons.

Data collection

Soil sampling was performed in February and May at the beginning and end of each growing season for two consecutive years (2016 - 2017). It was carried out during the dry season to see the effect of irrigation practice on soil salinity. Composite soil samples were collected from 16 different farmer's fields with the help of hand auger for laboratory analysis (Figure 3). To account for depth effect on soil salinity, from six farmers (3 from each water source) field soil samples were collected from three layers; 0-30, 30-60, and 60-90 cm depth in each growing season. Samples were dried at room temperature then ground and sieved in 250 µm and subjected to a series of physicochemical analyses. The analyzed parameters were: texture, pH, electrical conductivity (EC), total nitrogen, organic carbon, phosphorus, cation exchange capacity (CEC), exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, and Na^+).

Water sampling was done at the beginning and end of each growing season during the investigation period (Figure 3). It was carried out mainly to examine the effect of irrigation water sources on soil salinity in the area. The water samples were collected from two abstraction points along the river and four boreholes that farmers used for irrigating their crops. Totally six water samples were collected using plastic bottles in each growing season for laboratory analysis. The bottles used for the sample collection were washed thoroughly with detergent to make it clean for sample collection. The bottles were filled to the top, sealed, and labeled with a unique code number throughout the laboratory analysis period to enhance the accuracy of analytical results. The collected water samples were preserved in the icebox, transported, and analyzed according to the standards set for irrigation water quality (Ayers and Westcot, 1985). The analysis determined the concentration of pH, EC, OC, CO_3^{2-}, HCO_3^-, Cl^-, K^+, Ca^{2+}, Mg^{2+}, Na^+, and B.

Laboratory analysis

Soil sample analysis

The important physicochemical properties of soil samples were analyzed using standard laboratory procedures. Soil texture was analyzed using the Bouyoucos hydrometer method following the procedures suggested by Day (1965). The bulk density (BD) was estimated from undisturbed soil samples following the procedures used by Blake (1965). Soil pH was determined using pH meter

Figure 3. Soil and water sample collection in the area at the beginning of the season.

while EC was determined by using a conductivity meter. Organic carbon of the soils was determined following the wet digestion method as described by Walkley and Black (1934). The percentage OM of the soils was determined by multiplying the %OC value by a factor of 1.724. Available P and total N were tested following the procedure developed by Olsen et al. (1954) and the Kjeldahl procedure (Black, 1965), respectively. The ammonium acetate method was employed to determine the CEC and exchangeable bases (Black, 1965).

Soil salinization and sodicity resulting from poor irrigation practice become a major problem in irrigated agriculture. Salinization of the soils related to irrigation practice was determined by using the electrical conductivity of the saturated extract (ECe). As suggested by Ayers and Westcot (1985) the saturated extract (ECe) value above 4 dSm^{-1} are considered as saline soil. Soil sodicity is the process by which Ca^{2+} and Mg^{2+} on the soil exchangeable complexes are substituted for Na^{+} which in turn could affect soil structure. The SAR is a widely accepted index for characterizing the soil solution concerning its likely influence on exchangeable sodium. As suggested by Ayers and Westcot (1985), SAR was estimated by using Equation 1. The concentrations of all ions in Equation 1 are expressed in milliequivalents per liter.

$$\mathrm{SAR}=\frac{\mathrm{Na\ meq/l}}{\sqrt{(\mathrm{Ca}+\mathrm{Mg})/2}} \qquad (1)$$

Another important indicator of soil sodicity as a result of irrigated agriculture is the percentage of sodium on the exchange complex. The ESP was estimated by using Equation 2 as suggested by Landon (1991). The concentrations of all ions in Equation 2 are also expressed in milliequivalents per liter.

$$\mathrm{ESP} = (\mathrm{Na/CEC}) \times 100 \qquad (2)$$

Total dissolved solids (TDS) were estimated by using Equation 3 as suggested by Landon (1991). All the ionic concentrations in Equation 3 are expressed in milligrams per liter.

$$\mathrm{TDS\ (mg/L)=EC(dS/m)\times K} \qquad (3)$$

where K=640 in most cases (for EC: 0.5 -5 dS/m) or K=735 for mixed waters or K= 800 for EC > 5 dS/m.

Water sample analysis

The analysis of physio-chemical parameters of the water samples was carried out using the standard laboratory procedures. Electrical conductivity (EC_w) and pH (H_2O) were determined using conductivity meter and pH-meter (Greenberg et al., 1992), respectively. Soluble Na^{+} and K^{+} were determined by a flame photometer (RTI, 1991) while soluble Ca^{2+} and were analyzed directly by the atomic absorption spectrophotometer (APHA, 1998). Chloride, carbonate and bicarbonate ions were measured by titrating against silver nitrate standard solution with potassium chromate indicator with a procedure from (Greenberg et al., 1992). Similarly, phosphorus, nitrate, and boron were determined by using spectrophotometric as described by AOAC (1990).

The use of poor quality can create four types of problems such as toxicity, water infiltration, salinity, and miscellaneous (Ayers and Westcot, 1985). As Raghunath (1987) and Michael (1992) emphasized that the evaluation of water quality for irrigation purpose should be considering four most popular parameters: EC/TDS, SAR, RSBC and chemical concentrations like Na, Cl, and B. For current irrigation water quality evaluation, those parameters were considered. Sodium adsorption ratio (SAR) of irrigation was estimated by using Equation 1 as suggested by Ayers and Westcot (1985). It is carried out to predict the danger of sodium accumulation in the soil as a result of irrigation practices. In addition to that, total dissolved solids (TDS) were also estimated by using Equation 3 to predict the concentration of ions in the soil. Residual sodium carbonate (RSC) existing in irrigation water was estimated by using Equation 4 as suggested by Raghunath (1987). All ions concentration in Equation 4 is also expressed in milliequivalents per liter.

$$\mathrm{RSC} = (\mathrm{CO_3}+\mathrm{HCO_3}) - (\mathrm{Ca}+\mathrm{Mg}) \qquad (4)$$

Soluble sodium percentage (SSP) was estimated by using Equation 5 as suggested by Todd (1980). The presence of a high concentration of sodium ion in irrigation water could degrade soil structure due to its dispersing effect of clay particles. The concentrations of all ions in Equation 5 are expressed in milligrams per liter.

$$\mathrm{SSP=(Na+K/Ca+Mg+Na+K)\times 100} \qquad (5)$$

The permeability of soil is affected by sodium, calcium, magnesium, and bicarbonate contents of irrigation water. The permeability index (PI) of irrigation water was estimated by using Equation 6 as suggested by Doneen (1964). In Equation 6, the concentrations of all ions are also expressed in milliequivalents per liter.

$$PI = \left(\frac{Na + \sqrt{HCO_3}}{Ca + Mg + Na} \right) \quad (6)$$

Kelly's ratio (KR) is an equation developed for determining sodium related problems in irrigation water. The KR was estimated by using Equation 7 as described by Kelly (1963). The concentrations of all ions in Equation 7 are expressed in milliequivalents per liter.

$$KR = \frac{Na}{Ca + Mg} \quad (7)$$

Statistical analysis

Generalized linear model (GLM) procedure in the statistical package for the social science (SPSS) version 16 application was used in the analysis of the entire data. The general linear model (GLM) of two ways analysis of variance (ANOVA) was used to determine whether differences existed among experimental treatments concerning soil quality. The mean of each parameter was compared between irrigation water sources and management practices using a post hoc comparison test (Tukey's Honestly Significant Difference) to find exactly where the differences lie between the studied treatments. The probability level for determination of significance was 0.05.

RESULTS AND DISCUSSION

This study assessed the effect of on-farm water management practices and the source of irrigation water used on soil quality under a farmer's field condition in the area. Soil and water samples were collected before planting and after harvesting for two consecutive years. The results of laboratory analysis of soil and water samples for different parameters were recorded and the mean value of salinity indices obtained from the analysis of variance (ANOVA) for studied treatment is presented in Tables 3 and 4. The physicochemical property of irrigation water and some of its quality indicators are shown in Table 5. Correlation analysis carried out between soil and irrigation water quality parameters is shown in Table 6. The graphical presentation of irrigation water source and soil sampling time effect on soil quality in the area are also shown in Figures 4 and 5.

Effect of on-farm water management practices on soil salinity

The result of on-farm irrigation management practices and water sources used revealed that the majority of salinity parameters showed significant differences at P<5% among treatments. This implies that irrigation water management practices and sources of irrigation water have an impact on soil salinity build-up in the area. Moreover, about 64.3% of soil properties showed significant variations at P<5% among treatments at the end of the season. But, at the beginning of the season, only 42.9% of soil properties showed such variations (Table 3). This implies that variation of soil quality parameters is more pronounced at the end of the growing season compared with its initial values recorded at the beginning of the season. These variations might be attributed to management practices employed and irrigation water sources used during growing periods. In fact, throughout the study, Tr-1 and Tr-3 are designated for managed fields (WFD) while Tr-2 and Tr-4 are designated for unmanaged fields (FP). But, both fields were irrigated with surface and groundwater sources to see how water sources influenced soil fertility in the area.

The pH ranged from 8.13 (Tr-2) to 8.69 (Tr-4) and EC ranged from 0.61 dS/m (Tr-2) to 1.03 dS/m (Tr-4), respectively as shown in Table 3. The data indicate that lower and higher values for both parameters were observed in FP fields. But, both fields were irrigated with different water sources during the experimentation period. As clearly observed in Table 4, its value in WFD field conditions gets low (8.39) compared to its value (8.41) in FP fields. As compared to its initial value (pH=8.20), at the end of the season, pH values showed a slightly increasing trend. This may be attributed to the effect of treatments tried in the area under prevailing field conditions. The EC values did not show any significant variation among treatments. This implies that soil salinity levels were not as such influenced by on-farm water management practices employed and irrigation water sources used in the area. However, in both fields, its values showed an increasing trend compared to its initial values (Table 3). This may be attributed to irrigation management practices employed and irrigation water sources used during the study periods. Moreover, a higher value for both parameters was observed in groundwater irrigated fields throughout experimentation periods. This suggests that irrigation water source has pronounced effects on soil quality aside from management practices. However, the average value of both parameters (pH= 8.40; EC=0.84) remains below the limit (Table 2) in all treatments. Similar findings related to these parameters were also reported by Kefyalew and Kibebew (2016) and Hadera (2018) in the area.

The concentration of CEC and OMC showed significant variations among treatments at the end of the season. The values CEC showed a decreasing trend while OMC showed an increasing trend compared to their initial values (Table 3). This implies that both management practices and water sources influence soil fertility in the area. The highest OM content (4.9%) was observed at managed fields compared to unmanaged fields (3.1%). This suggests that on-farm water management practices can improve soil quality. Total nitrogen and available

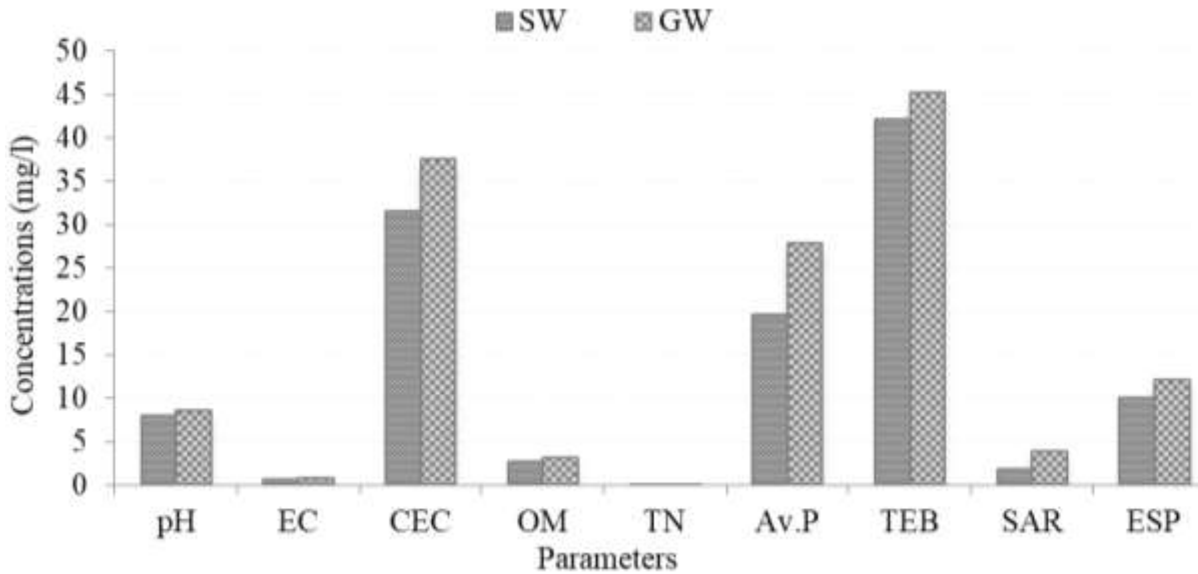

Figure 4. Graphical illustration of the effect of irrigation water source on soil salinity under farmer's field condition.

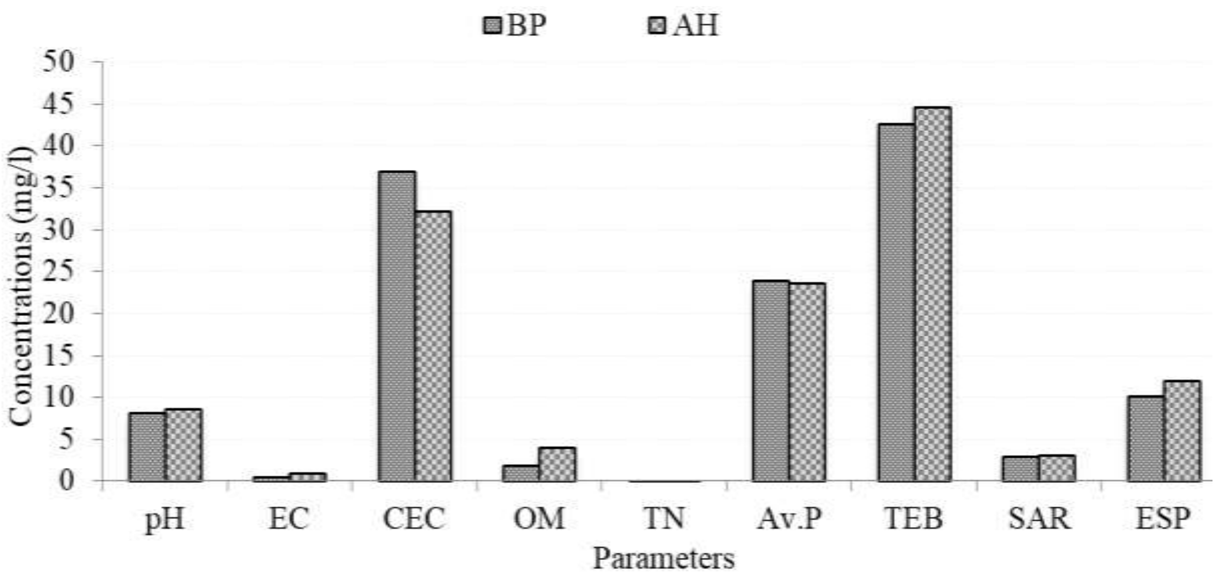

Figure 5. Graphical illustration of the effect of sampling time on soil salinity under farmer's field condition.

phosphorous values in the area were significantly varied at $P<0.05$ among studied treatments. This implies that treatment effects are noticeable and can influence soil fertility in the area. The concentration of these parameters also showed an increasing trend at the end of the season. This may also confirm that irrigation management and water sources could influence soil quality. Moreover, the high value of these parameters (TN=0.45%; AP=30 ppm) was observed under WFD installed fields as compared to FP fields (TN=0.22%; AP=17 ppm) (Table 3). This suggests that irrigation management practices can play an important role to manage soil fertility in irrigated fields through reducing leaching of nutrients. This finding was also agreed with other research findings reported by Hadera (2018).

As indicated in Table 3, the mean values of soil properties followed by the same letter in the same rows are not significantly different from each other. In fact, the values compiled in Table 3 shows how the concentration of studied soil properties varied among treatments during the study period. The values of exchangeable basis (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) are also show remarkable

Table 2. Soil and water quality parameters recommended for agricultural practices/purposes.

Parameter	Sample type	Symbol	Unit	Acceptable range	Source
Alkalinity/Basicity	Soil; Water	pH	0-14	6.5-8.4	
Electrical conductivity	Soil; Water	EC	dS/m	0-4	
Total dissolved solids	Soil; Water	TDS	mg/l	0-2000	
Sodium adsorption ratio	Soil; Water	SAR	meq/l	0-9	
Carbonate	Water	CO_3^{2-}	mg/l	0-3	Ayers and Westcot (1985)
Bicarbonate	Water	HCO_3^-	mg/l	0-519	
Chloride	Water	Cl^-	mg/l	0-355	
Boron	Water	B	mg/l	0-2	
Nitrate	Water	NO_3^-	mg/l	0-10	
Calcium	Soil; Water	Ca^{2+}	$Cmol_c$/kg; mg/l	0-20; 0-400	FAO (2006); Ayers and Westcot (1985)
Magnesium	Soil; Water	Mg^{2+}	$Cmol_c$/kg; mg/l	0.3-8; 0-60	FAO (2006); Ayers and Westcot (1985)
Sodium	Soil; Water	Na^+	$Cmol_c$/kg; mg/l	0.1-2; 0-1000	FAO (2006); Ayers and Westcot (1985)
Potassium	Soil; Water	K^+	$Cmol_c$/kg; mg/l	0.1-1.2; 0-2	FAO (2006); Ayers and Westcot (1985)
Phosphorous	Soil; Water	PO_4^{3-}	ppm; mg/l	5-25; 0-2	FAO (1980): Ayers and Westcot (1985)
Cation exchange capacity	Soil	CEC	$Cmol_c$/kg	15-40	FAO (2006)
Exchangeable sodium percent	Soil	ESP	%	<15	Landon (1991)
Organic matter content	Soil	OMC	%	0.86-5.17	Tekalign (1991)
Total nitrogen	Soil	TN	%	0.10-0.25	
Residual sodium carbonate	Water	RSC	meq/l	<2.5	Raghunath (1987)
Permeability index	Water	PI	%	>65	Doneen (1964)
Magnesium adsorption ratio	Water	MAR	%	<50	Raghunath (1987)
Soluble sodium percentage	Water	SSP	%	<60	Todd (1980)
Kelly ratio	Water	KR	meq/l	<1	Kelly (1963)

variations among treatments. This indicates that irrigation water management and water sources have noticeable influences on soil quality. All exchangeable basis except Ca^{2+}, showed an increasing trend at the end of the growing season. This increment may also be attributed to differences in irrigation management employed and water sources used. Because all of these parameters showed high values at the end of the season compared to their initial values. Higher values for these parameters are also observed in FP fields during the study periods (Table 3). Alemayehu et al. (2016) and Hadera (2018) reported similarly higher values for these parameters in the area.

The bulk density (BD) did not show any variation across the season and among the treatments (Table 3). But, relatively its higher value was observed in WFD installed fields (1.11 gcm^{-3}) compared with its value (1.07 gcm^{-3}) in FP fields. This may probably be due to differences in tillage practices and trampling effects of domestic animals freely grazing in the area. Moreover, its low value was observed at the end of the season compared with its initial value at the beginning of the season. This suggests that irrigation practice may have an impact on the physical property of the soil in the area.

As clearly observed in Table 3, total dissolved solutes (TDS) during the study periods did not show any variation among treatments. However, its values showed an increasing trend at the end of growing seasons under both field conditions. This suggests that on-farm water management practices slightly influenced salinity build-up in the area. Aside from management practices, irrigation water sources would also play a role in salinity build-up around the root zone. The average value of TDS in WFD installed fields is 528 mg/l compared with 547.23 mg/l in FP fields. This also confirmed that on-farm water management practices have an impact on soil salinity. Similar findings were also reported by Kefyalew and Kibebew (2016) and Alemayehu et al. (2016) in the area related to these parameters.

The sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) values during the study period showed significant variations at P<0.05 across the season and among treatments. This also highlights the importance of irrigation management to reduce the adverse effects of irrigation practices on soil quality in the area. Like others, these parameters are also shown an increasing trend at the end of growing seasons under

Table 3. The effect of irrigation water management practices on soil quality under farmer's fields.

Parameter	At the beginning of the season (BP)						
	Tr-1	Tr-2	Tr-3	Tr-4	Average	Sig.	LOS
pH	8.05[a]	7.99[a]	8.07[b]	8.71[a]	8.20	0.00	*
EC	0.56[a]	0.47[a]	0.48[a]	0.63[a]	0.54	0.67	NS
CEC	39.61[a]	32.08[a]	37.10[a]	39.17[a]	36.99	0.18	NS
OM	1.95[a]	1.98[a]	1.52[a]	1.88[a]	1.83	0.5	NS
TN	0.27[a]	0.29[a]	0.22[a]	0.28[a]	0.27	0.83	NS
AP	35.01[b]	17.35[a]	22.33[a]	30.96[a]	26.41	0.05	*
K^+	3.12[a]	2.74[a]	3.14[a]	3.47[a]	3.12	0.34	NS
Ca^{2+}	26.55[b]	22.64[a]	22.65[a]	19.75[a]	22.9	0.02	*
Mg^{2+}	11.86[a]	15.56[a]	13.96[a]	10.62[a]	13.09	0.26	NS
Na^+	3.85[a]	2.63[a]	2.79[b]	5.54[a]	3.70	0.05	*
BD	1.23[a]	1.11[a]	1.20[a]	1.21[a]	1.20	0.78	NS
TDS	358.42[a]	307.30[a]	300.77[a]	403.24[a]	342.44	0.67	NS
SAR	2.53[b]	1.82[ab]	2.63[a]c	5.31[a]	3.10	0.00	*
ESP	11.29[a]	8.31[a]	7.92[b]	13.19[a]	10.18	0.05	*
	At the end of the season (AH)						
pH	8.23[a]	8.13[b]	8.55[a]	8.69[a]	8.40	0.00	*
EC	1.04[a]	0.61[a]	0.65[a]	1.06[a]	0.84	0.25	NS
CEC	29.28[a]	25.31[b]	34.49[ab]	39.79[a]	32.22	0.00	*
OM	5.01[a]	2.25[b]	4.81[ab]	3.86[a]c	3.98	0.00	*
TN	0.38[a]	0.24[a]	0.51[a]	0.20[a]	0.34	0.14	NS
AP	30.99[a]	19.24[ab]	29.65[b]	28.82[b]	23.68	0.00	*
K^+	2.45[a]	2.26[a]	2.82[b]	4.10[a]	2.90	0.00	*
$Ca2^+$	23.22[a]	22.87[a]	43.76[a]	23.58[a]	28.36	0.36	NS
$Mg2^+$	7.98[a]	15.5[b]	8.13[a]	8.76[a]	10.09	0.00	*
Na^+	1.55[a]	3.91[b]	3.33[b]	5.27[b]	3.51	0.00	*
BD	1.12[a]	1.03[a]	1.10[a]	1.11[a]	1.09	0.34	NS
TDS	665.60[a]	416.00[a]	390.40[a]	678.40[a]	537.60	0.08	NS
SAR	2.68[a]	3.04[ab]	3.46[b]	4.53[b]	2.93	0.00	*
ESP	9.24[b]	15.43[a]	10.39[a]	13.10[a]	11.04	0.00	*

Tr; Treatments, * Significant at ≤ 5%, NS; Non-significant, LOS; Level of significant, BP; Before planting, AH; After harvesting

both WFD and FP fields' conditions in the area. This might be attributed to the effect of irrigation management practices and the source of irrigation water used in the area. It also clearly expresses how treatment influences soil quality. Furthermore, the average value of ESP in WFD fields (9.8%) is lower than the value of ESP in FP fields (14.3%). Hence, irrigation management practices have played a noticeable role in maintaining soil quality in the area. This finding also agreed with other findings reported by Alemayehu et al. (2016), Kefyalew and Kibebew (2016) and Hadera (2018).

Effect of irrigation water source on soil salinity

The farmers in the area used both surface and groundwater for irrigating their fields. As expressed in Figure 4, almost all of the studied soil properties showed an increasing trend in groundwater irrigated fields compared to surface water irrigated fields. This may be attributed to the difference in the quality of irrigation water used during the investigation period. It also supports water analysis results in which all studied parameters showed high concentration under groundwater samples. The pH and EC of the soil showed a slightly increasing trend in groundwater user's field. This also confirms that the irrigation water source has an impact on soil quality in the area. Hence, paying attention to the quality of groundwater is very important as long as it is supposed to be used for irrigation purposes. And also periodic assessment of its influence across the field is very important to sustain irrigated agriculture in the area. Soil OM, AP, and CEC showed a clearly observable increase in the case of groundwater user fields compared to

Table 4. Variation of soil salinity parameters across sampling depths in farmer's field condition.

Parameter	Surface water irrigated fields			Groundwater irrigated fields			Average	Sig	LOS
	0-30 cm	30-60 cm	60-90 cm	0-30 cm	30-60 cm	60-90 cm			
pH	7.86^{a}	7.77^{b}	7.48^{ab}	8.33^{a}	8.02^{a}	7.88^{a}	7.89	0.01	*
EC	0.63^{a}	0.42^{a}	0.27^{a}	0.78^{a}	0.72^{a}	0.50^{a}	0.55	0.23	NS
CEC	45.03^{a}	37.20^{a}	32.26^{a}	39.48^{a}	38.30^{a}	35.08^{a}	37.89	0.08	NS
OM	2.03^{a}	1.44^{a}	1.14^{b}	2.39^{a}	1.51^{a}	1.06^{a}	1.60	0.03	*
TN	0.28^{a}	0.15^{a}	0.09^{b}	0.24^{a}	0.10^{a}	0.08^{a}	0.16	0.01	*
Av.P	71.27^{a}	59.10^{a}	36.07^{a}	47.70^{a}	39.51^{a}	30.58^{a}	47.37	0.18	NS
Ca^{2+}	29.92^{a}	24.14^{a}	19.98^{a}	22.25^{a}	21.81^{b}	17.62^{a}	22.62	0.00	*
Mg^{2+}	9.89^{b}	5.59^{a}	5.28^{ab}	9.81^{b}c	5.58^{a}	4.93^{a}	6.85	0.00	*
K^{2+}	2.89^{a}	3.63^{a}	3.95^{a}	4.19^{a}	4.09^{a}	4.09^{a}	3.80	0.10	NS
Na^{2+}	2.98^{a}	1.30^{a}	1.18^{a}	4.47^{a}	4.49^{a}	3.64^{a}	3.01	0.12	NS
TDS	405.12^{a}	270.93^{a}	173.87^{a}	495.79^{a}	448.00^{a}	321.07^{a}	352.46	0.24	NS
SAR	2.75^{a}	1.55^{a}	1.33^{b}	4.26^{a}	3.73^{a}	3.38^{a}	2.83	0.05	*
ESP	7.92^{a}	3.74^{a}	3.72^{b}	10.31^{a}	11.27^{a}	10.13^{a}	7.85	0.05	*

*Significant at ≤ 5%, LOS; Level of significance, NS; None significant.

Table 5. Chemical properties of irrigation water across the source in the area.

Parameter	SW-1	SW-2	GW-3	GW-4	GW-5	GW-6	ASW	AGW	TA
pH	8.20	7.98	8.10	8.23	7.83	7.93	8.09	8.02	8.06
EC	0.52	0.48	2.03	2.73	1.63	1.91	0.50	2.08	1.29
Na^{+}	255.85	262.8	398.75	564.00	388.75	445.75	259.32	449.31	354.32
Ca^{2+}	39.30	38.08	65.55	45.05	60.55	69.13	38.69	60.07	49.38
CO_3^{2-}	32.75	27.50	44.25	52.75	79.00	81.00	30.13	64.25	47.19
HCO_3^{-}	314.50	280.25	932.50	1028.80	960.00	910.75	297.37	958.01	627.69
K^{+}	189.00	228.50	370.50	367.75	302.75	311.00	208.75	338.00	273.38
Mg^{2+}	26.50	27.35	49.50	50.63	57.60	58.65	26.92	54.10	40.51
Cl^{2+}	35.75	37.25	69.75	216.75	111.25	145.75	36.50	135.88	86.19
NO_3^{-}	96.10	126.88	38.80	26.63	44.18	32.83	111.49	35.61	73.55
PO_4^{3-}	0.62	0.79	1.12	0.99	1.09	0.87	0.71	1.02	0.87
B	0.05	0.08	0.52	0.75	0.28	0.14	0.06	0.42	0.24
SAR	7.68	7.43	9.37	13.45	9.10	10.17	7.56	10.52	9.04
SSP	79.28	80.51	78.38	83.99	75.91	76.63	79.90	78.73	79.31
KR	2.67	2.73	2.34	3.79	2.16	2.32	2.70	2.65	2.68
RSC	2.07	0.99	8.36	10.82	10.54	9.29	1.53	9.75	5.64
TDS	331.36	306.4	1295.40	1742.90	1041.60	1222.20	318.88	1325.53	822.2
MAR	80.69	79.19	94.29	95.40	93.21	94.10	79.94	94.25	87.1
PI	91.37	92.24	90.46	97.16	87.47	88.56	91.81	90.91	91.36

SW: Surface water, GW: Groundwater, ASW: Average value of surface water, AGW: Average value of groundwater, TA: Total average value.

surface water user fields. This implies that a high concentration of these parameters under those fields most probably due to the overuse of agricultural inputs. Similar results were also reported by Seid and Genanew (2013) and Hadera (2018).

It can be stated from the graph that the total exchangeable bases showed a slightly increasing trend in groundwater user fields. However, Mg^{2+} concentration gets high under surface water user fields and this may be related to the easily leachable nature of the element. Generally paying attention to the implementation of certain irrigation water management practices is critical to maintaining soil fertility in the area. Moreover, considering groundwater quality in the future is also very important to sustained irrigated agriculture in the area.

Wendemeneh et al. (2019) also reported very high concentration of these parameters in groundwater sources compared to surface water. This might be the

Table 6. Correlation analysis among water quality parameters, soil quality parameters and between water and soil quality parameters in the area.

Parameter	pH_w	EC_w	Ca_w	Mg_w	K_w	Na_w	TN_w	AP_w	SAR_w	pH_s	EC_s	Ca_s	Mg_s	K_s	Na_s	AP_s	SAR_s
pH_w	1	0.86	-0.73	-0.77	0.84	0.96[b]	0.24	0.43	0.99[a]	0.66	0.81	-0.03	0.66	0.60	0.96[b]	0.37	0.99[a]
EC_w		1	-0.28	-0.96[b]	0.85	0.99[a]	0.34	0.81	0.88	0.89	0.51	-0.29	0.32	0.21	0.64	-0.07	0.75
Ca_w			1	0.13	-0.40	-0.42	-0.09	0.30	-0.67	-0.01	-0.78	-0.23	-0.73	-0.79	-0.83	-0.72	-0.80
Mg_w				1	-0.91	-0.96[b]	-0.10	-0.90	-0.83	-0.98[b]	-0.53	0.10	-0.38	-0.24	-0.61	0.02	-0.70
K_w					1	0.86	-0.19	0.69	0.91	0.90	0.82	0.27	0.73	0.62	0.84	0.39	0.87
Na_w						1	0.34	0.72	0.94	0.84	0.60	-0.24	0.42	0.32	0.74	0.05	0.84
TN_w							1	0.09	0.14	-0.05	-0.34	-0.96[b]	-0.52	-0.51	-0.12	-0.62	0.02
AP_w								1	0.51	0.95[b]	0.16	-0.23	0.03	-0.13	0.22	-0.36	0.32
SAR_w									1	0.74	0.84	0.05	0.69	0.62	0.95[b]	0.39	0.99[a]
pH_s										1	0.50	0.01	0.38	0.24	0.54	-0.01	0.62
EC_s											1	0.56	0.97[b]	0.96[b]	0.97[b]	0.82	0.93
Ca_s												1	0.73	0.74	0.36	0.84	0.21
Mg_s													1	0.99[a]	0.90	0.92	0.82
K_s														1	0.87	0.96[b]	0.78
Na_s															1	0.71	0.99[a]
AP_s																1	0.58
SAR_s																	1

[a]Correlation is significant at $p < 0.01$; [b]Correlation is significant at $p < 0.05$; Subscript letters; w-stands for water and s-stands for soil.

reason why majority of salinity parameters showed high values under groundwater irrigated fields compared to surface water irrigated fields in the area. Seid and Genanew (2013) and Hadera (2018) reported similar findings concerning the source of irrigation water effects on soil salinity in the area.

As expressed in Figure 5, the majority of the studied soil salinity parameters showed an increasing trend over time in the area. This implies that irrigation has contributed considerably to salinity buildup in the area. However, some parameters such as OMC and TN showed a slightly decreasing trend over time. Since year-round cultivation without appropriate management practices could reduce their concentration in soil due to the oxidation process. The pH of the soil has not been shown, as such a remarkable change during the entire study periods in the area. This implies that the effect of irrigation under the farmer's field conditions could not affect the alkalinity of the soil. The remaining soil properties such as EC, AP, and exchangeable cations have shown considerable variation with time.

As clearly observed from Figure 5, their concentration increases over time in the area due to irrigation practices and in the future, it may affect the fertility/salinity of the soil. Hence, paying attention to the implementation of certain irrigation management practices is crucial in the area. The use of irrigation as a means of crop production without considering management issues could negatively affect the productivity of the soil. As compared with the previous findings reported by Alemayehu et al. (2016) and Kefyalew and Kibebew (2016), the present finding gets high in terms of salinity probably due to intensive use of agricultural inputs including the amount of water applied in the field. Hence, there is a restriction on the use of land for irrigation purposes since a high concentration of those cations will affect salinity sensitive crops. Therefore, time-based data is very crucial for certain soil quality parameters that show change with time to develop a mitigation strategy.

Variability of soil salinity across the depth

The spatial variability of soil properties across the depth (surface, sub-surface, and subsoil) is shown in Table 5. As the results indicated in Table 4, about 54% of the studied quality parameters showed a significant difference at $P<0.05$ across sampling depths. The remaining 46% of soil properties did not show such variations across the depth. This suggests that irrigation water sources used to cultivate crops could influence salinity parameters across the depth. As the results indicated in Table 4, all irrigated fields soil across the depth are non-saline and non-sodic (Ayers and Westcott, 1985; Abrol et al., 1988). The analysis of the soil samples revealed that the soil reaction ranged from moderate to slightly alkaline, which is not unexpected for soils of the arid and semiarid region. The spatial variability pH for the surface, subsurface, and subsoil showed significant difference at $P<0.05$ across the depth and source of water used. The values of pH across the depth ranged between 7.5 (subsoil) and 8.3 (surface soil) and the highest value observed in groundwater irrigated fields. It suggested that alkalinity is more pronounced at surface soil irrigated with groundwater.

TDS values across the depth under both water sources irrigated fields did not show such variation. And also relatively its higher value was observed at surface soils in groundwater irrigated fields. This implies that irrigating the fields with groundwater could influence soil salinity buildup in the area. Hence, the use of groundwater for irrigation needs special attention to mitigate its adverse effects on soil quality. As its use without considering any management options could aggravate salinity problems in the area. However, its values remain below the critical limit (4 dS/m) suggested for soil salinity problem (Table 2). These findings agreed with previous findings reported by Halcrow (2008) and Alemayehu et al. (2016).

As indicated in Table 4, the mean values of soil properties followed by the same letter in the same row are not significantly different from each other. The spatial variability of SAR for the surface, sub-surface, and subsoil are shown in Table 4. As shown in Table 4, its values ranged from 1.3 to 4.3, and the highest value was observed at the surface layer in groundwater irrigated fields. In addition to that, it also showed remarkable variation across the depth of investigated fields. During the investigation period, its values showed a declining trend across the depth under both water irrigated fields. Relatively, its higher values were also observed at groundwater irrigated fields. Hence, paying attention to groundwater quality is very important if the water is supposed to be used for irrigation. This finding agreed with the previous findings reported by Halcrow (2008), Kefyalew and Kibebew (2016) and Hadera (2018) which showed similarly high SAR values at surface soil in the area.

Table 4 shows how the concentration of studied soil properties varied across the depth of the soil. The values of ESP across the depth ranged from 3.74 to 11.27% and its higher value were observed in subsurface (30 - 60 cm) soil in groundwater irrigated fields. Its values showed significant variation across the depth and source of water used. Moreover, the analysis revealed that the sodicity problem was more pronounced under the groundwater user's fields. The SAR value, therefore, suggests that groundwater quality in the area should be taking into account during the planning of irrigation practices. However, ESP values across the depth of cultivated fields fell within the non-sodic class (less than 15) that suggested the occurrence of sodicity problems. This finding agreed with the previous findings reported by Halcrow (2008) in the area.

Chemical properties of irrigation water

Farmers in the area used both surface and groundwater sources for irrigating their fields. The research findings reported by Michael (1992) and Hillel (2000) showed that the quality of irrigation water influences soil fertility. Hence, the planning of any irrigation projects should be taken into account. Ayers and Westcot (1985) emphasized that water quality evaluation should focus on the farm level rather than at the project level. In this regard, the present evaluation was done at the farm level to know its influence on soil salinity aside from irrigation practices experienced in the area. As the results shown in Table 5, the values of pH and EC in the area ranged from 7.98 to 8.23 and 0.48 to 2.73 dS/m, respectively. The highest value in both cases was observed in groundwater samples. This may suggest that the use of groundwater for irrigation purposes is the most likely factor to influence soil quality compared to surface water. However, the average value of both parameters (pH=8.06; EC=1.29 dS/m) remains below critical limits (pH=8.50; EC=4.00 dS/m) recommended for irrigation uses (Table 2). In this regard, irrigation water used in the study area is found within a safe limit and suitable for irrigation. This finding is more or less similar to the previous study findings reported by Halcrow (2008) and Abay et al. (2016).

The concentrations of Ca^{2+} and Mg^{2+} in irrigation water varied from 38.08 to 69.13 mg/l and 26.50 to 58.65 mg/l, respectively (Table 5). The highest value for both parameters was also observed in groundwater samples. This implies that irrigating the farms with groundwater may increase salt contents in the soil which in turn could influence soil quality. However, the concentration of both parameters at both water sources remains below critical limits (Ca^{2+}=400 mg/l; Mg^{2+}=60 mg/l) recommended for irrigated agriculture (Table 2). The concentration of K^+ in irrigation water ranged from 189.00 to 370.50 mg/l, respectively (Table 5). Similarly, its highest value during the study period was also observed in groundwater samples. Unlike others, the concentration of this parameter in both water sources showed a very high value compared to the limit (Table 2). This may probably be due to the nature of underlying rocks that are found in the area. Similarly, high value for this parameter was also reported by Halcrow (2008) and Abay et al. (2016) in the area.

Sodium (Na^+) concentration in irrigation water ranged from 255.85 to 564.00 mg/l (Table 5). The highest value for this parameter was observed in groundwater samples. Likewise, its concentration at both water sources remains by far higher than Ca^{2+} and Mg^{2+}. This suggests that irrigating farmlands with the water may increase the alkalinity of the soils. Besides, it may cause a toxicity problem on growing crops aside from physical deterioration of soil quality. Hence, paying attention to groundwater quality is critical to reducing such problems in the area. As the standards compiled in Table 2, however, indicated that the value of Na^+ is found within the permissible range. The other common toxic ions found in irrigation water are chlorine (Cl^-) and Born (B). Their concentrations in the area varied from 35.75 to 216.75 mg/l and 0.05 to 0.72 mg/l, respectively as indicated in Table 5. The highest value for these parameters was also observed in groundwater samples. However, the concentrations of both parameters in studied water sources are found within an acceptable limit for irrigation (Table 2).

The value of carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-) in all sampling sources and locations varied from 27.50 to 81.00 mg/l and 280.25 to 1028.80 mg/l, respectively (Table 5). The highest value for these parameters is observed in groundwater samples. This also reflects how groundwater quality deserves considerable attention in the area. The concentration of CO_3^{2-} at both water sources remained above the limit (Table 2). The values of HCO_3^- are found within the range in surface water while remained above in groundwater (Table 2). This data also suggests the use of water for agricultural purposes may cause negative impacts on soil quality. Similarly, high values for these parameters were also reported by Halcrow (2008) in the area. Nitrate (NO_3^-) and phosphate (PO_4^{3-}) values in the area are ranged from 26.63 to 126.88 mg/l and 0.62 to 1.12 mg/l, respectively as shown in Table 5. The highest value for NO_3^- was observed in surface water while for PO_4^{3-} in groundwater samples. The high concentration of both parameters in the area may be attributed to the miss-use of agricultural inputs. Such type of farming system needs intensive use of agricultural inputs which in turn could favor the loss of nutrients drained to water sources. The concentration of NO_3^- in both water sources remains above the limit (10 mg/l) while PO_4^{3-} was found within the range (Table 2).

The SAR value of irrigation water in the present study area ranged from 7.43 to13.45 meq/l (Table 5). This implies that the observed values are relatively high and it might be due to the lower value of Ca^{2+} and Mg^{2+} compared to Na^+. The highest value was observed in groundwater samples compared to surface water samples. Water having SAR values less than 9 is considered as safe for irrigation uses (Table 2). In this regard, surface water average SAR value (AS=7.56) is found within the limit and suitable for irrigation. However, groundwater samples average SAR value (AG=10.52) remains beyond this limit and have a limitation on use for irrigation purpose. The value of RSC in the area ranges from 0.99 to 10.82 meq/l (Table 6). The highest value for this parameter was observed in groundwater samples compared to surface water. The water has a high concentration of carbonates that could increase sodium hazards in the area as it favors the precipitation of Ca^{2+} and Mg^{2+}. As the standards indicated in Table 2, RSC value in groundwater samples remain beyond the limit and have a limitation on the use of it for irrigation purposes.

The TDS values in the study area ranged from 306.40 to1742.90 mg/l (Table 5). Like others, its highest value was also observed in groundwater samples. This implies that groundwater quality is an issue in the area and needs due attention. The SSP and KR are also widely used parameters for evaluating the suitability of water quality for irrigation. Because excess sodium concentration in irrigation water produces undesirable effects on soil and crops. The values of SSP below 60% (Tod, 1980), KR <1 (Kelly, 1963) is considered good and safe for irrigation. However, both surface and groundwater samples' values in the area are shown above this limit (Table 5). This also suggests irrigating the fields with the water may cause sodium related problems. Similarly, MAR values under both cases found above the critical limit (MAR <50%) suggests it may influence the uptake of Ca^{2+} by crop plants. The permeability index (PI) is used to evaluate the effect of long term use of irrigation water on soil quality. Its value in the area is varied from 87.47 to 97.16% (Table 5). The average value of PI in both sampling cases (sources) remains similar during the study periods. According to the standards indicated in Table 2, its values are found within acceptable limits for irrigation uses.

Correlation analysis between soil and water quality parameters

Pearson's correlation analysis was carried out in order to explore the magnitude and direction of relationships between soil and water quality parameters in the study area (Table 6). The results showed that certain quality parameters between soil and water showed a significant relationship with each other, whereas others did not show such a relationship among themselves. As indicated in Table 6, the pH was significantly and positively correlated with Na_w (r = 0.96) and SAR_w (r = 0.99). This relationship indicated that irrigation water used in the area has an impact on soil alkalinity. Similarly, the SAR_s was significantly and positively correlated with Na_w (r = 0.95) and SAR_w (r = 0.99) (Table 6). This was also reconfirmed through the positive relationship (non-significant) that exists between the majority of soil and irrigation water quality parameters in the area. Hence, irrigators should consider the quality of irrigation water during the planning of irrigation practices in the area as it influences soil quality. The concentration of available phosphorous in soil was strongly correlated with its concentration in irrigation water (r = 0.95). This strong relation regarding available phosphorous probably suggesting that irrigation water has also contributed to the occurrence of a high amount of available phosphorous observed in irrigated fields in the area (Table 3). In general, there is sufficient evidence to conclude that majorities of soil properties highly influenced by irrigation water quality because in all cases the correlation coefficients were significantly different from zero. Therefore, irrigation management practices should also take the quality of irrigation into account during the planning of irrigation practices to maintain soil fertility in the area.

CONCLUSIONS AND RECOMMENDATIONS

Soil salinity is the major factor limiting agricultural productivity in irrigated fields located in arid and semi-arid regions. Thus, monitoring salinity builds-up under irrigated fields through implementing different management practices is very important to sustain agricultural practices in such areas. Therefore, this study was conducted to evaluate the effect of irrigation water management practices on soil salinity under farmer’s field conditions at Bochessa village for two consecutive years. In addition to that, it also assessed the influence of irrigation water sources on soil productivity across the depth of sampled fields in the area. The results revealed that on-farm water management practices and water sources used highly influences the salinity level of irrigated fields in the area. The majority of the investigated salinity parameters showed significant differences at P<5% among treatments. Besides, a variation of soil quality parameters is more pronounced at the end of the growing season compared with its initial values. The variation in concentration of the parameters might be due to management practices employed and irrigation water sources used during growing periods. Since high values for all of these parameters were observed under the farmer's practice (unmanaged fields) during entire study periods. Moreover, this investigation points out the different signs of soil quality degradation in the area as confirmed by the change in soil chemical properties.

The results further point out that alkalinity of the soil influenced by on-farm water management practices while salinity did not as such influence with such practices. Because the value of pH showed remarkable variation across treatment while EC did not show such variations. However, in both fields, their values show an increasing trend over time. Moreover, higher values for both parameters were observed under groundwater irrigated fields. This also implies that the irrigation water source has pronounced effects on soil quality. The concentrations of other properties such as CEC, OM, TN, and AP show significant variation among treatments, and their values showed an increasing trend over time. Moreover, higher values for these parameters were observed under managed fields. This suggests that irrigation water management practices can play an important role to maintain soil fertility. The SAR and ESP values during the study period showed significant variations among treatment. This also confirms that management practices and irrigation water sources have a meaningful impact on soil quality in the area. Hence, paying attention to improved management practices and quality of groundwater is very important to run agricultural practices in a sustained manner. In general, almost all studied parameters showed remarkable variation with time and in the future, both soil and water should be tested systematically to assess salt build-up under irrigated fields.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Determinants of fish consumption in the state of Qatar: Post blockade

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This study used a count data model to analyse the factors that affect fish consumption in Qatar after the blockade; aiming for effective evaluation, formulation and implementation, of policies for the fishery sector. To achieve this, the community of Qatar is divided into three groups based on their fish consumption rate: high, moderate, and low consumer. The determinants of fish consumption were confirmed using the Poisson model, namely demographic and attitude variables. The findings showed that consumption rates were high (90%); both Qataris and White-collars belonged to the moderate consumers group (52 and 41%, respectively), while Blue-collars occupied the larger portion of the highest consumer category (36%). Fish consumption determinants in Qatar with positive effect included employment, health awareness, and number of children; in contrast, negative determinants included higher level of education, high price, and accessibility to purchase fish. The study is the first to focus on socio-economics and attitudinal variables to understand the factors that determine fish consumption that in turn, encourages policy formulation. The study supports the government policy to open foreign investment opportunities to meet consumption demands and preserve marine resources. Furthermore, managers may use information on fish species to manage fish stock, especially identifying fish species that are highly consumed. They will therefore formulate the necessary policies for sustainable marine fishery.

Key words: Marine, consumption, Qatar, blockade, tilapia, sustainability.

INTRODUCTION

Fish is a protein-rich food for both humans and animals and a source of fish oil and omega 3, which help treat some diseases such as high blood pressure, asthma, arthritis, psoriasis, and some cancers (Larsson and Orsini, 2011; Van Gelder et al., 2007; Maciel et al., 2019). Globally, the demand for fish consumption continues to increase due to an increased population, thus putting pressure on the carrying capacity of the seas to sustain provision of fish. According to the Food and Agriculture Organization (2018), third of the world's fish face extinction and fish consumption from marine and aquaculture sources increased exponentially to 20.3 kg/ year between 2011 and 2016.

The Persian Gulf region is not different from the rest of

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the world: according to Second National Development Strategy 2018-2022, Qatar marine resources are facing demand pressures, owing to overharvesting. As a result, some agricultural systems such as aquaculture have been developed to meet the high demand (Planning and Statistics Authority (2019b). Aquaculture is a food production method invented to support the marine resources that are under high-pressure of human consumption. Aquaculture witnessed a rapidly growing and significant source of sustainable food (Little, 2016). Many countries depend on aquaculture to meet the high demand of fish; however, aquaculture is also facing some challenges, including the risk of disruption of the natural habitat of the fish caused by the technology, since most aquaculture enterprises are established at the coast. However, when aquaculture cages established offshore in the sea it can be more beneficial (Klinger and Naylor, 2012).

The main drivers of the decision to consume fish are studied empirically worldwide that include some demographic and attitude factors. Some of demographic factors are gender, age, number of children, income level, educational level, employment status, regions and national policies (Verbeke and Vackier, 2005; Can et al., 2015; Pieniak et al., 2008; Zhou, 2015). Attitude factors include health awareness, fish taste, preference for specific fish species, fresh versus frozen, fish price and some certain national policies that related to training, advertising and different marketing strategies are all found to be important in studying fish consumption (Brunso et al., 2009; Zhou et al., 2015; Brunso et al., 2009; Thong and Olsen, 2012; Leek et al., 2000).

Studies on fish consumption are essential in the context of Qatar owing to the impact that fish has on human wellbeing from social, economic and environmental perspective. The country endeavours to achieve food security and self-sufficiency, especially after the blockade by launching food security strategies aimed at 90% self-sufficiency in fish production. From economical perspective, studies on fish consumption will help in the estimation of the local demand, thereby identifying the gap between production and import. In addition, it will help managers to gain insight into some socio-economic characteristics and attitudes of the sector, which will ultimately assist in improving both consumers' satisfaction and markets. From environmental point of view, managers will be able to manage fish stock by using the insights acquired from these studies on fish consumption. In particular, they will be able to identify fish species that are under pressure of high demand. As a result, they could formulate the necessary policies pertaining to sustainability of fish.

In Qatar, however, there are few and outdated publications in fish consumptions attitudes. Therefore, this study may serve as an updated publication to help the government formulate policies pertaining to the production, consumption, import, and export of fish. Moreover, better understanding of consumers' preference and attitude towards consuming fish is very important for formulation, implementation, and evaluation of policies related to fishery sectors. In this study, we therefore aim to highlight some socio-economic characteristics of fish consumption in the state of Qatar and to measure the fish consumption rate.

Background of Qatar marine and aquatic resources

Qatar is characterized by the highest economic growth in the world. The fishery sector in Qatar is generally artisanal in nature, but grown remarkably in the last decade. According to food security strategy 2018-2023, in 2020, self-sufficiency in fish products in Qatar is estimated at 74% and the average annual consumption is about 22.3 kg per capita, roughly the same as the world average. The sector employs a significant number of employees from Asian countries (Fishery Annual Statistics State of Qatar Book, 2017).

Fishing equipment is of two types: outboard-powered fiberglass vessels and traditional 'dhows'. The most frequently used equipment include traps (*Gargoor*), followed by gillnets, hand and troll lines, in addition to seasonal trolling and hand lining. Qatar owns ships on which the labour force comprises expatriates from different Asian countries, such as India, Bangladesh, and Iran (Fishery Annual Statistics State of Qatar Book, 2017).

Economic fish species by local names include *Ghirsh, Shaari, Kanaad, Hamour, Safi Arabi,* and *Kofer*. Local and scientific names are listed in Table 1 in the Appendice.

Qatar communities buy fish from both supermarkets and traditional fish markets. The main fish market, 'Um Salal' has been recently opened as a main fish market for better services.

Fish management in Qatar is based on, vessel and gear fishing licenses, but there is no limit on the quantity of catches per day.

High consumption of fish puts some species under pressure of over-fishing; the government has put a limit on wild fish production at 14 000 tons per year to alleviate the pressure. In contrast, the national annual demand sits at approximately 21 000 tons; therefore, the government plans to increase aquaculture production from the current 1 000 tons seen in summer 2019 to 6 000 tons (Lund, 2019).

Marine aquaculture has just been implemented recently in Qatar. The country endeavours to achieve self-sufficiency through fish supply within five years (2018-2023); hence, a number of floating cage fish farming and Shrimp farming projects have been established. The production will include various fish species such as *shrimp, tilapia,* and *hamour*. As highlighted in its national development strategy, Qatari government aims to increase the self-sufficiency ratio of fish stocks to 65% through advanced fish farms by 2023. According to the Ministry of Municipality and Environment’s food security strategy 2018-2023, the government is planning to license six offshore cage aquaculture projects covering 270 ha of marine water area. *Tilapia* is the main fish species produced from these farms because of its high adaptability to harsh environments. In addition, it is a new freshwater species to the community; hence, studies on *tilapia* demands are essential to provide a suitable supply (Ministry of Environment and Municipality, 2020).

Over the last two years, the government has embarked on a mission to diversify its economy, increase self-sufficiency in the food sector, and establish free zones and other regulatory schemes to attract foreign investment. These endeavours create a new marketing strategy to attract investors and commercialize the sector to yield better rewards for the economy (Ministry of Municipality and Environment, 2020; Planning and Statistics Authority, 2019a).

MATERIALS AND METHODS

Fieldwork and data description

Many empirical studies collected data by using different methods, such as face-to-face surveys in the case of Vietnam and six qualitative focus group discussions in Spain and Belgium. Data were also collected through a quantitative cross-sectional consumer survey carried out in five European countries: Belgium, Denmark, the Netherlands, Poland, and Spain (Thong and Olsen, 2012; Brunsø, 2009; Pieniak et al., 2008). Moreover, different econometric models have been used to suit the different ways in which fish consumption rate is measured.

In this study, we used the data that the Social and Economic Survey Research Institute (SESRI) at Qatar University conducted in its fourteenth Qatar Semi-Annual Survey (QSAS) in May 2019. SESRI collected data for the QSAS via computer assisted telephone interviewing (CATI) method and uses scientifically grounded sampling and interviewing methodology to provide valuable information to decision-makers, politicians, scholars, and students about the general opinion of the three main groups of residents in Qatar (Qataris, white-collar and blue-collar workers). Qatar has a very diverse population that is classified into three population sub-groups, Qataris, white-collar expats and blue-collar workers. The first sub-group of the population are Qataris, who are the citizens of the state of Qatar. The other two sub-groups of the population, white-collar expats and blue-collar workers, are those who are working temporarily in Qatar and they are grouped according to their skill and income levels. The former are skilled professionals, while the latter are characterized by being male low-skilled workers. During the survey administration, the sub-groups of the population are determined by a series of income and nationality questions that sets the specific sub-group. The survey consisted of 2 335 completed telephone interviews conducted across the three segments of the Qatari population (Qataris (677), white-collar (821) and blue-collar workers (837)). Interviews were conducted by trained and experienced interviewers from both the SESRI call centre and a research facility located at Qatar University.

Some demographic variables included resident type, income, gender, marital status, employment, number of children and education. These demographic variables are of importance to our study as they describe the respondent type and they affect their attitudes towards specific issues. Other attitude variables include consumption frequency, preferred fish (local versus import), price of fish, health awareness, and cooking time to prepare fish. Attitude variables also include the factors affecting the purchase of fish and the reason for buying from a specific market. An assessment of willingness to consume the fish species *tilapia* if it were to be produced locally is also included in the survey.

Specification of empirical model

The dependent variable in this study is a positive discrete number ranging from 1 to 40, measuring the number of times people consume fish during a month. The study intends to achieve three objectives. The first is to study the fish consumption rate in general and divide consumers according to their consumption rate. The second is to identify the determinants of fish consumption in Qatar. Finally, to measure the extent to which Qataris accept and consume the emerging fish species *tilapia* which was introduced recently to Qatar.

To achieve our objectives mentioned earlier, we had to define an arbitrary cut-off point to separate the consumption rate into low consumption (LC: 1 to 3 times a month), medium consumption (MC: 4 to 8 times a month), and high consumption (HC: more than 9 times a month). Consumers were asked about the number of times they consumed fish during a month. They were classified accordingly into LC, MC, and HC.

International institutions, such as Institute of Medicine (IOM), Food and Agriculture Organization of the United Nations (FAO) and World Health Organization (WHO), recommended that fish should be consumed regularly at least twice a week in order to reach benefits and can be a protective factor against heart diseases (Hellberg et al., 2012).

RESULTS AND DISCUSSION

Descriptive analysis

Table 1 shows that fish consumption in Qatar is highly secured and the fish products are affordable, fresh, healthy, and tasty, meeting all indicators of food security. Out of the ten commercial fish species available, Qataris prefer to consume only four of them: *hamour, Safi Arabi, kanaad,* and *shaari.* Interestingly, these are the same fish species that are preferred by other resident types but at different rate as presented in Table 2 in the Appendice.

All community categories in Qatar show a very high level of health awareness about the health benefits of consuming fish, especially in development of children’s brains. They are also fully aware of fish being an important source of omega 3, but when asked about what omega 3 is, only 62% Qataris, 52% expatriates and 27% of labourers knew that omega 3 is essential healthy fats. The study also measures the willingness of the Qatari community to consume *Tilapia* as emerging species by asking them a hypothetical question about the willingness to consume *tilapia* if produced locally. This question

Table 1. Factors affected the purchase of fish in the state of Qatar.

Variable	Percentage
It is healthy	27
Easy to prepare	5
Like the taste	18
Affordable and fits budget	18
Always fresh and good quality	32

Table 2. Willingness to consume *tilapia* by resident type.

Variable	Yes (%)	No (%)
Qataris	50	50
White-collar workers	64	36
Blue-collar workers	69	31

comes in line with the Qatar strategy to produce *tilapia* for the first time as aquaculture products. We found that a significant number of community members (65%) are willing to consume it, while 35% are not.

Cross tabulation by respondent type in Qatar

The rate of fish consumption in Qatar is very high (90%); with Qatari (52%) and white-collars (41%) as MC and 36% of blue-collars are found to be HC.

The cross tabulation showed the difference among fish consumption typology concerning education, employment, and the willingness to consume fresh local fish as presented in Table 3 in the Appendice. Among all respondents, blue-collar workers reported the highest fish consumption compared to Qataris and white-collar workers. Moreover, the frequency of consuming fish increased with education and preference to consume local species for moderate consumers. White-collar workers and Qataris prefer local fish, while blue-collar workers prefer imported fish. This may be because of lower prices and willingness to consume species found in their home countries, such as freshwater fish.

Tilapia demand was further analysed by resident type; Table 2 explains the willingness to consume *tilapia* by different types of residents. We found that Qataris were divided into two equal categories in terms of willingness to consume *tilapia*. Both white-collar and blue-collar workers show willingness to consume *tilapia*.

Empirical results

Empirical studies on fish consumption generally concentrate on demographic and attitude variables of fish consumption determinants. The demographics factors play a vital role in influencing fish consumption, such as gender, age, number of children, income, educational level, and region (Verbeke and Vackier, 2005; Pieniak et al., 2008; Can et al., 2015; Brunsø et al., 2009; Zhou et al., 2015).

On the other hand, attitude factors include health awareness, knowledge about the health benefits of eating fish and the importance of fish for children's brain development. Moreover, if consumers preferred fresh fish to frozen fish or preserved imported fish. Perceived price of fish, fish preparation and cooking time are also some other attitudinal factors affecting fish consumption (Leek et al., 2000; Can et al., 2015; Thong and Olson, 2012; Brunsø et al., 2009; Zhou et al., 2015).

To investigate the determinants of fish consumption in Qatar, the study applied the Poisson estimation technique. The most common feature of the count data model is that the variables are discrete or non-negative and no monotonic transformation in the data. However, the study used the Poisson model because of the characteristic of the data that support the Poisson distribution through the maximum likelihood (Payne et al., 2015). Moreover, the dispersion between the mean and the variance is small as shown in Table 3.

Notable variation in observation numbers existed, particularly in the demographic variables such as age. The descriptive statistics indicated that Poisson estimation method is ideal for exploring the determinants of fish consumption. The dispersion in the data seems quite plausible, particularly, the unconditional mean and the variation measured by the standard deviation.

The following equation explains the possible determinants of fish consumption:

Table 3. Descriptive statistic for variables used in Poisson model.

Variable	N	Mean	Std. Dev.	Min	Max
Fish consumption	2 135	9.550	16.247	0	97
Awareness	2 135	0.443	0.497	0	1
Price	2 008	0.119	0.323	0	1
Gender	2 316	3.462	0.843	3	5
Marital Statues	2 311	1.314	0.537	1	3
Occupation	792	5.794	4.630	-9	15
Child Number	1 752	2.219	0.658	1	4
Education	2 312	2.168	0.756	1	3
Inaccessibility	2 008	0.532	0.499	0	1

Table 4. The estimated results of the Poisson model.

Variable	Poisson estimation method	z	P-value |z|
Occupation	0.0645*** (0.00700)	9.22	0.000
Awareness	0.351*** (0.0905)	3.88	0.000
Age	-0.358*** (0.0466)	-7.67	0.000
Price	-2.515*** (0.412)	-6.10	0.000
Gender	0.361 (0.224)	1.61	0.108
Marital Status	-0.224 (0.181)	-1.24	0.216
Child Number	0.132* (0.0724)	1.83	0.067
Education	-0.852*** (0.0897)	-9.50	0.000
Inaccessibility	-1.671*** (0.0763)	-21.89	0.000
Constant	4.229*** (0.584)	7.24	0.000
LR Chi^2 (9)	774.65	-	-
Prob > Chi^2	0.0000	-	-
Pseudo R^2	0.4096	-	-

$$logFishCon_i = \propto + \beta Occu_i + \beta Awrn_i + \beta Age_i + \beta fishPrice_i + \beta Gen_i + \beta Marit_i + \beta Child_i + \beta Educ_i + \beta Inaccess_i + \mu_i \quad \ldots\ldots\ldots\ldots\ldots\ldots \tag{1}$$

where $\boldsymbol{logFishCon_i}$ denotes the amount of fish consumption per month for the individuals (i). The natural logarithm is used for linear transformation; $\propto$ represents the constant; $\boldsymbol{\beta}$ denotes the coefficients of independent variables. The independent variables include the category occupation ($\boldsymbol{Occu_i}$), individual awareness about the health value of consuming fish ($\boldsymbol{Awrn_i}$), the age ($\boldsymbol{Age_i}$), fish price $(\boldsymbol{fishPrice})_i$, gender ($\boldsymbol{Gen_i}$), the category of marital status $(\boldsymbol{\beta Mart})$, number of children $(\boldsymbol{child})$, education level $(\boldsymbol{\beta edu})$, and accessibility to the fish market ($\boldsymbol{\beta Access}$). μ_i is the error term.

The poison model specified earlier was fitted to the data described in Table 3 and estimation results are presented in Table 4. As mentioned earlier, the dependent variable "fish consumption rate" is discrete or non-negative ranging from 1, 2, 3…to 40. Error statistics indicate a good statistical fit of the model. Demographic variables have the expected signs and together with the attitude factors, their influences have high statistical significance. On the other hand, except of gender and marital status, influences of demographic variables were significant. Results suggest that the fish consumption rate decreases with higher level of education, high price, and accessibility to purchase fish and increases with employment, health awareness, and number of children.

Results also showed that, age has a negative and significant impact on the amount of fish consumed per month in the state of Qatar. The impact of age could be attributed to the fact that fish consumption is very important for the development of the children brain. That is, it may be explained by, the level of health awareness that has a significant and positive effect on fish consumption.

The strong and negative relationship of the price of fish in Qatar and the amount of fish monthly consumed by the individuals aligned with the economic theory and consumer's rationality. This negative relationship could be attributed to the substitution effect caused by the low price of the other type of meat, for example, chicken. The fish consumption rate though increases with the number of children, shows low insignificant level which, may be influenced by the effect of price on the consumption rate.

The findings of this study agreed with those from other researcher for instance, the awareness of health benefits of fish are also found to be positive and significant (Verbeke and Vackier, 2005; Pieniak et al., 2008; Brunsø et al., 2009; Zhou et al., 2015; Can et al., 2015). However, while Can et al. (2015) study showed similar results in age groups, Verbeke and Vackier (2005) in their study showed that increasing age would influence fish consumption positively.

Both Brunsø et al. (2009) and Sayin et al. (2010) showed that price decreases the amount of fish consumed. However, a study conducted in Vietnam showed that fish prices are not expensive and there is high availability of fresh fish in Vietnam (Thong and Olson, 2012).

The significant and positive relation of occupation and the amount of fish consumed per month is further analysed by gender in other study. For instance, Zhou et al. (2015) showed that fish consumption for women in work would be less than non-working women because working-women will have less time for cooking, thus their consumption would decrease (Zhou et al., 2015).

Conclusion

Qatar fishery resources, including those in aquaculture systems, are an important sector for development. There is significant pressure of HC on some commercial species, such as *hamour*, *kanaad, shaari,* and *Safi Arabi*, by the entire Qatar community; this could affect diversity of fish and lead to their extinction. Fish is a very important renewable resource; it can be used for economic diversification, as opposed to oil, which is non-renewable. Qatar has particularly been paying attention to marine resources after the blockade.

This study applied different econometric techniques to analyse the determinants of fish consumption in Qatar: demographic (education, employment, and number of children in household) and attitude variables such as preference of fresh fish, price of fish, and accessibility to buy fish. High fish consumption rates were observed (90%) and the consumption rate was divided into three categories: HC, MU, and LC. The frequency of fish consumption is further analysed according to the resident type (Qatari, white-collar, and blue-collar workers). Among all respondents, blue-collar workers had the highest fish consumption (36%) within HC, compared to Qataris and white-collars (52 and 41%, respectively) ranked as MC. Clear differences between categories are found with regard to demographics variables of consuming fish such as occupation, education level, and the preference to consume local as opposed to imported fish species. White-collars and Qataris prefer local fish while blue-collars prefer imported fish. The willingness to consume the aquaculture product *tilapia* is also analysed. Both white and blue-collar workers have enough knowledge about *tilapia* and are willing to consume it. In contrast, 50% of Qataris are not willing to consume *tilapia*.

Among fish consumption demographic determinants, employment, education, age, and number of children are found to be the most important determinants compared to marital status and gender. These results are consistent with widely observed findings in the literature. The findings further indicate the reduction in food consumption in the elders' group.

The study also confirms the importance of attitude determinants such as health awareness, accessibility to buy fish, and price being highly statistically significant. The community of Qatar is aware of the fact that fish consumption is good for health. However, their consumption decreases with the increase in price, which makes them shift to alternative protein.

Rational and scientific exploitation of the fisheries in Qatar by adapting a management regime that can assure both increase in production and management of stock in a sustainable way is very important; this will also ease the change from the artisanal nature of fishing to a more commercialized sector, which will help diversify the economy. Finally, a health awareness campaign is necessary to increase the fish consumption rate of other species generally facing low demand. This is especially important to safeguard fish biodiversity. A strategy that concentrates on increasing the consumption of low demanded species, such as creating more marketing channels or process them into other fish products, is vital.

Future research may focus on fish supply chain evaluation and possible development. Moreover, research on fish waste treatment and sustainable food production systems are highly required in the state of Qatar. This can explain the possibility of using fish compost to fish/chicken feeds and invest on sustainable food production systems.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Growth, nodulation and yield response of green bean (*Phaseolus vulgaris* L.) to plant population and blended NPS fertilizer rates at Alage, Central Rift Valley of Ethiopia

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Recently Green bean production and demand is increasing in Ethiopia due to its fast maturity and nutritional value. However, various constraints are reported for its low productivity, including inappropriate uses of plant population and fertilizer rates. The objective of this study was to determine the optimum plant population and NPS rate for quality and economically feasible yield of Green bean. The experiment was conducted in field conditions at Alage, Central Rift Valley of Ethiopia, under supplemental irrigation in 2019. A factorial combinations of three plant populations (222222, 250000 and 333333 plants ha^{-1}) and five levels of blended NPS (0, 132, 142, 152 and 162 kg NPS ha^{-1}) were used in a randomized complete block design (RCBD) with three replications. Number of nodules per plant, number of effective nodule per plant, number of leaf per plant, plant height, and number of branches per plant, number of pod per plant, total above ground fresh biomass, pod diameter, pod length, harvest index and yield per plant and per hectare were recorded. All parameters were subjected to analysis of variance. The least significant differences (LSD) at the level of 5% significance were used to compare the treatments mean. The results showed that plant population and NPS rates had significant effects on number of nodules, number of leaf, number of branch, plant height, number of pod, pod length, harvest index, yield per plant and per hectare. The highest Green bean yield of 13.75 tons ha^{-1} and 16.06 tons ha^{-1} was obtained at the highest plant population (333333 plants ha^{-1}) and the highest NPS rate (162 kg NPS ha^{-1}), respectively. The highest acceptable marginal rates of return (57349%) and (6997.2%) were obtained from 333333 plants ha^{-1} and 162kg NPS ha^{-1}, respectively. Thus, it can be concluded that 333333 plants ha^{-1} and application of 162kg NPS ha^{-1} were gained the superiority for both agronomic and economic growth and productivity for plati variety of Green bean under supplementary irrigation at Alage area.

Key words: Green bean, plant population, NPS fertilizer rate, growth, yield.

INTRODUCTION

Green bean (*Phaseolus vulgaris* L.) is the strain of common bean which is grown for its unripe freshly eaten fibreless succulent pods (Abate, 2006; CIAT, 2006). It is widely cultivated in the world due to its contribution to soil fertility through nitrogen fixation (Demelash, 2018); and having high market value and protein (Damián et al., 2013; Celmeli et al., 2018). In Ethiopia, it is one of fresh legume vegetables grown for export market (Alemu et al., 2017), and domestic consumption in a variety of dishes (Dessalegn et al., 2006). Globally, green bean is cultivated over an area of 1.5 million hectare with a production and productivity of 22.83 million tons and 15.22 tons ha^{-1}, respectively. China is the leading producer of green bean, with 40% of area (0.57million ha) and 18.69 million tons (81.9%) of production followed by India and Indonesia (FAO, 2016). In Ethiopia, its production in the past five years (2013-2017) increased from 6200 to 7384 tons (FAO, 2017).

Green bean productivity could be raised through the use of improved varieties and agronomic practices including type, rate of fertilizers, spacing and crop protection (Mulugeta, 2011). On the other side, poor agronomic practices like low soil fertility, untimely and inappropriate field operations, erratic rain fall, drought, diseases, weed and insect could be a cause for low productivity (Chekanai et al., 2018). Limited production and productivity of common bean in Ethiopia is attributed to several production constraints, which include lack of improved varieties for the different agro-ecological zones, poor agronomic practices such as low soil fertility, untimely and inappropriate field operations (Mulugeta, 2011).

According to Wortmann (2006), the deficiency in N and P is the major constraint of common bean production, and responsible for the loss of grain yield up to 1.2 million tons in Africa. Production of crops using sulfur containing fertilizer enhances concentration of sulfur-rich proteins, cysteine and methionine (Pandurangan et al., 2015). Total number of nodules and active nodules increased with the increase in application of S up to 20 kg ha^{-1} (Ganeshamurthy and Reddy, 2000). In addition sulfur assimilation and nitrogen fixation is interdependent (Kalloniati et al., 2015). Pod fresh weights of green bean could increase from the application of sulfur containing fertilizer (Kovács et al., 2013). Girma (2016) also found that low soil nitrogen and phosphorus levels, and acidic soil conditions are important constraints for bean production in most cropping areas of Ethiopia.

Moreover, keeping appropriate plant population under prevailing resource and suitable agro-ecological condition can also increase green bean yield. In order to produce high dry matter as a result of intercepted solar radiation, crop has to cover the soil as early as possible (Abu et al., 2016), and the net light absorbed to be converted to dry matter of well-spaced plant is usually high (Snowden and Bruce, 2015). According to Chakravorty et al. (2009), closely spaced green bean attains maximum height, minimum number of branches and leaves per plant but the total pod yield obtained per hectare increases as a result of increased plant population per a given area. However, irrespective of the growing conditions and locations, 142 kg NPS ha^{-1} and 250000 plants ha^{-1} (40cm x 10cm) has been recommended for the crop (MoANR, 2016). The variation in plant population and NPS fertilizer rates with environment and variety calls for area-specific recommendation. The Central Rift Valley area of Ethiopia, including Alage is a suitable belt for the production of green bean for export and domestic markets. Research based recommendations on plant population and NPS fertilizer rate could increase productivity of the crop and increase the benefits of the growers in the area. Therefore, the present study was undertaken to determine the optimum plant population and NPS rate to obtain the highest yield of green bean for Alage area, representing the Central Rift Valley area of Ethiopia.

MATERIALS AND METHODS

Description of the study area

The study was conducted at Alage ATVET College during 2019 cropping season. The site is located 217 km south of Addis Ababa and 32 km west of Bulbula town at the coordinates of 7° 65'N and 38° 56'E at 1600 m above sea level, in the agro-ecology of dry plateau of the central rift valley of Ethiopian. The area has bimodal rainfall pattern where the short rain occurs during March and April and the main rain from June to September. The highest amount of rainfall is obtained in July and August with the annual rainfall of 800 mm. The mean annual minimum and maximum temperatures of Alage area are 11 and 29° C, respectively. The land is having sandy loam to sandy clay loam with some clay loam and few clay soils (Eylachew, 2004).

Description of treatments and design

The factorial combination of three plant populations (*222222* plants ha^{-1} from 30 cm x 15 cm spacing, 333333 plants ha^{-1} from 30 cm x 10 cm spacing and 250000 plants ha^{-1} from 40 cm x 10 cm spacing) and five blended NPS fertilizer rates (0, 132, 142, 152 and 162 kg ha^{-1}) were considered as treatments in the experiment. The amount of nitrogen, phosphorus and sulfur, corresponding to each rate of NPS fertilizer is shown in Table 1. Fifteen treatment combinations were laid in randomized complete block design (RCBD) with three replications. The gross plot size was 3.6 m × 2.4 m (8.64 m^2); with 12 and 9 rows in 30 and 40 cm inter-row spacing, respectively. There were 24 and 16 plants in each row with intra-row spacing of 10 and 15 cm, respectively. The outermost one row from one side and two rows from the other side for 40 cm inter-row and two rows from both sides for 30 cm inter-row spacing were considered as the border rows. The blocks were separated by 1.5 m width whereas the space between each plot within a block was 1.2 m. In accordance with specifications of the design, each treatment was assigned randomly to experimental units within a block. Plati variety of green bean seed having high yielding potential than the variety under production before (BC 4.4) was used as test crop in this

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Table 1. NPS fertilizer rate (kg ha-1) and corresponding nutrient content (kg ha^{-1}).

NPS (19% N, 38% P and 7% S) rates (kg/ha)	Nutrient contents of NPS (kg/ha^{-1})		
	Nitrogen	Phosphorus	Sulfur
132	25.08	50.16	9.24
142	26.98	53.96	9.94
152	28.88	57.76	10.64
162	30.78	61.56	11.34

experiment. This variety was released in 2016 by Melkassa Agricultural Research Center (MoANR, 2016).

Experimental procedures and crop management

The seeds of green bean plati variety were generously provided by the Melkassa Agricultural Research Center. The experimental site was ploughed and leveled by tractor on January 30, 2019. After laying out the site by spacing of 1.5 m and 1.2 m between blocks and plots, respectively, ridges were prepared manually on February 12, 2019 and then the seed was sown on February 21, 2019 at 5 cm depth based on the treatment decided for population density study. The calculated amount of NPS fertilizer for each experimental unit was applied in band method of application at the time of sowing. The research work took three months to complete till final harvesting on May 5, 2019. Beside all of these practices of treatments, uniform field management such as disease, weed and insect control, watering and other cultivation practices were done for all plots as per recommended for the crop (EARO, 2016).

Data collection

The effect of plant population and blended NPS rate on green bean was investigated by measuring growth, yield and yield component parameters data. Growth data include (plant height, leaf number and number of branch per plant) were taken in each plot from ten randomly selected plants at physiological maturity stages. Number of nodules and number of effective nodules were collected from the bulk of roots of 5 randomly selected plants by distractive sampling from each plot at 50% flowering. Effectiveness of the nodules was determined after cutting the nodules by the inside color they exhibit (determined pink as effective and cream white as ineffective). Nodules for each category were counted and presented as the percentage of the total. Yield component parameters (number of pods per plant, pod diameter, pod length, yield per plant and hectare) were recorded from the central rows of each plot and converted into yield per plant (kg plant^{-1}) and yield per hectare (tons ha^{-1}). Above ground total fresh biomass (kg plant^{-1}) was obtained by summing up the weighed crop residues and yields. Harvest index was determined as the ratio of horticultural matured yield to total above ground fresh biomass yield from the rows of net plot area and converted into percentage.

Soil sampling and analysis

Pre-planting soil samples were taken randomly using a zigzag model from the experimental plots at the depth of 0 to 30 cm before planting. Fifteen soil core samples were taken by an auger from the whole experimental field and combined to form a composited sample in a bucket. Then, the collected samples were air-dried at room temperature under shade and ground to pass through a 2 mm sieve for laboratory analysis of soil pH, and available phosphorus. Small quantity of 2 mm sieved soil material was received through 0.2 mm sieve for soil organic carbon (OC) and total nitrogen. The composite soil samples were analyzed for selected physicochemical properties mainly textural analysis (sand silt and clay), soil pH, total nitrogen (N), available sulphur (S), organic carbon (OC), available phosphorus (P), cation exchange capacity (CEC) (c mol kg-1), exchangeable potassium, magnesium and calcium using the appropriate laboratory procedures at the Soil and Water Analysis Laboratory of Horticoop Ethiopia (Horticultural PLC). Soil textural class was determined by Bouycos Hydrometer Method. Electrical conductivity of the soil was measured in water suspension with soil to water ratio 1:5 (W/V) by electro-conductivity meter method (Slavich and Petterson, 1993). Organic carbon was estimated by wet digestion method and organic matter was calculated by multiplying the organic carbon % by a factor of 1.72 (Walkley and Black, 1954). The soil pH was measured potentio-metrically in 1:2.5 soil-water suspensions with standard glass electrode pH meter (Van Reeuwijk, 1992). Cation Exchange Capacity was determined by leaching the soil with neutral 1 M ammonium acetate. Total nitrogen was determined by treating the sample with a mixture of concentrated sulfuric acid and digestion catalysis following the modified Kjeldhal method (Okalebo et al., 2002). Available phosphorus was determined by Olsen's method (Olsen and Sommers, 1982). Available sulfur was measured using turbidimetric method (Okalebo et al., 2002). Available potassium was measured by 1 M ammonium acetate method (Mehlich, 1984). The Physico-chemical properties of the experimental site soil before planting are shown in Table 2.

Data analysis

The results were analyzed using analysis of variance techniques (SAS, 2002) and mean separation was based on LSD at 5% level of significance. Simple partial budget analysis was made for economic analysis of optimum pod size with appropriate intra-row spacing. The economic analysis was calculated following the formula developed by CIMMYT (1988).

Partial budget analysis

Partial budget analysis was employed for economic analysis of fertilizer application and seed rate. The potential response of crop towards the added fertilizer and seed sown corresponding to fertilizer and seed price ultimately determine the economic feasibility.

According to CIMMYT (1988), the marginal rate of return (MRR), which refers to net income is obtained by incurring a unit cost of fertilizer, seed rate and labor. The net benefit (NB) was calculated as: $NB = (AY \times P) - TVC$, when, $APY \times P$= Gross Field Benefit, AY= Adjusted yield and P= green bean price

The actual yield was adjusted downward by 10% to reflect the

Table 2. Physico-chemical property of experimental site soil before planting

Soil property	Value	Rating
Soil textural properties		
Sand (%)	37.81	-
Silt (%)	42.41	-
Clay (%)	19.78	-
Textural class of soil	-	Loam
Soil chemical properties		
Electrical conductivity (ECe) (dS/m)	2.214	-
Cat-ion exchange capacity (cmol (+)/kg soil)	28.02	High
Organic carbon (%)	1.49	Medium
PH (H_2O) (W/V)	8.26	moderately alkaline
Total nitrogen (%)	0.13	Low
Available phosphorus (mg/kg (ppm))	14.53	Medium
Available sulfur (mg/kg (ppm))	29.43	Sufficient
Available potassium (mg/kg (ppm))	479.03	-

dS/m = decisiemens/meter, ppm = parts per millennium, mg/kg = milli gram/kilogram, W/V = weight of soil/volume of water, cmol = centimole/kilogram.

difference between the experimental yield and the yield farmers could expect from the same treatment. The dominance analysis was used to select potentially profitable treatments. The discarded and selected treatments were called dominated and un-dominated treatments, respectively. For each pair of ranked treatments, % MRR was calculated using the following formula:

$$\text{MRR (\%)} = \frac{change\ in\ NB\ (NBb - NBa)}{change\ in\ TVC\ (TVCb - TVCa)} \times 100$$

NBa = NB with the immediate lower TVC, NBb = NB with the next higher TVC, TVCa = the immediate lower TVC and TVCb = the next highest TVC. The % MRR between any pair of un-dominated treatments was the return per unit of investment in fertilizer and seed rate. Thus, a MRR of 100% implied a return of one Birr on every Birr spent on the given variable input.

RESULTS AND DISCUSSION

Effect of plant population and blended NPS fertilizer rates on growth parameters of green bean

Number of leaves per plant

Number of leaves per plant of green bean was significantly (P≤0.001) influenced by plant population. The highest (83.92) number of leaves per plant was achieved using 222222 plants per hectare which, however, was statistically similar with 250000 plants population; the lowest (71.24) number of leaves per plant of green bean was recorded using 333333 plant population per hectare (Table 3). Blended NPS fertilizer rates had highly significant (P ≤ 0.001) effect on number of leaves per plant of green bean. The highest number of leaf per plant (87.63) was recorded from the highest (162 kg/ha) NPS rate and it was statistically similar with 142 and 152 kg/ha NPS rates. The lowest number of leaf per plant (67.04) was recorded from the control (0) treatment and it was statistically similar with 132 kg/ha NPS rate (Table 3). Interaction effect of plant population and blended NPS rate on number of leaves per plant was not significantly different.

From the above presented data, there was a progressive decrease in number of leaf per plant with increases in plant population from 222222 to 333333 plants population per hectare (Table 3). This result is in agreement with the finding of Gebremedhin (2015) who reported that as plant population increased and number of leaves per plant of haricot bean decreased. Increasing rates of blended NPS fertilizer from 0 to 162 kg ha^{-1} also showed progressive increase in number of leaves per plant of green bean (Table 3). This result is in agreement with the finding of Jaisankar and Manivannan (2018) who reported that number of leaves per plant increased with the increase of N and P ha^{-1}. This result could be attributed to the promotion of chlorophyll formation by nitrogen (Negash et al., 2018) and functional growth of new leaves and tissue by phosphorus and sulfur (Faegheh and Hashem, 2015).

Number of branches per plant

The data pertaining to number of branch per plant are given in Table 3 from which it is evident that number of branch per plant was highly significantly (P ≤ 0.001) influenced by plant population. Number of branch per plant of green bean in the present study ranged from 5.73 to 9.64 (Table 3). The highest (9.64) number of branch

Table 3. Effects of plant population and blended NPS fertilizer application rate on growth of green bean.

Treatment	Number of leaves per plant	Number of branch per plant	Plant height (cm)	Number of nodule per plant	Number of effective nodule per plant
Plant population (plants ha^{-1})					
222222	83.92^{a}	9.64^{a}	50.74^{c}	43.81	27.01
250000	83.28^{a}	8.64^{a}	58.11^{b}	36.62	26.32
333333	71.24^{b}	5.73^{b}	63.09^{a}	38.38	29.53
LSD (5%)	**5.49**	**1.15**	**3.3**	**NS**	**3.42**
NPS rate (kg ha^{-1})					
0	67.04^{b}	6.76^{c}	54.62	29.48^{c}	25.38
132	73.03^{b}	6.86^{bc}	54.07	35.49^{bc}	26.29
142	84.09^{a}	8.29^{ab}	58.03	43.45^{ab}	30.51
152	85.6^{a}	8.69^{a}	55.64	44.78^{a}	26.51
162	87.63^{a}	9.43^{a}	55.31	44.79^{a}	29.42
LSD (5%)	**7.08**	**1.49**	**NS**	**8.42**	**NS**
CV	**9.23**	**19.2**	**7.69**	**22.02**	**16.56**

Means followed by the same letters in the same column are not significantly different from each other at 5% level of significance.

per plant was obtained with the lowest plant population (333333) which, however, were statistically similar with 250000 plant populations. The lowest (5.73) number of branch per plant was obtained from the highest (333333) plant population (Table 3). Blended NPS fertilizer rates had significant (P ≤ 0.05) effect on number of branch per plant. The lowest (6.76) number of branch per plant was achieved at control treatment which, however, was statistically at par with 132 kg/ha of NPs rates and the highest (9.43) number of branch per plant were recorded on 162 kg/ha of NPs rates and it was also statistically similar with 152 kg/ha of NPs rates (Table 3). Interaction effect of plant population and blended NPS rate on number of branches per plant was not significantly different.

The number of branches per plant was also influenced by plant population and blended NPS fertilizer rates. This might be due to the presence of limited competition among plants for soil nutrients. Moreover, at the smallest plant population plants could intercept more photo synthetically active radiation owing to better geometric situation that might have resulted in vigorous plant growth and more number of branches. The result was in conformity with the findings of Almaz (2019) who reported that the highest number of branches per plant was obtained at the smallest plant population. In addition, Alemayehu et al. (2015) also reported that the higher number of branches with the smallest number of plant population per hectare. In this study, a progressive increase in the number of branches plant^{-1} was observed from increasing application rates of blended NPS fertilizer from 0 to 162 kg ha^{-1} (Table 3). The finding is in line with Shumi et al. (2018b) who reported that increasing rates of blended NPS fertilizer from 0 to 250 kg ha^{-1} showed progressive increase in the number of primary branches plant^{-1} of common bean.

Plant height

Plant population had a highly significant (P ≤ 0.001) effect on plant height. Increasing plant population from 222222 to 333333 significantly increased plant height. Plant populations with 333333 produced 24.34% higher plant height than the smallest (222222) plant population (Table 3). However, blended NPS fertilizer rates and its interaction with plant population had no significant effect (P> 0.05). Plant height was the lowest at small number of plant population, and increased with increasing plant population reaching maximum at the highest plant population (Table 3). Such effect was probably due to competition of plants in higher densities for light, resulting in taller plants. Similar findings were reported by Khalil et al. (2015), who indicated that the denser plant population increased the plant height of faba bean due to competition among plants. Moreover, Moniruzzaman et al. (2009) also reported that plant height increased from 43 to 44.5 cm (maximum plant height) with increase in plant density from 250,000 to 500, 000 plants ha^{-1}.

Number of nodules per plant

Blended NPS fertilizer rates had a significant (P ≤ 0.01) effect on the number of nodules per plant of green bean. As NPS fertilizer rates increased from 0 to 142, number of nodules also increased (Table 3); however, with further increase in NPS rates the change in nodule number was not significant. This might be due to better root development as a result of starter nitrogen supplement in

NPS form, while formation of number of nodules might be due to the role of P and S. This result is similar with finding of Shumi et al. (2018b) who reported an increase in number of nodules with the increase in blended NPS rates until it reaches 200 kg/ha. Plant population and its interaction with blended NPS rates were not significantly different on number of nodules per plant.

Number of effective nodules per plant

The number of effective nodules per plant of green bean was not significantly (P > 0.05) affected by plant population and blended NPS fertilizer rate (Table 3). The result is in agreement with the finding of Xuan et al. (2017) who reported that effectiveness of nodules was reduced with an increasing concentration of nitrogen fertilizer application.

Effect of plant population and blended NPS fertilizer rates on yield and yield components of green bean

Number of pods per plant

The analysis of variance showed significant (P≤0.05) effect of plant population and NPS application rate on number of pod per plant, while their interaction had no significant effect. With increasing plant population from 222222 to 333333 plants ha^{-1} there were progressive decrease in number of pods per plant. Thus, the highest number of pods per plant (85.76) was recorded at the lowest plant population (222222 plants ha^{-1}) and it was statistically similar with 250000 plants ha^{-1} (83.44), while the lowest (69.48) was recorded at the highest plant population (333333 plants ha^{-1}) (Table 4). Blended NPS fertilizer rate has significant (P≤0.05) effect on number of pods per plant. The highest number of pods per plant (96.44) was obtained at the highest rate of application (162 kg NPS ha^{-1}) and it was statistically similar with the number of pod per plant obtained at application of 152 kg NPS ha^{-1} but statistically at par with that recorded for 142, 132 and 0 kg NPS ha^{-1}, while the lowest number of pod per plant (60.29) was recorded for the unfertilized plot (Table 4).

Wide space between the plants resulted in decreased inter plant competition that in turn lead to increased plant capacity for utilizing the environmental inputs in building great amount of metabolites to be used in developing new growth components and increasing its yield components. The result is in agreement with the findings of Almaz (2019) who reported that the number of pods per plant increased from 24.2 to 32.1 with increasing inter row spacing from 30 to 50 cm (from higher to lower plant population ha^{-1}) and from 25.2 to 30.2 with increasing intra row spacing from 8 cm to 12 cm (higher to lower plant population ha^{-1}). Since the lowest number of pod per plant was recorded at the highest plant population per hectare, this difference might be attributed to higher competitions between plants for growth requirements which are capable to increase number of pod bearing branches that triggers high yield per plant.

Increasing application rates of blended NPS fertilizer from 0 to 162 kg ha^{-1} resulted in progressive increase of the number of pods per plant. The highest number of pods at the highest rates of NPS (162 kg ha^{-1}) might be attributed to the fact that NPS enhances establishment of beans, promote the formation of nodes, canopy development and pod setting and also the increase in number of pods with these levels might be due to various enzymatic activities which controlled flowering and pod formation. This result is in conformity with the findings of Shumi et al. (2018b) who recorded that, increasing application of blended NPS fertilizer from 0 to 250 kg ha^{-1} increased the number of pod plant^{-1} of common bean from 8.7 to 18.52. Moreover, Shumi et al. (2018a) noted that the highest (8.64) and lowest (6.45) number of pod per plant were obtained at 150 and 0 kg of P ha^{-1} in blended NPS fertilizer, respectively.

Pod diameter

Main and interaction effects of plant population and blended NPS fertilizer rates had no-significant (P > 0.05) effect on pod diameter of green bean (Table 4). This result is contrary to that of Munirazzaman et al. (2009) who noted that wider pod diameter was recorded at the smallest plant population. This might be because of using available growth inputs to produce dry matter which was equally partitioned to the reproductive part of green bean.

Pod length

Pod length of green bean was significantly (P ≤ 0.05) influenced by blended NPS fertilizer rates. The longest (14.72 cm) pod length was recorded at 162 kg/ha NPS fertilizer rate which, however, was statistically similar with 152 kg/ha NPS rates while the shortest pod length (13.27cm) was recorded from the control treatment; blended NPS fertilizes with other rates performed in between the two (Table 4). Plant population and its interaction with blended NPS fertilizer rate had no significant (P > 0.05) effect on pod length of green bean. The finding is in contrary to Munirazzaman et al. (2009) who obtained highest pod length at lower plant density.

Pod length was thus influenced by blended NPS fertilizer rates. Pod length was lowest at the control (0) treatment while it was highest at the highest NPS rates (Table 4). This could be due to the availability of sufficient N, P and S which ultimately increased the rate of photosynthesis by chlorophyll formation, and thus more photo-assimilate partitioned to its pod length. This finding is similar with Moniruzzaman et al. (2008) who reported

Table 4. Effect of plant population and blended NPS fertilizer rate pod characters of green bean

Treatment	Number of pod per plant	Pod diameter	Pod length
Plant population (plants ha^{-1})			
222222	85.76^{a}	8.39	14.04
250000	83.44^{a}	8.31	14.08
333333	69.48^{b}	8.29	13.83
LSD (5%)	**11.86**	**0.36**	**0.51**
NPS rate (kg ha^{-1})			
0	60.29^{c}	8.19	13.27^{c}
132	70.02^{bc}	8.19	13.79^{bc}
142	84^{ab}	8.39	13.87^{bc}
152	87.04^{a}	8.63	14.26^{ab}
162	96.44^{a}	8.25	14.72^{a}
LSD (5%)	**15.3**	**0.46**	**0.66**
CV	**19.92**	**5.7**	**4.9**

Means followed by the same letters in the same column are not significantly different from each other at 5% level of significance

that pod length was increased with the increase in N up to 120 kg/ha, S up to 20 kg/ha and 50 kg/ha of P_2O_5 (Jaisankar and Manivannan, 2018).

Green pod yield per plant

Pod yield per plant of green bean was significantly ($P \leq 0.05$) affected by plant population and it was in the range of 0.21 to 0.26 kg. Plant population with 250000 plant/ha produced 19.23% higher green pod yield per plant than the highest (333333) plant population (Table 5). Similarly, blended NPS fertilizer rates had a highly significant ($P \leq 0.001$) effect on green pod yield per plant. The lowest (1.04) green pod yield per plant was achieved at the control (0) treatment and it was highest at 162 kg/ha of NPS rates which, however, was statistically similar with 142 and 152 kg/ha of NPS rates (Table 5). Interaction effect of plant population and blended NPS rate on green pod yield per plant was not significantly different. Thus, green pod yield per plant was significantly influenced by plant population blended NPS fertilizer rates. This result is in line with the findings of Moniruzzaman et al. (2009) and Ayoub and Abdella (2014) who reported that green pod yield per plant was decreased from 87.3 to 58.8 g plant^{-1} with increasing plant density from 250 x 10^3 to 500 x 10^3 plants ha^{-1}. This green pod yield per plant difference might be due to reduced competition between plants for growth requirements like nutrient and light. Increasing NPS fertile rates from 0 to 142 kg/ha significantly increased green pod yield per plant but further increase had no significant effect. This result is in conformity with that of Moniruzzaman et al. (2008) who noted that green pod weight per plant increased significantly with the increase in N up to 120 kg ha^{-1}, increase in P up to 120 kg ha^{-1} and increase in S up to 20 kg S ha^{-1}.

Green pod yield per hectare

Both plant population and blended NPS fertilizer rates showed a highly significant ($P \leq 0.001$) effect on green pod yield per hectare. The highest pod yield (13.75 ton ha^{-1}) was recorded from the highest (333333) plant population and it was statistically at par with 250000 plant population, whereas it was lowest at the smallest (222222) plant population (Table 5). The highest yield per hectare (16.06 ton ha^{-1}) was recorded at the highest rate of application of NPS fertilizer (162 kg NPS ha^{-1}) and it was statistically similar with 152 and 142 kg ha^{-1} NPS fertilizer rate, while the lowest (4.16 ton ha^{-1}) was recorded at the control (0 kg ha^{-1} NPS) (Table 5). Interaction effects of plant population and blended NPS rate on green pod yield per hectare was not significantly different.

The result is in line with the findings of Moniruzzaman et al. (2009) who reported that green pod weight ha^{-1} was increased from 20.0 to 24.5 ton ha^{-1} with the increase of plant density from 250, 000 to 500,000 plants ha^{-1}. Moreover, Essubalew et al. (2014) reported that green bean yield ha^{-1} was increased by 49.43% as plant spacing decreased from 40 cm x 10 cm to 40 cm x 7cm (250000 to 357143 plants ha^{-1}) and the total marketable yield ha^{-1} decreased from 3,473 kg ha^{-1} to 2,531 kg ha^{-1} as plant spacing decreased from 50 cm x 7 cm to 40 cmx7 cm (285714 to 357143 plants ha^{-1}). With regard to NPS rates it was similar to the findings of Moniruzzaman et al. (2008) who found that green pod yield was significantly increased with the increase in nitrogen rate

Table 5. Effect of plant population and blended NPS fertilizer rate on pod yield of green bean

Treatment	Green pod yield per plant (kg)	Green pod yield/ha (tone/ha)	Harvest index
Plant population (plants ha^{-1})			
222222	0.23^{ab}	10.14^{b}	71.01
250000	0.26^{a}	12.76^{a}	70.59
333333	0.21^{b}	13.75^{a}	70.53
LSD (5%)	**0.04**	**1.54**	**4.09**
NPS rate (kg ha^{-1})			
0	0.1^{c}	4.16^{c}	41.25^{c}
132	0.18^{b}	10.56^{b}	52.38^{b}
142	0.29^{a}	15.05^{a}	63.05^{a}
152	0.29^{a}	15.23^{a}	60.59^{ab}
162	0.30^{a}	16.06^{a}	62.77^{a}
LSD (5%)	**0.05**	**1.98**	**5.28**
CV	**22**	**16.8**	**7.73**

Means followed by the same letters in the same column are not significantly different from each other at 5% level of significance.

of 120 kg N ha^{-1}, 120 kg P_2O_5 ha^{-1} (by 23.14% over control), and sulfur 20 kg ha^{-1} (by 25.83% over control). Such response of the crop may be due to the availability of sufficient amount of nitrogen, phosphorus and sulfur for the formation of more number of leaves per plant which could be capable of producing high dry matter and bearing long and high weighing pods which in turn produce maximum yield of green pod per hectare.

Harvest index

The data pertaining to harvest index are given in Table 5 from which it is evident that harvest index was significantly ($P \leq 0.001$) influenced by blended NPS fertilizer rates. Harvest index of green bean in the present study ranged from 41.25 to 63.05 (Table 5). The highest harvest index (63.05) at 142 kg/ha NPS rate which was statistically similar with that of 152 and 162 kg/ha NPS rates was observed (Table 5). This might be due to uptake of available N, P and S to produce high dry matter that is highly partitioned to reproductive part than vegetative part of green bean which contributed to raise harvest index. Plant population and its interaction effect with blended NPS fertilizer rates had no significant ($P > 0.05$) influences on harvest index of green bean.

Above ground total fresh biomass

The data pertaining to above ground total fresh biomass are given in Table 6 from which it is evident that above ground total fresh biomass was significantly ($P \leq 0.01$) influenced by the interaction effects of plant population and blended NPS fertilizer rates. Above ground, fresh biomass per plant increased with the increase in plant population and NPS fertilizer rates; but, the extent of its increment in relation to both plant population and blended NPS fertilizer rates was distinct (Table 6). In the present study, above ground total fresh biomass ranged (Table 6). At 0 kg/ha blended NPS fertilizer rate, increasing plant population per hectare from 222222 to 250000 increased above ground total fresh biomass by 13.33%, whereas further increase in plant population resulted in a 36.36% decrease. At 162 kg/ha NPS fertilizer rate, increasing plant population from 222222 to 333333 reduced the above ground total fresh biomass by 18.18 and 16.67% (Table 6). Similarly, using plant population with 222222 plants/ha, increasing blended NPS fertilizer rates from 132 to 162 enhanced the above ground total fresh biomass by 13.33, 25 and 9.09%. Similar results are evident at the other plant population and blended NPS fertilizer combinations (Table 6).

This result is in accordance with Cakmak (2008), Tarekegn and Serawit (2017), Lake and Jemaludin (2018) who reported that shoot dry mass of common bean and dry matter production of French bean was increased significantly with the application of different levels of nitrogen and phosphorus fertilizers.

Partial budget analysis

The partial budget analysis of the 15 treatments is shown in Table 7. Based on this result, the highest net benefit of 173, 450.55 Birr ha^{-1} was obtained with MRR of 5,734.9% from 333333 plant populations and at 162 kg/ha of NPS fertilizer rates. The highest (214216.32 Birr ha^{-1}) net field benefit was obtained with MRR of 6997.20. According to CIMMYT (1988), the minimum acceptable marginal rate of return (MRR%) should be between 50 and 100%. In agreement with this study, Shumi et al. (2018) reported

Table 6. Interaction effects of plant population and blended NPS fertilizer rate on above ground total fresh biomass of green bean.

Treatment	**NPS rate (kg/ha)**				
Plant population (plant/ha)	0	132	142	152	162
222222	0.13^{de}	0.13^{de}	0.15^{de}	0.2^{ab}	0.22^{a}
250000	0.15^{de}	0.17^{cd}	0.19^{ab}	0.21^{a}	0.18^{bc}
333333	0.11^{e}	0.18^{bc}	0.16^{cd}	0.14^{de}	0.15^{de}
LSD (5%)	**0.04**				
CV (%)	**16.07**				

Means followed by different letters in the same column are significantly different from each other at 5% level of significance.

Table 7. Partial budget analysis of effect of plant population and blended NPS fertilizer rate on green bean.

PP (Plants/ha)	**APY (ton/ha)**	**GB (birr/ha)**	**TVC (birr/ha)**	**NB (birr/ha)**	**MRR (%)**
222222	9.13	136950	8066.85	128883.15	0
250000	11.48	172200	9075	163125	3396.5
333333	12.37	185550	12099.45	173450.55	5734.9
NPS rate (kg/ha)					
0	3.75	56250	0	56250	0
132	9.5	142500	2214.48	140285.52	3794.8
142	13.55	203250	2370.88	200879.12	38742.7
152	13.72	205800	2527.28	203272.72	1530.4
162	14.46	216900	2683.68	214216.32	6997.2

GB = Gross benefit, NB= Net benefit, MRR (%) = Margin rate of return in percent, NPS cost= 15.64 birr/kg, NPS application cost = 150 birr/ha, TVC= Total variable cost APY= Adjusted pod yield down wards by 10%, Price of green pod/kg = 15 birr/kg, Cost of seed = 48.89, 55 and 73.33 kg/ha for 222222, 250000 and 333333 plants/ha, respectively.

the highest net benefit with the application of 150 kg ha^{-1} NPS compared with the control (0) treatment on common bean. Therefore, the most attractive plant population and NPS fertilizer application rate for producers or farmers with higher net return was 333333 plant population per hectare and 162 kg/ha NPS fertilizers application rate.

Conclusion

The major production variables that a producer can manipulate to influence the potential yield of a given crop are soil fertility, plant population, spacing, variety selection and crop management activities. Among those fertilizer rate and plant populations per a given area require special focus to maximize the yield obtained from improved varieties of crops. Results from the present study showed that the plant population and application of blended NPS fertilizer rate stimulated the growth and yield of green bean and to obtain maximum growth and yield, the economical plant population and application rate have been optimized. From the current results, it can be concluded that, growth and yield of green bean economically improved with 333333 plants ha^{-1} and 162kg NPS ha^{-1}. Therefore, this treatment can be suggested for better growth, yield and yield attributing characteristics of green bean for Alage and areas having similar agro-ecologies and soil types.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Drivers and restrictions of range pasture improvement by agro-pastoralists in Kiruhura District, Uganda

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Range pastures provide the basic ruminant feeds resource for livestock production in semi-arid areas despite ruminant nutrition remaining a challenge affecting productivity. Different livestock development interventions have been promoted to improve livestock nutrition with low farmer adoption rate. A cross sectional exploratory study was conducted between March and July 2018 to identify the drivers of range pastures improvement technologies adoption in rangelands with specific objectives as: (a) Assessing the knowledge, attitudes and practices of pastoralists in regard to range pasture improvement practices and technologies; (b) identifying the forage species planted by pastoralists and strategies for their sustainable utilization; (c) identifying the incentives for the adoption and maintenance of range pasture improvement practices and; (d) identifying the key players and their roles in range pasture improvement promotion and constraints faced in attempt to improve rangeland pastures. A structured questionnaire guided interview was conducted with 294 agro pastoralists while qualitative data was obtained using, KII. Results revealed that farmers had knowledge on range pasture improvement technologies, although adoption rate was low (19.5%). The range pasture improvement practices, included: Pasture establishment, bush clearing, paddocking, conservation, reseeding and over-sowing and water development. However, results also revealed knowledge gaps in silage and hay making, reseeding and understanding principles of range management. The level of education, household income, off farm activities, access to laborers and credit, agriculture exhibitions, farmers' meetings and on-farm demonstrations influenced farmers' adoption of fodder production technologies. Farm gate milk prices, sensitization, financial support, farm output of adopters and inputs support seemed to drive farmers to improve their range pastures. These findings underline the importance of farm-gate milk prices and institutional support as drivers for farmer decision for investment in pasture improvement. Therefore, policy and development interventions should emphasize improvement of milk farm gate prices and farm support systems.

Key words: Farm-gate milk prices, range over-sowing, re-seeding, species recruitment.

INTRODUCTION

Range pastures provide the basic ruminant livestock feeds resource for production in rangelands. Ruminant animals have the ability to convert such forages into milk, mohair, meat, hides and skins and draught power, providing man with food, fiber and income thus reducing vulnerability to poverty. Range pastures provide cheap and readily available animal feed resources despite being with low nutrients due to poor management affecting productivity and net benefits. The season availability, fluctuating quantity and quality of year round range forage supply remain a major constraint to sustaining livestock productivity. Range grasses, herbs, forbs, shrubs and trees contribute to rural farmers' economic and environmental sustainability (Peters and Lascano, 2003). Pasture legumes offer a lower-cost alternative to nitrogen fertilizers and purchased protein supplements for improving dairy cattle feed resources in the tropics (Mapiye et al., 2006). However, the low quality and quantity of the range pastures caused by poor management and environmental conditions including variable rainfall and temperatures limit livestock productivity. Mutanga et al. (2004) noted that availability and quality of nutrients in ruminant diet are two of the major factors which limit animal production in the tropics, besides water accessibility and tropical animal diseases. Rusdy (2020) also reported that the low availability and fluctuating quantity and quality of forage growing in grassland, shrinking grassland area and poor management were the main causes of increased land degradation and reduced productivity of animals grazing on tropical grasslands. The lowered productivity of livestock in turn affects incomes, nutrition and food security of households, whose livelihoods is dependent on livestock, making them more vulnerable to climate extreme events and poverty. Despite Ugandan rangelands being endowed with natural pastures, they are unsustainably utilized leading to degradation. Rangeland degradation is globally attributable to both anthropogenic and natural causes and is the major threat affecting grazing rangelands (Zerga, 2015). This degradation is caused by climate variability, overgrazing by ruminants attributed to continuous grazing management and termites due to; their high population densities, poor pasture renovation, poor use of fire, limited reseeding and over sowing with legumes and nutritive grass species, and pasture preservation strategies (Bolo et al., 2019) leading to difficulties to produce food locally (Abusin et al., 2020). Zerga (2015) noted shift in species composition, loss of range biodiversity, reduction in biomass production, less plant cover, low small ruminant productivity, and soil erosion as indicators of rangelands degradation. Rangeland degradation affects animals and plants equally as increased degradation limit the availability and quality of forage and water resources, denying ruminant livestock good nutrition impacting human livelihoods. Overgrazing due to poor grazing methods has caused reduced vigor of available palatable species, reduced herbage production, accelerated soil and water erosion, bush and weed invasion, reduced stocking rate, poor species recruitment and loss of soil organic matter and reduced carbon sequestration, contributing to global warming and climate change. The range productivity is further worsened by water scarcity, soil mining, invasive species and termite invasion. Strategies to address these problems in rangelands would be to embrace good agronomic practices including climate smart technologies. Rusdy (2020) reviewed the benefits of incorporating *Leucaena leucocephala* to overcoming land degradation and increasing soil fertility and its nutritive value in relations to animal production in grasslands.

Several development agencies have traditionally emphasized and invested in capacity building for livestock development though they have not managed to improve the rangelands. It should be noted that in the 1990s, the Dryland Husbandry Project (DHP) brought many farmers on board for capacity building in range pasture management with moderate participation and adoption of management technologies and practices. The technologies and practices adopted then included: pasture establishment, organic manuring, water harvesting, over-sowing and reseeding, legume pasture seed production and erosion control with a relative number of farmers adopting at the time. However, there was unanticipated drop out of implementation of pasture improvement practices and technologies in the 2000s upon projects expiry. It has been observed that about fifteen years later, many farmers started reviving their interest in implementing the previously dropped practices and technologies raising a key question in this study, which is "what are motivates and drives farmer's decision to invest in range pasture improvement?" Adoption of a pasture improvement technology refers to use of the technology for one and/or more than one year, on the other hand non adoption of technology refers to not using these technologies or using them for less than one year. Manyeki et al. (2013) asserted that the rate of adoption is the relative speed with which members of a social system utilize an innovation and can be measured as the number of individual who utilize a new technology within a specified period. This study therefore aimed to identify the drivers and limitations of range pasture improvement for enhancing livestock productivity by pastoralists in rangelands in Uganda.

The following questions guided the study: How do the knowledge, attitudes and practices of pastoralists affect decisions to adopt range pasture improvement practices and technologies? What are the forage species planted

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by pastoralists and how are they utilized? What are the incentives for the adoption and maintenance of range pasture improvement practices? Who are the key players in range pasture improvement promotion, their roles and what constraints do they face in attempt to improve rangeland pastures? Thus, the objectives of the study were to: (a) assess the knowledge, attitudes and practices of pastoralists in regard to range pasture improvement practices and technologies; (b) identify the forage species planted by pastoralists and strategies for their sustainable utilization in the semi-arid rangeland; (c) identify the incentives for the adoption and maintenance of range pasture improvement practices and (d) pinpoint the key players and their roles in range pasture improvement promotion and constraints faced in attempt to improve rangeland pastures. The generated information will guide extension services' provider stakeholders working in Uganda rangelands in rationalization of their activities for improvement of the livestock feed resources.

Theoretical framework

Theoretically, there are several factors that can influence farmers participation and adoption of agricultural technologies, which includes: socio-demographic attributes such as age- sex, level of education, family size; socioeconomic factors like income- land size, off-farm income, production systems, production goals; institutional factors like- access to credit, farmer exposures and extension contact, and improved livestock husbandry practices characteristics like its relevance, compatibility, simplicity, costs; as well as physical and environmental factors like- climate and soil factors according to Kaliba et al. (1997, 1998). Social networks and differences in expected returns to a new technology may influence individuals' adoption decisions and the diffusion of new technologies (Ntume et al., 2015).

If favorable, these factors therefore, influence farmers' decision to adopt range pasture improvement technologies and enhance range productivity. The study analyzed these factors in relation to adoption of natural pasture improvement. Studies on agriculture technology adoption have shown various drivers to be in control. Ainembabazi and Mugisha (2014) examined the role of farming experience on the adoption of agricultural technologies by small holder farmers in Uganda, while Mudombi (2015) investigated the adoption of improved sweet potato in Zimbabwe. Alomia-Hinojosa et al. (2018) explored farmer perceptions of agricultural innovations for maize legume intensification in Nepal. Onuche et al. (2020) investigated the perception and uptake of aquaculture technologies in central Nigeria and reported that age, primary occupation and distance to urban center negatively affected adoption of innovation. The same authors also found out that technical know-how, "other income", education and gender were drivers of perception and adoption of aquaculture innovations drivers of perception and adoption of aquaculture innovations.

Previous assessment reports on adoption of livestock development technologies' have focused on general husbandry and the impact on production. Other existing studies looked at the effectiveness of extension programs, although few examined the mechanisms that drive technology adoption. These studies also did not analyze what drives pastoralists in decision making with regard to natural pastures improvement. This study focused on establishing the influence of different independent variables on the adoption of range pasture improvement technologies and practices by the pastoralists from the Pastoralists' socio-economic context (Figure 1).

METHODOLOGY

Description of the study area

The study was carried out in Kiruhura District one of the rangeland district located at: 00°12′53″S 30°46′12″E in Ugandan rangelands popularly referred to as "cattle corridor". The "cattle corridor" extends diagonally from the South-west bordering with Rwanda to the North-east direction bordering with Sudan/Ethiopia/Kenya borders (UIA, 2016). Uganda has livestock population of: 14.2 million cattle, 16 million goats, 4.5 million sheep, and 4.1 million pigs with greatest concentration of animals found in the "cattle corridor and a poultry population of 47.6 million (MAAIF and UBOS, 2018). The District experiences a bi-modal pattern of rain seasons, which normally occurs from March to May and mid-August to October. On average the annual rainfall is about 900 mm. Notwithstanding the rainy seasons, the district is affected by very long dry periods with a temperature ranging from 17 - 30°C. It has savannah woodlands type of vegetation with a wider cover of thorny shrubs. It is estimated that 57.6% of Kiruhura population is engaged in livestock farming and 32.4% is engaged in agricultural production (KDLG, 2012). The District has both fenced (30%) and unfenced farms (70%) which cover an area of 762,766 acres. Kiruhura District is composed of 2 counties namely Nyabushozi and Kazo composed of 15 sub-counties and 3 town councils (KDLG, 2012) from which four sub counties were selected for the study (Figure 2).

Study design and sampling frame

A cross section study was conducted to collect data on rangeland pasture agronomic practices and technologies conducted between March and July 2018. Kiruhura district was purposively selected for being the dairy hub of the region and having participated in the Dryland Husbandry Project (DHP). The district was also selected for the reason that the farmers of the district have adopted breeding improvement of their herds compared to other districts of the cattle corridor. In order to get an understanding of adoption characteristics, both adopters and non-adopters were randomly sampled for questionnaire interview. All farmers that had adopted pasture establishment technology were sampled. Four sub counties were selected from the two counties of Nyabushozi and Kazo. Two sub counties of Nyakashashara and Kenshunga in Nyabushozi county were randomly selected using random numbers, while Kazo and Burunga sub counties from Kazo county were purposively selected for having participated in Dryland husbandry project (DHP)

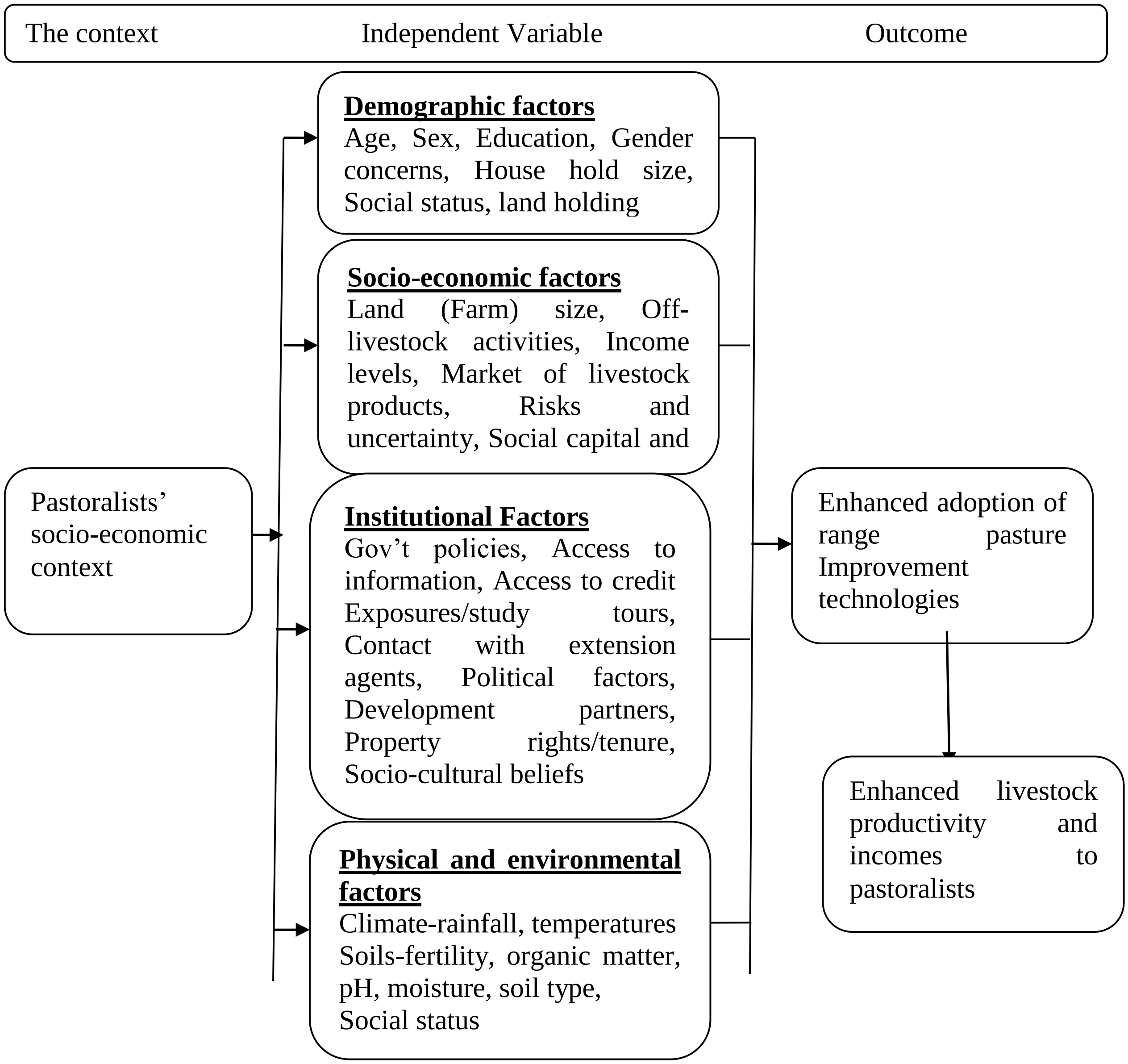

Figure 1. Theoretical framework on adoption of range pasture improvement.

and for inhabiting the Kazo dryland husbandry agro pastoralists association (KDHAPA), a pasture improvement based association. The sampling frame therefore included all pastoral households totaling to 1,113HHs in the four selected sub counties.

Sample selection and sampling technique

To obtain the desired sample, a simplified formula for the proportions by Yamane (1973) that assumed a 95% of confidence level and precision of 0.05 was adopted for this study that gave a sample size of 294 respondents distributed in the four selected sub counties. In addition, some key informants were identified with help of local council leaders. The KIIs included progressive dairy farmers, elder farmers, farmers' leaders, NGO focal persons and livestock extension agents. Walks along community routes/roads were also made in the study areas and observations were made in those communities. A standard structured questionnaire was self-administered to a total of 294 respondents who were randomly selected, including all households that had adopted pasture establishment technology from the four of the study sub-counties to collect quantitative data. For this purpose, a list of farmers was prepared in consultation with the local extension personnel, local leaders, Non-Government Organizations and the interviewed farmers separately for all the selected eight parishes.

Data analysis

Qualitative data obtained through focus group discussions, KIIs and

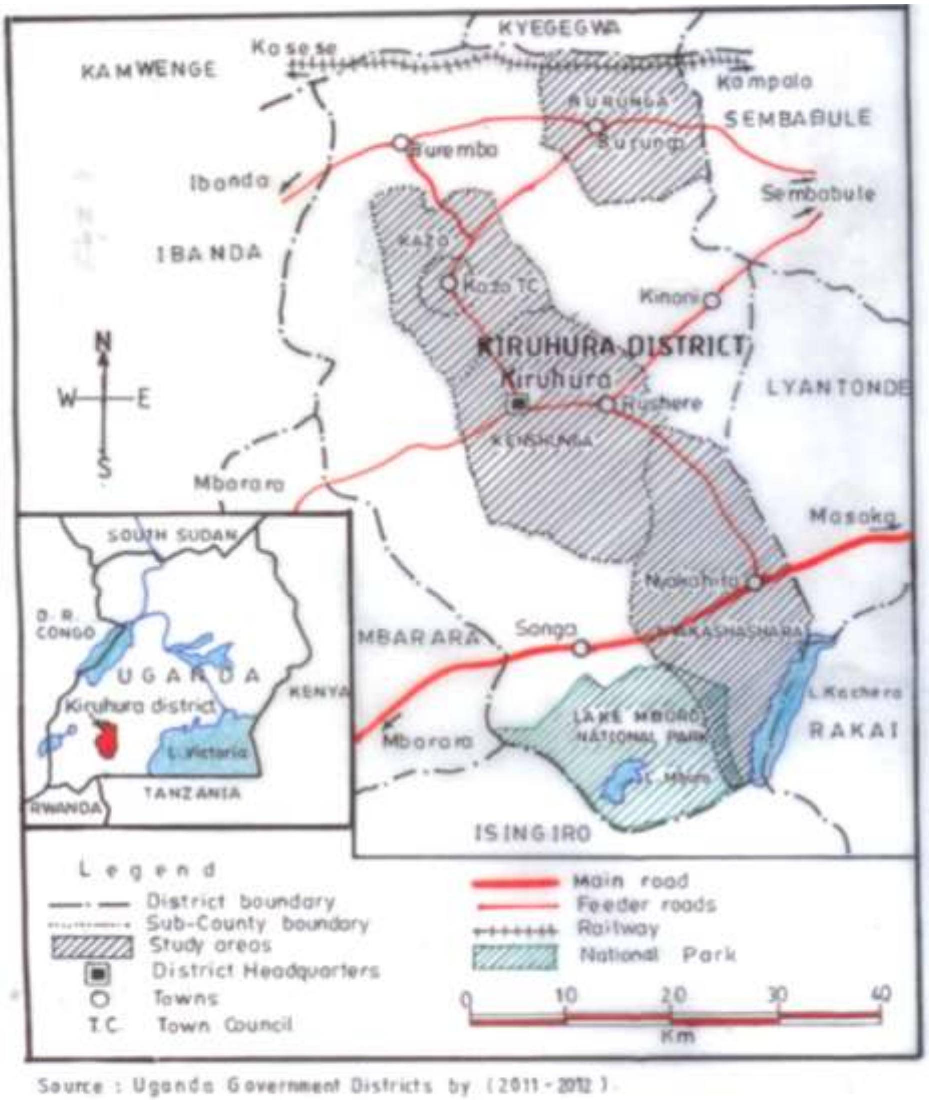

Figure 2. A map of Kiruhura District showing the study areas.

observations was organized and meaningfully reduced into themes and contents that were in line with the objectives and the concept of the study according to Miles and Huberman (1994). Quantitative data was edited, coded, entered in the computer and cleaned to ensure accuracy, consistency, uniformity and completeness. The data was then analyzed using Statistical Package for Social Scientists (SPSS) version 20 to generate descriptive statistics and regression analysis. Chi square and analysis of variance (ANOVA) were run to determine significant relationships. Regression analysis model was used to examine the relationship between a set of independent variables as the factors that influence the probability of adopting components of agricultural technologies and adoption as the dependent variable as given by the model adopted from Kaliba et al. (1998) and Gujarati (1995) given below:

Y= BO + B1AG + B2GE + B3ED + B4YF + B5FS + B6NA + B7AI + B8AN + B9AC + B10OE + B11ES + B12LE + B13IL + B14TD + B15MG + e

Where:
Y= Technology adoption
BO = Constant
B1-B15 = gradient for different variables
e = Error term

The following factors were included as explanatory variables in the model: the age of respondent in years (AG), gender (GE), education level (ED), years of farming (YF), farm size in hectares (FS), number of animals kept by household (NA), acreage under improved pasture (AI), acreage under natural pasture (AN), access to credit (AC), accessible to off farm employment (OE), accessible to extension services (ES), leadership (LE), income levels (IL), own title deed (TD), membership of organization (MG).

RESULTS AND DISCUSSION

Socio -demographic characteristics of respondents

The socio-demographic characteristics of respondents including age, sex, education, farm size, farming labor

Table 1. Socio-demographic characteristics of study respondents.

Variable	Category	Frequency (N=294)	Percent response
Sex of respondent	Male	224	76.2
	Female	70	23.8
Age category of respondent	24 to 29	4	1.4
	30 to 49	118	40.1
	50 to 65	116	39.5
	66 to 79	56	19
Highest level of Education	No formal education	59	20.1
	Primary level	115	39.1
	Secondary level	84	28.6
	Tertiary education	36	12.2
HH Land acreage (ha)	<50	88	29.9
	50 to 100	123	41.8
	101 to 150	42	14.3
	>150	41	13.9
Farming labor	1-2	38	12.9
	3-4	119	40.5
	5-6	85	28.9
	>6	52	17.7
Domestic animal species kept	Cattle	294	100
	Goats	234	81.6
	Sheep	37	12.6
	Local chicken	66	22.4

Source: Authors' computation from field survey data 2018.

and other livelihoods activities are presented in Table 1. The study also revealed that the mean farm labor was 4.85±0.14 persons. Data on education level of respondents showed that majority of respondents has acquired primary and secondary level education although women trailed behind men in all education levels (Table 1). Although equal numbers of men and women (20%) did not acquire any formal education, majority of the women acquired primary (49%) and tertiary (5%) education qualification, compared with 35% and 12% of men with primary and tertiary education level respectively. It was also noted that a large number of men (33%) respondents had acquired secondary education compared to 26% of women respondents.

Education plays a major role in agricultural technology adoption. Women farmers generally have lower education levels compared to men which affect their understanding and adoption of technologies, especially if the technology requires use of more technical and intensive knowledge. Uneducated illiterate women are most likely to fear change and cling to the tradition, as they see it. The lagging of women in education affect their adoption of agricultural development technologies. In many cases, social and cultural barriers and greater time burdens are major constraints by women in acquiring information, education and training. The agro pastoralists women attainment of low level of education exhibited could also be attributed to their culture associated with early marriage and devaluation of formal education. This gender based difference in education could also be attributed to gender inequality that have been promoted socio-culturally especially among pastoral societies. However, many pastoralists women participate more in non-curricula church based functional adult literacy activities than men which probably enlighten them on the value of education. This gives them some level of empowerment albeit with limited technical skills.

Ogunlana (2003) observed that women's limited access to education opportunities and lower access to mass media and other forms of ICT as compared to men are one of the factors contributing to gender gaps in adoption of new technologies. Owuor et al. (2020) reported that education impacts agricultural output through supporting farmer adoption of new productivity enhancing technologies. Paltasingh and Goyari (2018) found that a minimum threshold level of education is significantly influencing the adoption of modern varieties of paddy and thereby the farm productivity of adopters only. Weir (1999) reported that education enhances the farming skills and productive capabilities of the farmers. It enables farmers to follow some written instructions about the application of adequate and recommended doses of chemical and other inputs (Huang and Luh, 2009).

In this study, majority of respondents were men which could be attributed to gender roles and the patriarch nature consistent with many pastoral groups' cultures. Men own livestock and therefore participate in livestock related activities with some few exceptions. This result is consistent with Bettencourt et al. (2015) who made similar observation that in regard to division of labor women are in charge of small animals and men of big ones. The low participation of the young population (Table 1) could be attributed to the fact that young people are usually not interested due to their negative perception of farming as being archaic and nonpaying, and taking long to bring results compared to industrial sector with regular income and job security. This study further established that younger trained farmers were also less interested in the adoption of improved husbandry practices compared to the medium and older people who were more experienced and innovative in farming. This could also be attributed to the drudgery of farming, lack of property, lack of collateral for loans to acquire farm inputs, limited knowledge in on scientific advancements in agricultural field. In addition, lack of land of their own could also deter young people from investing their energy into projects that are long term. The youths therefore seem to prefer to engage in activities that have quick fixed and secure income such as motor cycle public transport business (popularly known as Boda boda in Uganda) activities.

A study by Mutua et al. (2017) established that personal choice, preference for paid over unpaid labour and gender norms in asset access, ownership and control influence young smallholder participation in livestock production and trade. The older farmers therefore are more likely to try pasturing improvement practices for improving dairy productivity as their main source of cash income. Musaba (2010) reported that older farmers with demanding family responsibilities venture in activities that will help to support their families.

This study also showed that the mean farm size was 105.19 ± 6.82 ha (Range 20-900 ha). However, the average pasture land was low at 1.0289 ha of the total farming land which would only support minimally one livestock unit in a rangeland. The allocation of small land could be due to shortage of land that is put to multiple land use including crop production despite the inherent limitations of rangelands. Similar observations were made by Mapiye et al. (2006) and Yesuf and Kohlin (2008) who reported a relationship between farm size and adoption of an innovation and a positive correlation between farm size and adoption of new technologies. Onim (1992) found out that small landholdings limited the farmer's choice to cultivate improved forages as available land was used for subsistence food crops. The herd size also seemed as limitation to pastures establishment with small herds' farmers being more likely to establish pastures than households with large herds.

Labor is key in livestock production especially for agro pastoralists who have to divide labor between livestock and crop production in addition to other livelihood activities. Prokopy et al. (2008) reported that labor availability, including both family and hired labor, tended to increase adoption of best farm management practices. However, Joachim et al. (2018) reported that adoption of some agricultural technologies such as row planting increases the labor requirement but lack similar increases in yields or farm productivity. Mwangi (2015) categorized these factors into human specific factors, socioeconomic, technological and institutional factors.

Knowledge, attitudes and technologies of pastoralists in regard to range pasture improvement

Pastoralists' knowledge on range pasture improvement

The study indicated that, all the agro pastoralists were at least exposed to some knowledge on rangelands management and knowledge on livestock production and different extension methods as source of knowledge and skills were employed (Table 2). Results further indicated that agricultural exhibitions, farmers' meetings and on-farm demonstrations played an important role in motivating farmers to improve their pastures. However, respondents attested to not having been fully trained on range management principles for sustainable range health. The results further indicated that only 34(30.4%) of 38.1% of respondents that attended the meetings adopted pasture establishment. Analysis also revealed that attending the meetings influenced pasture establishment adoption (P=0.007). Furthermore, the logistic regression revealed a positive relationship between on-farm demonstrations exposure and pasture establishment (P=0.001). Results also revealed that 26 (40.6%) of 64 (21.8%) who attended agricultural exhibitions adopted pasture establishment. The logistic regression test indeed revealed that participation in agricultural exhibition significantly (P=0.003) influence pasture establishment. The results further indicated that 174 (59.2%) had attended a number of capacity building trainings on livestock production and of those, 34 (19.5%) had adopted some pasture management technologies. However, attending trainings did not influence pasture establishment (P = 0.979), although pastoralists'

Table 2. Pastoralists' source of and kind of knowledge acquired on range pasture improvement.

Variable	Alternative variable (N=294)	Percent response
Acquisition of knowledge	All acquired some form of knowledge	100
Major Sources of information	Listening to radios farmers programmes	65
	Consulting friends and neighbors	51
	Training by livestock extension workers	33
	Attending farmer organization meetings	24.1
	Reading newspapers and leaflets	16.
	Attending farmers' meetings	38.1
	Visiting On-farm demonstrations	17.7
	Attending agricultural exhibitions	21.8
Kind of knowledge acquired	Bush clearing techniques	88.5
	Pasture species	65.8
	Reseeding	44.5
	Over sowing	32.4
	Grazing management	48.5
	Use of agrochemicals	15.6

Source: Authors' computation from field survey data 2018.

exhibitions (P=0.000) and attending trainings (P=0.018) influenced paddocking technology. Similarly, exhibitions and trainings influenced adoption of pasture preservation technologies (P=0.002) and meetings on pasture improvement and on-farm demonstrations greatly influenced pasture reseeding (P=0.001) and (P=0.034) respectively.

Pastoralists own their knowledge and skills of assessing their environment albeit not based on scientific knowledge but from years of observational experience. Pastoralists manage and use vast rangeland areas worldwide and as a result they suffer from and contribute to land degradation, but also they are major actors in land rehabilitation. Pastoralists possess indigenous systems of landscape classification that provides a valuable basis for assessing rangeland resources including biodiversity. For instance, in his rangeland assessments using ecological and anthropogenic indicators, Oba (2012) noted that pastoralists considered soils, vegetation and livestock productivity as their main indicators for understanding rangeland degradation. Oba further reported that pastoralists used key-plant species against landscape-grazing suitability and soils were considered in assessing landscape-grazing potential. Most pastoralists are able to acknowledge environmental changes taking place on rangelands. For example, Pastoralists in Botswana identify contributing factors as dynamic rainfall, overgrazing and fire (Kgosikoma et al., 2012).

Agricultural exhibitions supplement the trainings farmers will have received on range pasture improvement. It can be argued that as farmers participate in these exhibitions, they gain confidence and become conversant with the practice which encourages practicing and increases the extent of adoption. Therefore, more participation in agricultural exhibitions enlightens farmers and thus influencing them to effectively adopt pasture improvement. However, attending other trainings on livestock production did not influence pasture establishment but influenced paddocking, rotational grazing and pasture preservation technologies. The positive impact training, exhibition and demonstrations could be attributed to their ability to provide the farmers with a higher –order thinking skills and enhancement of tactile hand-eye connections which improves their ability to recall facts. Exhibitions and demonstrations also cause admirations that farmers desire to replicate on their farms. In their review of behavioral factors affecting the adoption of sustainable farming practices, Francois et al. (2019) found out that adoption of sustainable practices is influenced by how farmers learn, understand and perceive these practices, particularly the associated difficulties, costs, benefits and risks.

Agro-pastoralists' Adoption of range pasture improvement and utilization technologies

This study identified a number of practices and technologies that different farmers implemented on their farms (Table 3). Through multiple response analysis, the results revealed varying levels in kind of technology or practice adopted and sites of adoption of range pasture

Table 3. Range Pasture improvement practices and technologies in the study sub counties.

Technology/practice	Sub county			
	Nyakashashara	Kenshunga	Burunga	Kazo
	% (n=75)	% (n=78)	% (n=69)	% (n=72)
Water harvesting	100	100	100	100
Bush clearing	94.7	100	84.1	95.8
Perimeter fence	94.7	88.5	91.3	87.5
Paddocking	46.7	33.3	10.1	29.2
Rotational grazing	21.3	24.4	5.8	8.3
Pasture establishment	16	20.5	4.3	12.5
Pasture reseeding	5.3	6.4	7.2	20.8
Silage production	6.7	7.7	1.4	4.2
Hay production	10.7	5.1	2.9	1.4
Range over-sowing	3.4	4.4	8.2	10.6

Source: Authors' computation from field survey data 2018.

improvement, although water harvesting was implemented by all respondents (Table 3). Field observation also revealed extensive bush clearing but with low recruitment of desirable pasture species and high dominance of herbaceous weedy species that seemed to demoralize adopters.

The observed bush encroachment and farmer's effort to clear them support observations made by Haussmann et al. (2016) who noted ecological consequences associated with physical clearing, especially when the topsoil is disturbed and habitat structure is altered that ultimately favor the growth of perennial grass species as well as re-establishment of fast-growing, undesired species. Bush encroachment and water scarcity were major challenges affecting rangeland productivity and livelihoods to the extent that they take priority for agro pastoralist investment thus the high adoption rates recorded in this study. The weed emergency scenario is a natural ecological phenomena process considering that soil is a natural seed bank of weed seeds. Any disturbance to their habitat will provide such conditions like change in burial depth, moisture and light for their emergency. The ability of aggressive weeds to outcompete and displace desirable species as their strategies to survive must be well understood before planning any bush management to enable appropriate management of subsequent occurrence. An understanding of seed ecology is essential for developing effective management programs for problematic weed species including invasive species. Rangeland vegetation dynamics complexity can be understood from the "state-and-transition model", where rangeland dynamics are described as a set of discrete "states" of vegetation at a specific site and changes between states that occur as discrete "transitions" (Briske, 2017; Liao et al., 2018). Some studies have reported that abiotic factors such as drought, light, salinity, seed burial depth, soil pH, and temperature as well as disturbance events such as a fire, flooding or tillage can play an important role in initiating or inhibiting seed germination (Baskin and Baskin, 1998; Cuneo et al., 2010). Humphries et al. (2018) acknowledged drought, salinity, alternating temperature, photoperiod, burial depth, soil pH, artificial seed aging, and radiant heat as influencers of seed dormancy.

Analysis of study sites for variation in adoption of practices and technologies established that the technology adoption between sub counties differed (Table 4). Technology adoptions were more in Kenshunga and Nyakashara than in Burunga and Kazo sub counties. The difference could be attributed to the difference in climate where Kenshunga and Nyakasharara have favorable climate for primary production than the latter sub counties. In addition, Nyakasharara and Kenshunga have more improved breeds of cattle dairy farmers which attract good product market that becomes an incentive for adoption of technologies. There was no difference in adoption of pasture preservation between sub counties. The high adoption of water development, bush clearing and perimeter fencing could be attributed to an immediate benefit or impact the innovation has on farm productivity. For instance, water availability during drought reduce water stress and while increasing grazeable land with more herbage increasing stocking rate and better animal body condition giving the farmer an obvious value. In addition, farmers must perceive that there is a problem that warrants an alternative action to be taken. Musaba (2010) made similar observation and revealed that there was no difference in outcomes between alternative and conventional practices and that it would be less likely that farmers would adopt a given improved practice.

While adoption of range pasture improvement would substantially increase livestock productivity, resulting in an increase income and better livelihood, the different

Table 4. Relationship of Range improvement technology adoption between sub counties.

Technology/practice		SS	df	Mean Square	F	Sig.
Bush clearing	Between Groups	.990	3	0.330	6.015	0.001
	Within Groups	15.908	290	0.055		
Perimeter fence	Between Groups	.232	3	0.077	.893	0.445
	Within Groups	25.101	290	0.087		
Paddocking	Between Groups	4.893	3	1.631	8.274	0.000
	Within Groups	57.165	290	0.197		
Rotational grazing	Between Groups	1.886	3	0.629	5.032	0.002
	Within Groups	36.227	290	0.125		
Pasture establishment	Between Groups	1.015	3	0.338	2.926	0.034
	Within Groups	33.543	290	0.116		
Pasture reseeding	Between Groups	1.161	3	0.387	4.492	0.004
	Within Groups	24.979	290	0.086		
Silage production	Between Groups	.169	3	0.056	1.162	0.325
	Within Groups	14.066	290	0.049		
Hay production	Between Groups	.365	3	0.122	2.544	0.056
	Within Groups	13.870	290	0.048		

Source: Authors' computation from field survey data 2018.

technologies had varying levels of adoption in the different study sites. The site difference in internal Paddocking, bush clearing, rotational grazing and pasture establishment observed could be attributed to individual's interest motivated by other factors like the land size, price of milk, individual's income, exposures to demonstration farms, having attended different trainings, social networks among others. However, profitability of the outcome of adoption may play an intrinsic motivation. On the other hand, factors that typically decrease range pasture improvement technology adoption by non-adopters may include: advanced age, credit constraints, and perceptions about technologies including compatibility with the existing system, mindset, sociocultural beliefs and fear of risks/uncertainty that may be associated with the technology. The lack of difference in pasture preservation technologies observed could be due to the meagre adoption rate in all sites and this could be attributed to lack of necessary equipment for mowing and transport and tools, storage facilities, limited knowledge of technologies, conservativeness of pastoralists, lack of economic knowledge and the fear of the large herd size compared to quantity required to sustain them. It is also likely that the characteristics of a technology, such as simplicity, visibility of results, usefulness towards meeting farmer's expectation or need and cost implication of investment promote will also influence the farmer's decision.

OECD (2001) observed that assimilation and adoption of new technology at the farm level is a function of science, economics and human behavior. The author further noted that technology and change will most likely be assimilated and implemented when: the benefits of implementation will be quickly realized (within one to two years), the tools for implementation are readily available and accessible in the local marketplace, the risk of the implementation are small and the change or new technology can be comfortably integrated into other basic on-going aspects of daily life.

Analysis of the effect of different factors on adoption of range pasture improvement technologies

Influence of income, labor and off-farm income activities on technology adoption

The logistic regression modeling contextual analysis to understand the relationships between the demographic variables with pasture improvement technology adoption revealed that the farm size, household income levels, off farm activities significantly influenced pasture

Table 5. Effect of level of education on range pasture management practices and technology adoption.

Technology	Level of Education			
	None (n=59)	Primary (n=115)	Secondary (n=84)	Tertiary (n=36)
	%	%	%	%
Pasture establishment	6.8	5.2	19.0	38.9
Paddocking	32.2	16.5	33.3	63.9
Rotational grazing	11.9	7.8	16.7	41.7
Pasture reseeding	3.4	8.7	13.1	16.7
Pasture preservation	20.3	7.0	21.4	47.2

Source: Authors' computation from field survey data 2018.

management technology adoption at (P=0.001), (P=0.007) and (P=0.000) respectively. The results also indicated that there was no relationship between age of the household head and adoption of range pasture improvement and farming labor. However, this does not mean that these factors do not influence probability of adopting the technologies. On the contrary, household income levels and off farm income activities strongly influenced paddocking technology (P=0.018) and (P=0.000) respectively; with rotational grazing at (P=0.003) and (P=0.017) respectively; and with pasture preservation at (P=0.002) and (P=0.000) respectively. The study further revealed that only farming labor and off farm income activities had a significant relationship with pasture reseeding technology at (P=0.024) and (P=0.003) respectively. The study also showed that the household income was influenced by the off farm income activities, and these greatly influenced adoption of internal and perimeter paddocking for rotational grazing and pasture preservation.

Off-farm income activities are an important strategy for overcoming financial capital constraints for disadvantaged rural households. Having income enables the farmer to hire labor and purchase inputs used in adoption of technologies. Similar findings were given by Singha et al. (2011) in the study on technology adoption of different selected land based enterprises under diversified farming systems in India. Diiro (2013) reported a higher adoption intensity and expenditure on purchased inputs among households with off-farm income relative to their counterparts without off-farm income.

Influence of education of the household head on technology adoption

The results has direct relationship between level of education and pasture management practices and technologies with farmers with higher level of education adopting more of the practices than the lower education farmers (Table 5). The Chi-square test revealed that attainment of education influenced adoption of pasture management (P=0.000), paddocking (P=0.000), rotational grazing (P=0.000) and pasture preservation technologies (P=0.000). However, the level of education did not influence pasture reseeding technology (P=0.121).

Paltasingh and Goyari (2018) found that minimum threshold level of education influences the adoption of modern crop varieties increasing the farm productivity of adopters. It is therefore evident that education enhances farm productivity in the case of adopters of modern technology. Education enhances the farming skills and productive capabilities of the farmers (Weir, 1999). It enables them to follow some written instructions about the application of adequate and recommended doses of chemical and other inputs (Huang and Luh, 2009). While Manyeki et al. (2013) found age and education level of household head, land ownerships and affiliation to farmers group, sex, formal technical training affecting adoption of natural pasture improvement technologies in Kenya, in this study, farmers' exhibition, farmers' meetings, and exposures on demonstration farms influenced adoption of range pasture improvement technologies and practices.

Influence of household head sex, access to credit and labor on pasture establishment

Results indicated that 40 (13.6%) of respondents adopted pasture establishment technology and of whom 12 (30) were women compared to 28 (70%) of the men. In total, however, the sex of the household head did not influence (P=0.281) on pasture establishment in this study, although access to credit played a significant role (P=0.000) in pasture establishment. The low participation of women could be attributed to their lack of land and capital to hire labor as most agro pastoral women are not in formal employment. Results further showed that household access to laborers and access to credit had significant influence on adoption of range pasture establishment at (P=0.032) and (P=0.000) respectively. Belonging to a farmer organization and access to laborers influenced paddocking at (P=0.029) and (P=0.000) respectively. It was also established that access to credit and laborers similarly influenced practicing of rotational grazing at (P=0.010) and (P=0.018) respectively; belonging to organization and access to credit also influenced pasture reseeding at (P=0.051) and (P=0.041) respectively; similarly, access to credit was significant in influencing pasture preservation (P=0.011). Labor and financial capital is key inputs into production. Labor does the physical work of fencing, weeding and driving of animals into pastures while financial support provides an enabling environment. Farmers' membership to groups is likely to increased adoption of specific technologies although this may further be influenced by other factors as calculated by the farmer in his/her decision making on allocation of resources.

Generally, Moyo and Salawu (2017) identified age, education level, family size, farm size, extension service provision and credit access as factors influencing adoption of agricultural new technologies by farmers. Mwaura (2014), Vohra (2016) and Omollo et al. (2018) reported that gender of household head, education, social/development group membership, and access to extension services, social participation, scientific orientation, innovativeness and modernization of the beneficiaries were the most important factors influencing households' participation in fodder production. Mureithi et al. (1998) and Wanyama et al. (2003) acknowledged farmer's participation in on-farm trials, farming experience and land ownership as influencer of range pasture production technologies adoption.

Effect of agro pastoralists' attitudes and incentives on the adoption of range pasture improvement technologies

Although one would expect incentives to influence adoption of pasture improvement technologies, this study found that majority (81.6%) of respondents did not behave the same. However, they suggested that better farm gate milk prices 88 (29.9%), continued sensitization 64 (21.8%), financial support 54 (18.4%), better results from adopters 9 (3.1%) and support with inputs 8 (2.7%) would motivate them to improve their pastures. Surprisingly, some respondents 17 (5.8%) still mentioned that they would not be motivated for pasture improvement claiming it was not necessary. Through the interview of key informants, one elder acknowledged reduction in farm gate milk prices due to increasing milk processing plants and abolishment of milk vendors. In his words, the farmer asserts that with milk vendors, the price of milk would reach Uganda shillings 1200 per liter in the dry season compared to shillings 550 per liter currently". Another farmer mentioned that, "we improve pastures to minimize death of our livestock in drought but it is not a profitable venture". They claimed this demotivates farmers. The results also indicated that the pastoralists who adopted the technologies were motivated by accessing knowledge through farmer trainings by extension agents, persistent drought that results in loss of pastures, access to financial support and support with inputs mostly pasture seeds.

Enhanced farm productivity, better products' prices, and inputs motivate farmers to invest in technology as they see benefits increment rather than lose. Sensitization is key for knowledge acquisition. The more contact with extension workers, the more likely the farmer to adopt technology. This is probably because extension agents would be focused achieving their own planned extension activities. Attitude and behavior of farmer play a major role in decision making. The negative attitude by farmers towards adoption of range pasture improvement could be attributed to farmers' risk orientation of the technologies, inferiority complex of implementing technologies from highly educated extension worker, fear to make mistakes in implementation, fear of additional expenditure that may come with the implementation and anticipated work drudgery.

Ambetsa et al. (2020) on their assessment of technical efficiency in Kenya, found a higher likelihood of sugar cane farm output from application of farm inputs like fertilizer, labour, seed-cane and farm size as technologies for technical efficiency. Baba et al. (2017) showed that the attitude and behavior of the farmers had a positive effect on the rate of technology adoption of goat farming. Arega (2009) found that extension information was important in adoption of new technologies. On the other hand, lack of market information, financial risks, and access to markets reduce farmers 'incentives to adopt range pasture improvement practices and technologies. However, some studies have indicated that characteristics of innovations comprising relative advantage, complexity, compatibility, trialability and observability, technology characteristics, information sources, knowledge, awareness, attitude and group influence (Oladele, 2005; Moyo and Salawu, 2017). A conceptual framework for an adoption pathway by Mohammad et al. (2003) suggested that farmers move from learning to adoption, to continuous or discontinuous use over time. This explains why in this study area, farmers who initially had adopted, dropped out and recently readopted again.

The forage species adopted by agro pastoralists and strategies for their sustainable utilization

Field observation recorded a number of pasture fields were established by either integrating them in the cropping system or grown in sward and some limited forage conservation technologies carried out. The variety of pasture species both natural and introduced species ranged from grass pasture including *Chloris gayana, and Pennisetum purpureum*, to herbaceous legumes that included *Dolichos (lablab)*, *Stylosanthes spp*, Siratro and *Centrocema spp* and browse species that included *Calliandra calothyrsus.* and *Glyricidia sapiuem* were the

Table 6. Pasture species, area coverage and utilization in study areas.

Pasture species established	Pasture land coverage in acreage in study area	Method of utilization
Chloris gayana	166.25	Hay making, Seed production for sale
Pennisetum purpureum	62.25	Silage, cut and carry
Brachiaria spp	4.5	Field grazed
Pannicum maximum	1.25	Hay making
Herbaceous legumes	25.5	Hay, cut and carry
Woody legumes	1.5	Cut and carry
Maize	30	Silage making

Source: Authors' computation from field survey data 2018.

most abundant browse species (Table 6). Unlike other more arid lands that would not support the growth of improved pasture species like *Pennisetum purpureum* and *Chloris gayana*, Kiruhura district has moderate rainfall that can support establishment of pasture species albeit with good agronomic practices. The most common natural grass species maintained were *Themeda triandra, Pannicum maximum and* Brachiaria spp*.,* while *Chloris gayana, Pennisetum purpurieum*were the more abundant improved grass species. Selective adoption of *Chloris gayana* and *Pennisetum purpureum* could be due to their seed availability, favorable climate, ease of establishment, specie's productivity and their long time experience with the animals utilizing related varieties since they exist in their natural environment. Crop residues utilization though on a small scale, was found commonly used in households with small herd size and practicing crop production although no effort was made to enhance utilization. Crop residues included maize stovers, bean husks, banana vines and banana peels. It was also acknowledged during KII interviews and observation during field excursion that due to poor management such as overgrazing, overstocking, continuous grazing, mis-use of fire, there was very low recruitment of desirable species and the pastures have been invaded by weeds with common weedy species including *Sporobolus pyramidalis*, *Lantana camara*, *Solanum incanum, Cymbopogon nardus* and *Acacia hockii.* Similarly, a wide range of broadleaved weeds also invaded some of these pastures. These include: *Clerodendrum spp.*, *Urena lobata*, Sida spp among others. Maize for silage production, woody legumes and *Pannicum maximum* were planted by a negligent number of respondents whereas the respondents identified the financial support by the government and provision of pasture seeds by research institutions and NGOs as a big push to farmers. The total acreage planted with pastures by sampled farmers was about 302.5 acres with mean total pasture establishment acreage for adopters of 1.03±0.22 acres. The study revealed that the concept of pasture improvement and utilization in qualitative terms was lacking in adopter farmers as most of them did not own the technologies whereas others could not link harvesting maturity, processing conditions, storage and voluntary intake by animals. The dominant utilization practice was continuous grazing contrary to controlled grazing allowing for pasture resting that can be achieved through rotational grazing. Hay and silage making were not common since they were adopted at low rate and often poorly handled. Some did not mind quality of the pastures as most of them were overgrown and preserved in a poor environment. While others used hay to mulch their banana plantations claiming it makes better mulch without applying economic reasoning. It appears that in this study area, the species of pasture grown by the farmers were influenced by the promoters including development agents who hard targeted seed multiplication for their business albeit with limited information to farmers, farmers' exposure during exhibitions and guidance from extension workers. The farmers did not display knowledge of pasture nutrition value and utilization but rather physical or qualitative value of the species. This is contrary to Mganga (2013) who reports that the species of choice for a majority of livestock farmers in the ASALs of Kenya was greatly influenced by the forage value for livestock.

Although sustainable utilization of improved pasture would expect forage harvesting at appropriate maturity and preservation in form of hay or silage accordingly, very few farmers practiced these technologies moreover not considering quality loss. This could be due to labor associated problems, lack of knowledge and/or lack of necessary equipment including silos and barns. Ndathi (2013) observed that most farmers did not conserve the harvested feeds well mainly due to inadequate skills and lack of conservation structures. According to Peters and Lascano (2003), close linkages between farmers, researchers, private sector, and extension workers are essential for both the development and diffusion of improved multipurpose grass and legume species.

The players and their roles in range pasture improvement promotion

The study established that individual, public and private

Table 7. Farmers' restrictions of pasture improvement per studied sub county.

Restrictions to pasture improvement	Sub county			
	Nyakashashara % (n=75)	Kenshunga %(n=78)	Burunga % (n=69)	Kazo % (n=72)
Limited knowledge on pasture production	28	39.7	69.6	59.7
Low farm gate milk prices	20	65.4	36.2	59.7
Limited capital	68	28.2	30.4	43.1
Limited labor	69.3	21.8	33.3	33.3
Prolonged and frequent drought	50.7	30.8	29	13.9
Limited access to pasture seeds	48	9	43.5	11.1
High costs of inputs	13.3	21.8	24.6	20.8
Limited gov't policy intervention on milk prices	22.7	17.9	21.7	12.5
Negative farmers' attitude	6.7	6.4	20.3	20.8
Limited access to equipment/farm tools	17.3	11.5	1.4	12.5
Termite destruction of forages	1.3	10.3	5.8	4.2
Destruction of forages by wild animals	14.7	0	0	0
Poor quality pasture species	4	1.3	4.3	0

Source: Authors' computation from field survey data 2018.

sector play a major role in range improvement with each player providing a specific package depending on their interests and capacity. Among public sector players include: research organization and academic institutions who undertake on research; and the extension sector who provide knowledge and farm inputs to farmers. The Ministry of Agriculture Animal Industry and Fisheries (MAAIF) extension departments provide farmers with inputs like quality pasture seeds, fencing materials and mechanized labor like tractors for ploughing. Private sector is mainly involved on produce marketing thus sensitization on standards, contracting farmers and such sometime they determine pasture seed varieties, to be produced by farmers and support with enabling resources such as fencing materials to partnering farmers in pasture seed production. A number of local and international CSOs support farmers with inputs and advocacy for access to better services.

The presence of several players in Kiruhura district could probably be attributed to the social capital of politician, production system, the high livestock population, the willingness of farmers to transform from agro pastoralism to improved herds for dairy farming due to increasing demand for dairy products, the establishment of dairy cooperative union and moderate favorable climate, and farmers' partnership with academia in dairy research. Hanyani-Mlambo et al. (1998) acknowledged that the researchers and extension specialists placed emphasis on on-farm research and farmer-to-farmer extension to provide evidence to farmers of the economic benefits and costs of legume forages. Francis and Sibanda (2001) as well as Hanyani-Mlambo et al. (1998) found that potentially effective technologies and management strategies were promoted through participatory action research (PAR) involving farmers, researchers and extension workers in order to ensure sustainable livestock farming.

Farmers' limitation of range pasture improvement in Kiruhura district

Efforts by Agro pastoralists in the Kiruhura district face a multitude of constraints as they attempt to improve range pastures to enhance livestock productivity. This study showed that agro pastoralists in the study area suffered from limited knowledge, low milk prices, lack of capital, lack of labor, lack of pasture seeds, and prolonged drought conditions among that restricted or demotivated them from investing in range pasture improvement (Table 7). The average milk price per liter was 1000 Uganda shillings.

The above limitations could be attributed to the climate failure, poor infrastructure development, and low education level associated with culture, lack of competitor in dairy products markets and failure of farmers to actively participate in strengthening of cooperative Unions. Low and erratic rainfalls coupled with high evapotranspiration rates are known to be the major limiting factors for primary productivity in the semi-arid areas. Changing climate with prolonged droughts make dry season feeding a big problem for livestock in semi-arid areas rangelands. This certainly would necessitate application of climate smart technologies such as irrigation, and feed conservation technologies to cater for periods of scarcity. The increasing frequency of drought in the semi -arid areas is a major source of concern for farmers. This is due to the direct effect on natural pastures that get depleted in the short or long term. In many of these grazing areas, majority of nutritive natural species that are traditionally adapted have either disappeared and been replaced by annuals, shrubs, bush, bare patches and unpalatable species that may be invasive.

Consistent with the findings of this study were the studies by Kabirizi et al. (2004), Mapiye et al. (2006) and Maleko and Koipapi (2015) who cited high cost of inputs, low yields and lack of persistence of legumes, lack of capital, land shortage and shortage of labor as major constraints to adoption of forage legumes. Poor pastures caused by bush encroachment lead to low livestock carrying capacity as was acknowledged by Sangeda and Maleko (2018). Poor agronomic practices due to lack of policy guidelines, low capita for proper investment, negative pastoralists' attitude towards range improvement, invasion with invasive species and abundance of termites all lead to rangeland degradation affecting livestock productivity. Bolo et al. (2019) identified related causes of rangeland degradation as overgrazing, overgrazing, climate change and variability, Invasive/alien species and bush encroachment and Breakdown of traditional governance systems and unsuitable government policies/by-laws as causes of rangeland degradation in Kenya. Constraints on any of the factors of production can inhibit uptake of forage technologies (Kabirizi et al., 2004). Kumwenda and Ngwira (2003) acknowledged that such constraints are severe among the resource-poor smallholder dairy cattle farmers for whom forage legume technologies are most needed.

CONCLUSION AND RECOMMENDADTIONS

(i) Socio-economic, technological and institutional factors are key drivers for farmer decision in investment in range pasture improvement technologies. These including the level of education, farm size, household income, off farm activities, access to credit, household access to laborers, extension support and belonging to a farmer organization.
(ii) Limited knowledge on range management principles, low milk prices, lack of capital and labor, and prolonged drought conditions, higher costs of inputs restrict and demotivate farmers from investing in range pasture improvement. Pastoralists should be organized into cooperatives to enhance their decisions on determining the farm gate prices and demand for better extension services and access to farm inputs.
(iii) Farmer support systems including participation in agricultural exhibitions, attending farmers' meetings, holding on-farm demonstrations, access to farm inputs and attending trainings for knowledge and skills enhancement and confidence building are very important in encouraging farmers to improve their animal feed resources.
(iv) Proper understanding of proper range management principles and the adoption of range pasture improvement technologies should be promoted through participatory action learning and research involving farmers, researchers, private sector and extension workers in order to ensure its sustainability. However, there is need for regular refresher sensitization sessions and farm follow up to fast track the process and progress of adoption of range pasture improvement technologies.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Evaluation of ten botanical insecticides against the sweet potato Weevil, *Cylas formicarius* (Fabricius, 1798) (Coleoptera: Brentidae)

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The sweet potato weevil, *Cylas formicarius* (Fabricius) (Coleoptera: Brentidae), is a destructive insect pest that damages sweet potatoes both in the field and during storage. To identify new environmentally friendly insecticides to control this insect pest, three assays (olfactory test, anti-feeding assay, and toxicity assay) were conducted to evaluate the efficacy and mode of action of 10 botanical insecticides against *C. formicarius* adults in 2015 and 2016. Of these 10 botanical insecticides, tea saponin, pyrethrins, and veratrine showed significant repellency in olfactory tests. Eight botanical insecticides showed anti-feeding effects in the feeding choice test. Five botanical insecticides had high toxicity. Among them, the lethal concentrations of rotenone were lowest followed by pyrethrins. The lethal time values of rotenone were shortest followed by nicotine. In conclusion, rotenone, pyrethrins, nicotine, and toosendanin have the potential to control *C. formicarius* adults. Of these, pyrethrins and toosendanin are more environmentally friendly than rotenone and nicotine and were identified as better insecticides to control *C. formicarius*.

Key words: Toxicity, repellency, anti-feeding, Coleoptera, Brentidae, environmentally friendly insecticides.

INTRODUCTION

The sweet potato weevil, *Cylas formicarius* (Fabricius) (Coleoptera: Brentidae), is an important insect pest of the sweet potato, *Ipomoea batatas* (L.) Poir.. *C*. *formicarius* attacks sweet potatoes both in the field and during storage, thus causing significant damage and yield losses between 3 and 80% (Kandori et al., 2006). Adult *C. formicarius* damage the vines, crowns, petioles, and storage roots of sweet potatoes, and the females lay their eggs under the epidermis of older portions of vines and storage roots. The larvae then dug tunnels into the vines and storage roots, into which they excrete feces (Reddy et al., 2014). Feeding injuries disrupt the translocation of water and nutrients in plants and induce storage roots to produce terpenoids and phenolic compounds, which

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causes storage roots to develop a bitter taste, and unpleasant smell, ultimately making them inedible (Akazawa and Uritani, 1960).

Traditionally, chemical insecticides are employed to control *C. formicarius* (Zhang et al*.,* 2013; Wang et al*.,* 2018). However, the concealed feeding habits of the weevil decreased the effectiveness of chemical insecticides. The improper use of chemical pesticides also causes “3R” problems (Resistance, resurgence, and residue). Although at present, resistance to a specific insecticide by weevils has not been reported, many other pests, including *Euschistus heros*, *Laodelphax striatellus*, and *Frankliniella occidentalis*, have reportedly developed resistance to insecticides used to control weevils (Castellanos et al*.,* 2019; Zhang et al*.,* 2019; Wang et al*.,* 2012). The difficulties in controlling *C. formicarius* by chemical insecticides may be partly because insecticides tend to induce insect resistance. Sexual attractants, such as (Z)-3-dodecen-1-YL (E)-2-butenoate (Dilipkumar et al*.,* 2019; Reddy et al*.,* 2012; Smit et al*.,* 2001) and microbial pesticides, such as *Beauveria bassiana* and *Metarhizium brunneum* (Reddy et al*.,* 2014), and nematodes (Mannion and Jansson, 1992), also exert a controlling effect on *C. formicarius* populations and have been evaluated as alternatives for chemical insecticides (Yu et al*.,* 2010). However, they work slowly and cannot prevent damage in time (Dotaona et al*.,* 2017).

Botanical insecticides are typically extracted from poisonous plants. Their active ingredients are the secondary metabolites produced by the plant secondary metabolic pathway. These can effectively control a wide range of insect pests, including *Spodoptera littoralis* (Brem et al*.,* 2002), *Xanthogaleruca luteola*, *Ostrinia nubilalis* (Jaoko et al*.,* 2020), and *Coptotermes formosanus* (Mao and Henderson, 2007). Botanical insecticides quickly affect pests, degrade rapidly, are environmentally friendly and target-specific (Singh and Kaur, 2018; Kamaraj et al*.,* 2018). They are considered as better alternatives to chemical insecticides.

Although a number of secondary metabolites that were named botanical pesticides have shown a controlling effect on *Cylas* spp. (Leng and Reddy, 2012; McNeil et al., 2012; Junor et al., 2008; Williams et al., 2003; Nta et al., 2018; Pan et al., 2019), their efficacy and mode of action have not been compared. Therefore the botanical insecticide best for controlling *C. formicarius* cannot be determined.

In this study, the efficacy and mode of action of 10 botanical insecticides with high insecticidal effect and wide insecticidal range against *C. formicarius* adults were evaluated. These insecticides were 25% pyrethrins, 50% rotenone, 6% celangulin, 1% stemonine, 98% matrine, 99% nicotine, 70% cnidium lactone, 1% veratrine, 98% tea saponin, and 2% toosendanin. The findings of this study provide basic data for the development of a powerful botanical insecticide to control *C. formicarius*.

MATERIALS AND METHODS

Insects, host plant material and botanical insecticides

Damaged sweet potato storage roots, containing *C. formicarius* larvae and pupae, were collected from Guangxi University Farm (Nanning, China) in December 2014 and were placed in netting bags (30 cm × 60 cm; mesh diameter 0.25 mm). Then, they were transferred to an insect rearing room at the College of Agriculture and were raised at 24 ± 2°C, 70-80% relative humidity, and a photoperiod of 14:10 h (L:D). When adult weevils appeared, additional sweet potatoes were added to the netting bags to enable reproduction and subsequent larval development. The second-generation adult weevils (5-8 days after emergence) were collected for experiments. The sweet potato variety ‘Jidanhuang’ was used in the experiment. The storage roots of sweet potatoes were washed with tap water to feed weevils. The washed storage roots were cut into strips (2 cm × 3 cm × 7 cm) for bioassay.

The following ten botanical insecticides were purchased from Shaanxi Angsheng Biomedical Technology Co. (Xi’an, China): pyrethrins (25%, from *Tanacetum cinerariifolium*), rotenone (50%, from *Derris trifoliata*), celangulin (6%, from *Celastrus angulatus*), stemonine (1%, from *Stemona japonica*), matrine (98%, from *Sophora flavescens*), nicotine (99%, from *Nicotiana tabacum*), cnidium lactone (70%, from *Cnidium monnier*), veratrine (1%, from *Veratrum nigrum*), toosendanin (2%, from *Melia azedarach*), and tea saponin (98%, from *Camellia sinensis*). High-performance liquid chromatography was used to determine the content of active ingredients of these botanical insecticides.

Olfactory test

A Y-tube olfactometer was used for olfactory tests to determine the repellency effect of different botanical insecticides on *C. formicarius* adults. The two arms of the Y-tube olfactometer (two arms and one stem, 15 cm in length, each at a 120° angle, and with an inner diameter of 2.0 cm) were connected to odor bottles. One of the odor bottles contained the botanical insecticide. An air pump (VLC6503-24V with a speed governor TAA02-24V, Chengdu Qihai Electromechanical Manufacturing Co. LTD, Chengdu, China) was connected to the stem of the Y-tube, and was used to draw charcoal-purified clean air from the odor bottle to the Y-tube. Airflow through each of the Y-tube arms was set to 200 ml·min^{-1} (combined flow 400 ml·min^{-1}) (Yan and Wang, 2006). All olfactory tests were undertaken in complete darkness (the olfactometer was covered with a black cloth).

One of the botanical insecticides (0.1 g) was added into one of the odor bottles. The other odor bottle was left empty and was used as control. Groups of 10 adult weevils that were starved for 3-4 h were introduced into the Y-tube via the entrance of the stem. The air pump was activated and continued to pump for 5 min. After 5 min, the number of adult weevils in each arm was recorded. Weevils that did not enter any arm were not included in the analysis. Each weevil was tested only once and then discarded. When each botanical insecticide had been tested, the olfactometer was cleaned with neutral soap and 99% acetone and dried in an oven (60°C) for at least 2 h. Six replicates were applied for each insecticide.

Antifeedant assay

The two-choice test was used to determine the antifeedant activity of each botanical insecticide. The active ingredients of the botanical insecticides were prepared into four concentrations (0.25, 0.5, 1, and 2 g·L^{-1}) with deionized water + Tween 80 (0.5%). Sweet potato strips that had been used for the bioassay were completely immersed in one of the prepared dilutions of the botanical insecticides for 5 to 8 s as treatments or were immersed in deionized water + Tween 80 (0.5%) for 5-8 s as control. All treatments and control strips were removed and air-dried for 30 min with a fan at 24 ± 2°C. Then, one treatment strip and one control strip were transferred into both ends of a horizontal transparent plastic cylinder (60 cm in length and 18 cm in diameter). Ten adult weevils, starved for 3-4 h, were introduced into the middle of the cylinder, and the number of feeding holes on both treatment and control sweet potato strips were recorded after 24 h. Five replicates were applied for each treatment.

Toxicity assay

The no-choice test was used to determine the toxicity of each botanical insecticide. During the first round of tests, the active ingredient of the botanical insecticides was prepared into four concentrations (0.25, 0.5, 1, and 2 g·L^{-1}) with deionized water + Tween 80 (0.5%). Sweet potato strips were treated with the same method as for the antifeedant assays. The treated sweet potato strips were transferred into treated glass bottles (12 cm in height and 12 cm in diameter). The inner wall of these glass bottles was treated with the same diluted botanical insecticides and then air-dried. Each bottle contained one sweet potato strip, and the bottles were covered with a piece of netting cloth (16 cm × 16 cm). Control sweet potato strips were transferred into control glass bottles (the inner walls of which were treated with deionized water + Tween 80 (0.5%) and air-dried). Twenty adult weevils, which were starved for 3-4 h, were introduced into each bottle. The number of dead weevils in each bottle was recorded after 24 and 72 h. Three replicates were applied for each concentration of each botanical insecticide.

According to the results of the first round of tests, insecticides with high toxicity were chosen. Different concentrations of active ingredients were prepared to identify the concentration range that induced a mortality rate between zero and 100%. These included 25% pyrethrins, 50% rotenone, 2% toosendanin, 99% nicotine, and 6% celangulin. The used experimental method was the same as that of the first round of tests. After 24 and 72 h of treatment, the number of surviving weevils in each bottle was recorded. Three replicates were applied for each concentration of each botanical insecticide. Then, five insecticides were prepared at a single concentration, and the number of surviving weevils was recorded every 2 days after treatment. This identified the time range that induced a mortality rate between zero and 100%. The method was the same as the first round of tests. Three replicates were applied for each botanical insecticide. All bioassays were performed in a bioassay laboratory at 24 ± 2°C, 70-80% relative humidity, and a photoperiod of 14:10 h (L:D).

Statistical analysis

The repellency rate was calculated using the following equation:

$$\text{Repellency rate (\%)} = \frac{C - T}{C + T} \times 100$$

where T represents the number of *C. formicarius* adults in the Y-tube treatment arm, and C represents the number of *C. formicarius* adults in the control arm. Independent sample t-test was used to analyze the significance between the number of *C. formicarius* adults in the treatment arm and that in the control arm.

The antifeedant rate was calculated in the same way as the repellency rate. However, here, T represents the number of feeding holes of *C. formicarius* adults on the treated sweet potato strip, and C represents the number of feeding holes on the control sweet potato strip. Independent sample t-test was used to analyze the differences between the feeding holes of *C. formicarius* adults on the treatment strip and the feeding holes on the control strip. Tukey's multiple comparison test was used to assess the differences in antifeedant rates of different botanical insecticides and different concentrations. Results with $p < 0.05$ were considered significant. The adjusted mortality for the toxicity assay was calculated using Abbott's formula (Fleming and Retnakaran, 1985) as follows:

$$\text{Adjusted mortality (\%)} = \frac{C - T}{C} \times 100$$

where T represents the number of surviving adults in treatment bottles and C represents the number of surviving adults in control bottles. Tukey's multiple comparison test was used to evaluate differences in the adjusted mortality rate between different botanical insecticides. The adjusted mortalities were arcsine-transformed prior to ANOVA.

Concentration–mortality data and time–mortality data were subjected to probit analysis to identify the lethal concentrations that cause 50 and 90% mortality (LC_{50} and LC_{90}), the time required to cause 50 and 90% mortality (LT_{50} and LT_{90}), their 95% fiducial limits, and chi-square values. The data were analyzed using SPSS version 22.0 (IBM Corp., Armonk, NY, USA) for Windows 10.

RESULTS AND DISCUSSION

According to the olfactory test, tea saponin (T = 5.477, df = 10, $p < 0.0001$), pyrethrins (T = 4.635, df = 10, p = 0.001), and veratrine (T = 2.997, df = 10, p = 0.013) exhibited a significant repellency effect against weevils. Cnidium lactone (T = 2.236, df = 10, p = 0.089) and celangulin (T = 0.649, df = 10, p = 0.552) had a repellency effect, but they did not exhibit a significant difference compared with control. Toosendanin, matrine, stemonine, nicotine, and rotenone had no repellency effect. The repellence effects of different botanical insecticides were significantly different (F = 3.153, df = 9, 50, p = 0.004) (Figure 1). The results of the olfactory test showed that the olfactory organ of the weevil plays a role in insecticide recognition. Moreover, the protective effect of several botanical insecticides on plants may be partly associated with the odor of the insecticides.

In the antifeedant assay of the 10 tested botanical insecticides, pyrethrins exhibited the strongest antifeedant activity, which was followed by toosendanin. Veratrine, stemonine, matrine, rotenone, tea saponin, and nicotine also exhibited antifeedant activity, but only at high concentrations. Cnidium lactone and celangulin had no antifeedant activity (Table 1). These results showed that antifeedant activity was very common in the tested botanical insecticides.

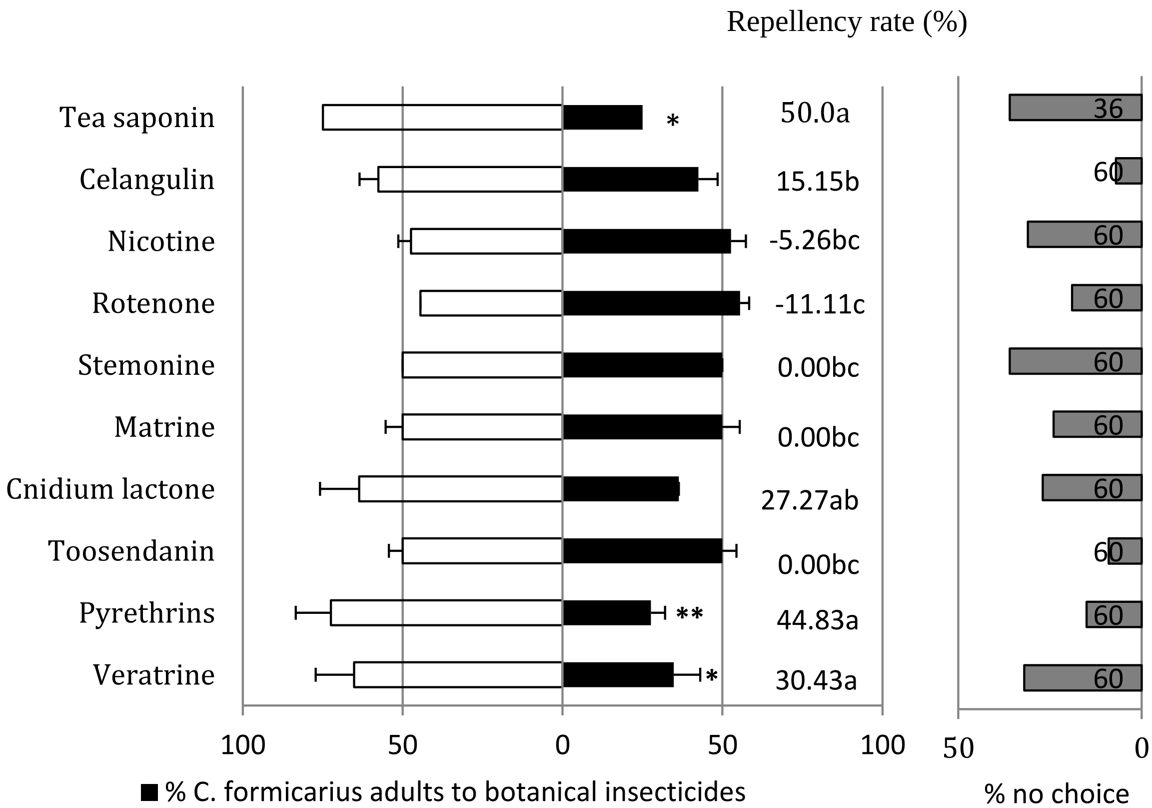

Figure 1. Repellence effect of the botanical insecticides on *C. formicarius* adults in two-choice tests. * represents significant difference between the number of *C. formicarius* adults in the treatment arm and the control arm at the 5% level according to t-test; ** represents the 1% level. Error bars indicate SE. The right bar plots indicate the percentage of no choice in each test and the total number of tested *C. formicarius* adults is shown on these bars. The repellence rate (between the two bars), followed by the different lowercased letters, indicate significant differences among different botanical insecticides at the 5% level, according to Tukey's multiple comparison test.

In the toxicity assay of these 10 botanical insecticides, five botanical insecticides showed high toxicity and rotenone exhibited the highest toxicity. At 72 h after treatment, the adjusted mortality of rotenone at concentrations of 1 and 2 $g{\cdot}L^{-1}$ reached 100%. Pyrethrins showed the second-highest toxicity with an adjusted mortality of 78.33% at a concentration of 2 $g{\cdot}L^{-1}$. Toosendanin and celangulin showed moderate toxicity. Cnidium lactone, matrine, tea saponin, and stemonine showed weak toxicity. The adjusted mortality was only 3.33-8.33% at 2 $g{\cdot}L^{-1}$ after 72 h (Figure 2). Different lowercased letters above the bar indicate significant differences in different botanical insecticides according to one-way ANOVA ($p < 0.05$).

Concentration–mortality probit analysis was performed on five botanical insecticides with high mortality. The results showed that rotenone had the highest toxicity. The LC_{50} values of rotenone were 0.016 and <0.001 $g{\cdot}L^{-1}$ at 24 and 72 h after treatment, respectively, which was followed by pyrethrins and toosendanin. The LC_{50} value of celangulin exceeded the concentration of the raw insecticide 24 h after treatment. The LC_{90} values of rotenone were 0.068 and 0.006 $g{\cdot}L^{-1}$ after 24 and 72 h, respectively, which was followed by pyrethrins and nicotine. The LC_{90} values of azadirachtin and celangulin exceeded the concentration of their raw pesticides (Table 2). Time-mortality probit analyses showed that the LT_{50} value of rotenone was shortest, followed by that of nicotine, while that of celangulin was the longest. The LT_{90} value of rotenone was the shortest, followed by nicotine. The LT_{90} value of celangulin exceeded 50 days (Table 3).

According to the results, rotenone showed no repelling activity, a certain degree of antifeedant activity, but the strongest toxicity. At the same time, a preliminary experiment showed its moderate fumigation activity (the fumigation mortality rate of 0.1 g of raw insecticide after 24 h of treatment was 66.67%, unpublished data). Several studies demonstrated the high toxicity of rotenone for pests, mites, and nematodes (Li et al., 2017;

Table 1. Antifeedant activity of the botanical insecticides against *C. formicarius* adults in two-choice tests at different concentrations after 24 h of treatment.

Botanical insecticide	Anti-feeding rate at different concentrations (%)			
	0.25 (g·L^{-1})	**0.50 (g·L^{-1})**	**1.00 (g·L^{-1})**	**2.00 (g·L^{-1})**
Veratrine	23.77 ± 5.52^{aB}	38.41 ± 0.75^{aAB}	49.40 ± 3.50^{aAB}*	59.43 ± 6.50^{aAB}*
Pyrethrins	86.47 ± 6.85^{aA}*	90.38 ± 8.00^{aA}*	95.78 ± 2.52^{aA}*	97.92 ± 2.08^{aA}*
Toosendanin	19.33 ± 0.92^{aB}	46.94 ± 9.31^{abAB}	64.92 ± 10.87^{abAB}*	97.87 ± 2.13^{bA}*
Cnidium lactone	27.84 ± 2.55^{aB}	12.15 ± 1.21^{aABC}	-5.61 ± 3.24^{aB}	-0.51 ± 2.05^{aB}
Matrine	3.03 ± 0.50^{aBC}	3.39 ± 0.66^{aBC}	27.31 ± 14.53^{aAB}*	33.90 ± 6.61^{aAB}*
Stemonine	-15.06 ± 5.88^{aBC}	15.70 ± 6.15^{abABC}	46.48 ± 2.74^{abAB}*	69.23 ± 1.58^{bAB}*
Rotenone	3.21 ± 4.83^{aBC}	8.38 ± 7.10^{aBC}	9.57 ± 1.03^{aAB}	35.37 ± 3.35^{aAB}*
Nicotine	-54.02 ± 8.29^{aC}	-51.65 ± 23.33^{abC}	9.40 ± 1.90^{bAB}	39.93 ± 7.31^{bAB}*
Celangulin	-25.06 ± 3.41^{aBC}	-13.00 ± 3.11^{aBC}	12.31 ± 3.59^{aAB}	-14.49 ± 4.63^{aB}
Tea saponin	4.18 ± 0.73^{aBC}	10.10 ± 1.48^{abBC}	19.35 ± 2.23^{bAB}*	35.76 ± 3.65^{cAB}*

Means within a row, followed by the same lowercase letter(s), do not differ significantly at the 5% level according to Tukey's multiple comparison test. Means within a column, followed by the same uppercase letter(s), do not differ significantly at the level of 5% according to Tukey's multiple comparison test. * represents significant differences between the number of feeding holes of *C. formicarius* adults on treatment sweet potato strips and the number of feeding holes on control strips at the 5% level (according to t-test).

Wen et al., 2016) as well as moderate antifeedant activity (Hu et al., 2005). However, the results of others suggest that rotenone can induce Parkinson's disease in humans (Bu et al., 2019; Bandookwala et al., 2019). Nicotine also had no repellence activity, but exhibited moderate antifeedant activity (Rimal and Lee, 2019), high insecticidal activity (Wang et al., 2016), and moderate fumigation activity (the fumigation mortality rate of 0.1 g of raw insecticide after 24 h was 63.89%, unpublished data). However, this botanical insecticide is quickly absorbed into the mammalian bloodstream. From the bloodstream, it is easily transferred to breast milk, causing emphysema, heart rate variability, and histopathological changes in the lung and liver of suckling infants (Kobayashi et al., 2020). Consequently, the application of rotenone and nicotine as insecticides for the control of *C. formicarius* has potential ecological risks (Walia et al., 2017).

Pyrethrins showed a moderate repellence activity (repellence rate 44.83%), the strongest antifeedant activity (antifeedant rate 97.92% at a concentration of 2 g·L^{-1}), and high toxicity (adjusted mortality rate 78.33% after 72 h of treatment at a concentration of 2 g·L^{-1}). Furthermore, pyrethrins had a high fumigation activity (the mortality rate in response to 0.1 g of raw insecticide was 91.67% after 24 h of treatment, unpublished data). The strong antifeedant activity and high toxicity of pyrethrins have been confirmed before (Prota et al., 2014; Paramesha et al., 2018). Moreover, it has been shown that pyrethrin has no significant negative impact on non-target organisms (Papanikolaou et al., 2018). Toosendanin had no repellence activity, but strong antifeedant activity with an anti-feeding rate of 97.87% at a concentration of 2 g·L^{-1} (Jaoko et al., 2020) and moderate toxicity (with an adjusted mortality rate of 56.67% after 72 h of treatment at a concentration of 2 g·L^{-1}) (Ma et al., 2013). The preliminary experiment also identified its high fumigation activity (the mortality rate of 0.1 g of raw insecticide was 92.0% after 24 h of treatment, unpublished data). Toosendanin is an environmentally safe insecticide (Zhang et al., 2007). Therefore, pyrethrins and toosendanin were considered the best environmentally friendly bioinsecticides of all tested insecticides for the control of *C. formicarius*.

Veratrine is an activator of sodium channels in saliva, and induces vomiting (Andrews et al., 1998). The antifeedant activity of veratrine against weevils as identified by this study (antifeedant rate 59.43% at 2 g·L^{-1}) and against *Helicoverpa armigera* as reported by Tian et al. (2018) may be related to its emesis-inducing property. Veratrine also showed moderate repellence activity (repellence rate of 30.43%) and weak toxicity (adjusted mortality rate of 20% at 2 g·L^{-1}). Moreover, veratrine exhibited strong fumigation activity (the fumigation mortality of 0.1 g of the raw insecticide was 96.77% at 24 h after treatment, unpublished data), indicating good application prospect for the protection of stored roots indoors.

Stemonine (Brem et al., 2002) and matrine (Mao and Henderson, 2007) exert an antifeedant effect and have weak toxicity for weevils, but showed no repellence and fumigation effect. Celangulin did not show repellence and antifeedant effects at all. However, it exhibited a weak fumigation effect and had moderate toxicity, which is lower than that of pyrethrin and azadirachtin, and its control speed is also relatively slow (Zhang et al., 2011).

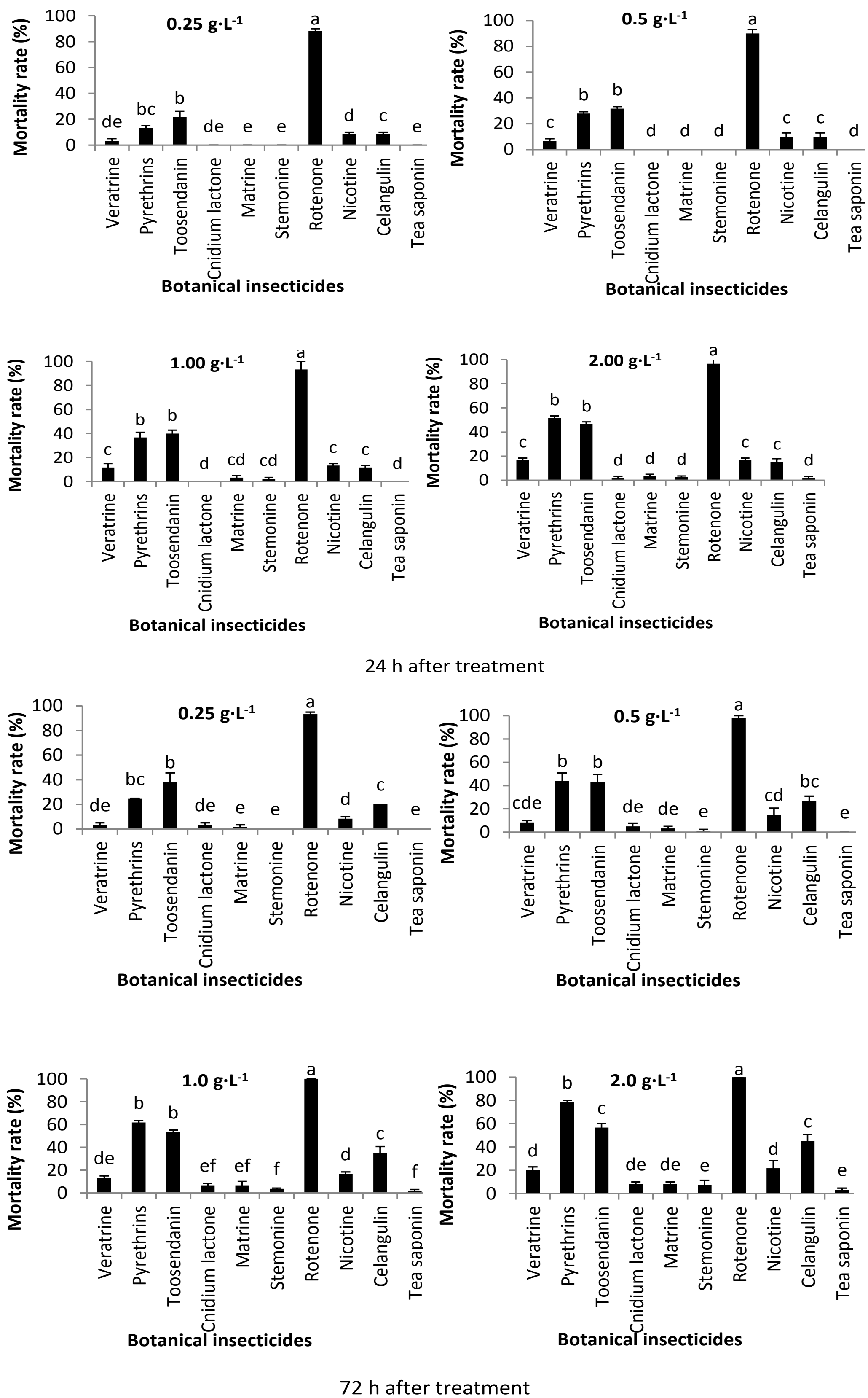

Figure 2. Toxicity effect of botanical insecticides against *C. formicarius* adults in no-choice tests.

Table 2. Concentration–mortality probit analysis of five botanical insecticides against *C. formicarius* adults, at 24 and 72 h after treatment in no-choice tests.

Botanical insecticide	Hours after treatment	N	Slope ± SE	LC_{50} ($g·L^{-1}$) (95% CI)	LC_{90} ($g·L^{-1}$) (95% CI)	X^2	*Df*	P
Pyrethrins	24	240	1.220 ± 0.332	1.646 (0.775-16.659)	18.469 (3.896–+∞)	0.525	2	0.769
	72	240	1.635 ± 0.336	0.648 (0.435–1.481)	3.938 (1.653–28.934)	0.020	2	0.990
Toosendanin	24	240	0.568 ± 0.275	2.874 (0.324–+∞)	-	0.375	2	0.829
	72	300	0.526 ± 0.191	0.950 (0.240–+∞)	-	0.217	3	0.975
Nicotine	24	300	0.834 ± 0.191	11.952 (6.395–50.915)	411.210 (79.625–+∞)	2.341	3	0.505
	72	300	1.522 ± 0.227	3.887 (2.947–5.485)	27.032 (15.214–73.780)	3.781	3	0.286
Celangulin	24	300	0.458 ± 0.276	-	-	0.160	3	0.984
	72	240	0.686 ± 0.220	3.166 (0.832–+∞)	-	0.868	2	0.648
Rotenone	24	300	2.007 ± 0.228	0.016 (0.013–0.019)	0.068 (0.052-0.100)	1.612	3	0.657
	72	300	0.869 ± 0.395	<0.001 (0-0.002)	0.006 (0-0.012)	0.715	3	0.870

LC_{50} = concentration that was lethal for 50% of the weevil population; LC_{90} = concentration that was lethal for 90% of the weevil population. The Em dash (-) indicates that LC_{50} or LC_{90} values were beyond the maximum concentration range for botanical insecticides. X^2 = Pearson's chi-square goodness-of-fit test.

Table 3. Time–mortality probit analysis of the botanical insecticides against *C. formicarius* adults in no-choice tests.

Botanical insecticide	Concentration of active ingredient ($g·L^{-1}$)	N	Slope ± SE	LT_{50} (day)	LT_{90} (day)	X^2	*df*	P
Pyrethrins	0.5	60	1.656 ± 0.301	5.810 (4.541–8.480)	34.509 (18.547–122.877)	2.715	2	0.257
Toosendanin	1	60	1.449 ± 0.278	4.192 (3.220–5.836)	32.103 (16.719–128.916)	3.391	2	0.184
Nicotine	4	60	1.125 ± 0.263	1.614 (0.799–2.319)	22.233 (11.228–125.668)	0.139	2	0.933
Celangulin	4	60	1.523 ± 0.311	7.261 (5.391–12.570)	50.426 (23.246–294.920)	0.091	2	0.956
Rotenone	0.004	60	4.564 ± 0.564	1.344 (1.155–1.544)	2.566 (2.175–3.241)	0.451	2	0.798

LT_{50} = time that was lethal for 50% of the weevil population; LT_{90} = time that was lethal for 90% of the weevil population.
X^2 = Pearson's chi-square goodness-of-fit test.

Several studies have investigated the insecticidal activity of tea saponin (Lin et al., 2018; Rizwan-Ul-Hao et al., 2009; Zhu et al., 2019). In the present study, tea saponin had the strongest repellence and moderate antifeedant activity, but its acute toxicity is insufficient to control weevil in time. At the same time, tea saponin is also an exploitable surfactant (Zhu et al., 2019), which can be added to an insecticide formulation to work as a surfactant, repellent, and antifeedant.

Conclusions

The results of olfactory tests showed that tea saponin, pyrethrins, and veratrine had significant repellence effects against weevils. Antifeedant assay showed that pyrethrins and toosendanin had strong antifeedant activity. Toxicity assay showed that five botanical insecticides had high toxicity. Rotenone had the highest toxicity with the lowest LC_{50} values and LC_{90} values, followed by pyrethrins, toosendanin and nicotine. Time–mortality probit analysis showed that the LT_{50} value and the LT_{90} value of rotenone were shortest followed by nicotine.

Rotenone showed no repellence activity, a certain degree of antifeedant activity, and the strongest toxicity activity. Preliminary experiments indicated its moderate fumigation activity. Nicotine showed no repellence activity, but exhibited a moderate antifeedant activity, toxicity activity, and fumigation activity. However, application of rotenone and nicotine as insecticides for the control of *C. formicarius* induces potential ecological risks. Pyrethrins showed a moderate repellence activity, the strongest antifeedant activity, and high toxicity. Furthermore, its high fumigation activity was high. Toosendanin showed no repellence activity, but strong antifeedant activity and moderate toxicity. A preliminary experiment also identified its high fumigation activity. Neither of the two botanical insecticides had significant negative impact on non-target organisms. Therefore, pyrethrins and toosendanin can be considered the best environmentally friendly bioinsecticides for the control of *C. formicarius*._Veratrine showed strong fumigation activity and moderate anti-feeding activity, indicating its application prospect for the protection of roots stored indoors. Although tea saponin is less toxic to weevils, it had the strongest repellent ability, moderate anti-feeding activity and good surfactant activity, suggesting its merit as surfactant that can be added to insecticide preparations.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Effect of calorie protein ratio on the growth performance and haematology of two strains of pullet chicks

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In a 56 days experiment, 432-day old chicks were used to determine the influence of varying levels of calorie:protein ratio on the growth performance and haematology of two strains of commercial pullet chicks. Each of the strains, (i)Nera Black (NB) and (ii)Isa Brown (IB) were randomly allocated to three dietary levels of calorie:protein ratio designed to contain normal calorie:protein ratio (NC:P), high calorie:protein ratio (HC:P) and low calorie:protein ratio (LC:P). This gave a total of six treatments, replicated thrice to give 18 replicates comprised 24 birds each. Results showed that strain effect was significantly (p<0.05) higher in NB for average daily feed intake (ADFI) 27.81g and average daily weight gain (ADWG) 9.20g and lower (p<0.05) feed conversion ratio (FCR) 2.99 than corresponding values for IB. Strain effect also influenced (p<0.05) all haematology indices except haemoglobin, red blood cell and basophils. It also affected the serum indices at higher (p<0.05) values for glucose, calcium, and phosphorus in NB chicks. Calorie:Protein ratio effect was significantly higher (p<0.05) in ADFI (29.64g) for birds fed HC:P while those on NC:P recorded ADWG (9.32g) and FCR (2.72). All the haematological and serum indices values were influenced (p<0.05) by the calorie protein ratio effect whereas other determined parameters were not. Strain x Calorie Protein effect on the growth performance showed NB chicks fed HC:P recorded highest (p<0.05) ADFI (30.52g), while those on LC:P had highest ADWG (9.61g). Best FCR (p<0.05) was observed among chicks fed LC:P (2.74) while NB chicks on HC:P showed the best PER (1.51). All the haematology parameters except basophils and serum indices albumin and total protein were significantly influenced (p<0.05) by the strain x calorie:protein ratio. The study showed that Nera Black strain performed optimally than Isa Brown in the tropical zone where the trial was conducted.

Key words: Commercial pullet, high calorie: protein ration: Low Calorie:protein ratio. Normal Calorie:protein ratio.

INTRODUCTION

Feed utilization by the different classes of farm animals is predicated on the availability of the nutrients content of

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which two namely, energy and protein appear to be the major determinants for their evaluation for variables such as cost, suitability, quantity and quality of products (Dawood and Mohammed, 2015; Dairo et al*.,* 2010; Li et al., 2013). The sources of these two nutrients are also very important for optimal growth of the animals.

Research have shown that a good understanding of the precise manipulation of the calorie and protein in the feed improved the growth and production performances of the local *Desi* breed of poultry birds in Pakistan through the genetic constitution of the birds using selective inbreeding and cross breeding (Sahota et al., 2003; Anjum et al., 2012).

Olomu and Offiong (1980) reported a requirement of 23% crude protein (CP) with 2800 kcal/kg metabolizable energy (ME) for broiler chicken, while Onwudike (1983) suggested a CP of 22% and 2900 kcal/kg ME. Ojewola and Longe (1999) established the regime of 27% crude protein in the diets of broiler chicken at starter phase with a decrease to a maximum of 24% during the finisher phase. Most of the requirements recommended for broiler chicks were adapted for the pullet chicks in addition to the values suggested by NRC (1994).

The environmental variations no doubt have impacted the feeding and performance of the various classes of farm animals. Therefore, the manipulation of the calorie and protein contents of the feed was exploited as a way out of the effect of heat overload as a result of calorie intake through the feed. Reports have shown that adequate provision of calorie and protein in the feed of these animals particularly, poultry is not just enough. The values often time recorded are at best called ideal data. However, the interaction between the nutrients especially ME and CP in proportion to one another have been used to ameliorate the heat load and hence help in the management of heat stress for a better performance (Balnave and Brake, 2005; Syafwan et al., 2011).

In Nigeria, most of the pullets on commercial poultry farms are imported from the temperate zones of the world with sharp contrast in weather conditions; therefore, it becomes very necessary to investigate the responses of the pullet chicks to different calorie and protein values which often come with strict instruction in their breeders manuals. It becomes very necessary therefore to investigate the calorie protein regime for some of the common breeds imported as egg type chicken in Nigeria.

MATERIALS AND METHODS

Location of experimental site

The study was carried out at the Teaching and Research Farm of the Ekiti State University, Ado-Ekiti. The town is located on latitude 7° 31[1] and 7° 49[1] North of the equator and longitude 5° 71[1] and 5°27[1] East of the Greenwich meridian. The town has two distinct seasons which are (i) the rainy seasons from May to October and (ii) the dry season that starts from November to April of every year.

Experimental design, preparation of diets, birds and management

The experimental diets for the chicks were formulated to have three regimes of calorie protein ratios indicating 3 factors of Calorie: Protein ratios and designated as (i) Normal Calorie: Protein ratio (NCP) of 165:1; High calorie Protein ratio (HCP) of 167:1 and Low Calorie Protein ratio(LCP) of 160.1. The metabolizable energy (ME) in the diets of the pullet chicks should be about 2850 kcal/kg ME with a crude protein (CP) of about 17% was taken as the standard for a guide. Diets in which the standards were used for these two nutrients gave the normal calorie protein ratio (NCP) of 165:1 (Table 1). The ME was then reduced a bit lower to about 2,700 Kcal/kg with protein of about 16.17% to give high calorie protein ratio (HCP) of 167:1 while the low calorie protein ratio (LCP) diet was obtained by increasing the protein slightly above the standard to about 18% and ME of about 2900kcal/kg to give 160:1 The protein and energy contents of the diets were manipulated to obtain the different categories of the Calorie Protein ratios using the recommended ideal data (NRC,1994). Diet 1 that represented Treatment 1 contained 17.03% CP and 2808kcal/kg ME, the HCP contained 16.17% and 2702 kcal/kg which represented the diet for treatment 2 and LCP while diet three contained 18.04% and 2906 kcal/kg. The above arrangement was done for each of the strains to give six treatments groups (Table 1).

A total of 432 day old chicks that comprised 216 Isa Brown and Nera Black strains each were procured from a reputable hatchery in Ibadan, South west Nigeria and were divided into six treatment groups of 72 day old chicks. The treatment groups were replicated thrice in a 2 x 3 x 3 factorial manner that translate into 18 replicates in all. The factors are 3 calorie protein ratio, 2 strains of birds namely Isa Brown and Nera Black and 3 replicates. Each of the replicate contained 24 day old chicks. Before the arrival of the day old chicks, the brooding house was washed and well fumigated with a mixture of 1 part of $KMNO_4$ to 3 parts of formalin and rested for one week. The pens were allocated to the treatment replicates randomly and well labelled. On arrival, the day old chicks were weighed with initial average weight of 30.00 g/day old chicks and randomly distributed to the replicates as labelled. Routine medications and vaccination were given to the chicks according to the schedule followed by the Poultry Unit of the Teaching and Research Farm. The birds were fed ad libitum for a period of 56 days and data collected as indicated below. The average pen temperature was about 31.5°C at the initial stage and later reduced to about 29.4°C

Data collection

Data were collected on the growth performance, such as feed intake and body weight gained from which the feed conversion ratio and protein efficiency ratio were derived. Mortality of the birds was also recorded.

Blood collection

At the last day of the 8th week of the experiment, 2 ml of blood samples was collected from the pullet chicks' wing veins using sterilized syringe with 22 gauge needles into 18 vacutainer tubes that contained ethylene diamine tetra acetate (EDTA) as anticoagulant while the second set of the blood samples did not contain speck of EDTA. The first set was used to evaluate haematology indices of the experimental pullet chicks such as packed cell volume (PCV), haemoglobin (Hb), red blood cell count (RBC), white blood Cell count (WBC) and the non-differential; while the other set of 18 was used to determine the serum samples namely, total protein, albumin, creatinine, and urea. The two sets of

Table 1. Composition of chick's experimental diets with three calorie: protein ratio (%).

Feed Ingredients	NC:P (165:1)	HC:P (167:1)	LC:P (160:1)
Maize	53.50	48.00	56.00
Groundnut Cake	4.00	3.00	8.00
Soya Bean Meal	12.00	8.00	12.00
Palm Kernel Cake	8.00	9.00	12.00
Wheat Offal	18.80	28.30	8.30
Bone Meal	2.00	2.00	2.00
Oyster Shell	1.00	1.00	1.00
Salt	0.30	0.30	0.30
Chicks' Premix	0.20	0.20	0.20
DL-Methionine	0.10	0.10	0.10
L-Lysine	0.10	0.10	0.10
Total	100	100.	100.
Determined/Analyses			
Dry matter (%)	91.70	92.60	91.50
Crude Protein (%)	17.01	16.17	18.04
Crude Fiber (%)	1.10	5.30	4.00
Ash(%)			
NFE(%)			
Ether extract (%)	17.20	17.90	17.20
ME(Kcal/kg) Calculated	2808	2702	2906

NC:P (Normal Calorie:Protein) HCP (High Calorie Protein) LC:P (Low Calorie:Protein).

Table 2. Effect of calorie protein ratio on the growth performance of pullet chicks.

	Calorie protein ratio				
Parameter	**NC:P (C)**	**HC:P**	**LC:P**	**SEM**	**p-value**
Initial live weight (g/bird)	30.10	30.10	29.90	-	-
Final live weight (g/bird)	526.77 ^{b}	514.70 ^{c}	551.77 ^{a}	0.63	0.0001
Average daily weight gain (g/bird)	8.87 ^{b}	8.65 ^{b}	9.32 ^{a}	0.01	0.0001
Total feed intake(g/bird)	508.00 ^{b}	569.00 ^{a}	486.00 ^{c}	0.049	0.0001
Average daily feed intake (g/bird)	26.43^{b}	29.62 ^{a}	24.97 ^{c}	0.34	0.0001
Feed conversion ratio (FCR)	2.98^{b}	3.42^{a}	2.68^{c}	0.01	0.0001
Protein efficiency ratio (PER)	1.56^{b}	1.52^{c}	1.60 ^{a}	0.01	0.0001
Mortality (%)	0.17	0.50	0.17	0.23	0.49

a ,b ,c Means in the same row with the different superscript are significantly different at ($p<0.05$).

the blood samples were immediately taken to the laboratory of the Department of Animal Production and Health Sciences. The serum in the set of blood without anticoagulants was separated using laboratory centrifuge at 2500 revolution per min in a bench top Harris Centrifuge (Model C2473/2) and stored in a refrigerator at 4^{o}C and later analysed for parameters as indicated for serum above

Chemical and statistical analyses

The experimental feeds was analysed for proximate using techniques described by AOAC (2005) while the metabolizable energy (ME) was calculated using the prediction equation described by Pauzenga (1985) as indicated below,

ME=37 x %CP +81.8 x %EE+35.5 x% NFE

The haematology and serum indices of the blood sample as indicated above were determined according to Sastri (2004). All the data were subjected to statistical analysis using SAS (1987) computer software for ANOVA and means separated by Duncan Multiple Range Test at 5% level of probability. The variables analysed were growth performance, haematology and serum indices.

RESULTS

The effects of calorie protein ratio on the growth

Table 3. Strain effect on growth performance of pullet chicks.

Parameter	Strain s			
	ISA brown	NERA black	SEM	P-value
Initial live weight (g/bird)	30.10	29.90		
Final Live weight (g/bird)	516.94[b]	545.21[a]	0.52	<0.0001
Average daily weight gain (g/bird)	8.69[b]	9.20[a]	0.01	<0.0001
Average daily feed intake (g/bird)	26.50[b]	27.51[a]	0.28	<0.0001
Feed conversion ratio (FCR)	3.05[b]	2.99[a]	0.01	<0.0001
Protein efficiency ratio (PER)	1.54[b]	1.56[a]	0.01	<0.0001
Mortality (%)	0.11	0.44	0.19	0.57

[a,b]Means in the same row with the different superscript are significantly different (p<0.05).

Table 4. Strains X Calorie:protein ratio effects on growth performance of pullet chicks.

Parameter	ISA BROWN			NERA BLACK			SEM	p-value
	NC:P	HC:P	LC:P	NC:P	HC:P	LC:P		
Initial live weight (g/bird)	29.90	30.20	30.10	30.20	30.00	29.60	-	-
Final live weight (g/bird)	510.40[e]	504.55[f]	535.88[c]	543.13[b]	524.86[d]	567.65[a]	0.89	<0.0001
Average daily weight gain (g/bird)	8.58[e]	8.47[f]	9.03[c]	9.16[b]	8.84[d]	9.61[a]	0.02	<0.0001
Average daily feed intake (g/bird)	26.08[c]	28.73[b]	24.70[d]	26.79[c]	30.50[a]	25.23[c]	0.48	<0.0001
Feed conversion ratio	3.04[b]	3.39[a]	2.74[c]	2.92[b]	3.45[a]	2.63[c]	0.46	<0.0001
Protein efficiency ratio (PER)	1.53[d]	1.53[d]	1.56[c]	1.59[b]	1.51[e]	1.63[a]	0.041	<0.0001
Mortality (%)	0.00	0.00	0.33	0.33	1.00	0.00	0.33	0.0012

[a,b,c]Means in the same row with the different superscript are significantly different at (p<0.05).

performance are shown in Table 2. The final live weight (FLW), average daily weight gain (ADWG), feed conversion ratio (FCR) and protein efficiency ratio (PER) were all significantly better (p<0.05) for the pullet chicks fed low calorie protein ratio (LCP) with recorded values of 551.77g, 9.32g , 2.68 and 1.60 respectively. However, this group of chicks showed the lowest (p<0.05) average daily feed intake of 24.97 g (ADFI). Pullet chicks fed diets containing high calorie protein (HCP) ratio recorded significantly higher (p<0.05) average daily feed intake (ADFI) of 29.62g but showed the lowest (p<0.05) feed conversion ratio (FCR) of 3.42 and protein efficiency ratio (PER) of 1.52. Birds fed normal calorie protein ratio (NCP) recorded the next best values of the growth indices after the LCP groups. Mortality of the chicks was not affected at all (p>0.05).

The strain effects on the growth performance are presented in Table 3. The strain effect increased significantly (p<0.05) the ADFI (27.51 g), FLW (545.21 g) and ADWG (9.20g) with better FCR (2.99) and PER (1.56) of NB over the values recorded for IB. The mortality was not significantly (p>0.05) affected at all. Strain x calorie protein ratio interaction on growth performance is shown in Table 4. It significantly increased (p<0.05) the values of FLW (567.65 g), ADWG (9.61 g) and best FCR (2.63) and PER (1.63) for NB pullet chicks fed LCP diet. The IB strains on HCP diet showed the lowest FLW (504.55g). The ADWG, FCR and PER followed the same trend of having the highest values recorded for pullet NB chicks fed LCP diet. The ADFI was significantly highest (p<0.05) for NB chicks fed HCP diet (30.50 g) while the lowest values were recorded by IB chicks on LCP diet (26.79g). Strain x Calorie protein ratio interaction did not influence (p>0.05) mortality of the strains of birds.

Calorie protein ratio effect on haematology is shown in Table 5. The packed cell volume (PCV) was significantly (p<0.05) influenced with highest value recorded by pullet chicks fed the LCP diet (27.50%) while birds on HCP and NCP had similar values (25.83 and 25.33% respectively) but significantly (p<0.05) the lowest. The differentials such as lymphocytes neutrophils and eosinophil were significantly influenced (p<0.05) while other haematology indices such as red blood cell (RBC), white blood cell (WBC) and basophils were not significant (p<0.05).

Table 6 shows the Strain x Calorie protein ratio interaction on haematology. PCV was significantly (p<0.05) higher and similar generally for NB chicks fed with NCP, HCP and LCP diets and IB pullet chicks on LCP diet (27.67, 26.33, 26.33 and 27.33% respectively) while IB on NCP had the lowest value (24.33%). The haemoglobin concentration (Hbc) almost followed the

Table 5. Effects of calorie-protein ratio on haematology of pullet chicks.

Parameter	Calorie:Protein ratio			SEM	p-value	Range
	NC:P	HC:P	LC:P			
PCV (%)	25.33^{b}	25.83^{b}	27.50^{a}	0.30	0.18	22.9-40.7
Hbc (g/dl)	8.22	8.41	8.85	0.21	0.54	7.40-12.2
RBC (x10^{6}µl)	3.53	3.30	3.58	0.16	0.81	1.58-3.82
WBC (x10^{3}µl)	15780.0	15941.7	15975.0	236.12	0.69	9.20-28.6
Lymphocytes (%)	63.67^{a}	63.67^{a}	47.00^{b}	1.36	0.36	5.91-18.4
Neutrophils (%)	29.67^{b}	25.17^{c}	50.50^{a}	1.26	<0.0001	2.23-6.92
Monocytes (%)	3.67	3.33	4.00	0.26	0.67	0.04-0.12
Eosinophils (%)	2.83^{a}	3.00^{a}	1.67^{b}	0.33	0.0019	0.67 – 2.07
Basophils (%)	0.17	0.17	0.50	0.21	0.55	0.36-1.12

^{a,b,c}Means in the same row with the different superscript are significantly different at (p<0.05).

Table 6. Interaction Effect of Strain and Calorie-Protein ratio on haematology.

Parameter	ISA brown			NERA black			SEM	p-value	Range
	NC:P	HC:P	LC:P	NC:P	HC:P	LC:P			
PVC (%)	24.33^{c}	25.33^{bc}	27.33^{a}	26.33^{ab}	26.33^{ab}	27.67^{a}	0.42	0.18	22.9-40.7
HBc (g//dl)	8.11^{b}	8.45^{ab}	9.18^{a}	8.32^{ab}	8.38^{ab}	8.52^{ab}	0.30	0.36	7.40-12.2
Rbc (x10^{6}µl)	3.54	3.45	3.31	3.51	3.15	3.85	0.23	0.74	1.58-3.82
Wbc (x10^{3}µl)	15683.3^{ab}	15700.0^{ab}	15266.7^{b}	15876.7^{ab}	16183.3^{ab}	16683.3^{a}	333.92	0.21	9.20-28.6
Lymphocyte (%)	67.00^{a}	63.33^{ab}	69.00^{a}	60.33^{b}	64.00^{ab}	55.00^{c}	1.92	<0.0001	5.91-18.4
Neutrophil (%)	30.33^{bc}	25.33^{c}	33.33^{b}	29.00^{bc}	25.00^{c}	67.67^{a}	1.79	<0.0001	2.23-6.92
Monocyte (%)	3.33^{ab}	2.33^{b}	4.33^{a}	4.00^{a}	4.33^{a}	3.67	0.37	<0.0001	0.04-0.12
Eosinophil (%)	4.33^{a}	3.67^{ab}	1.33^{c}	1.33^{c}	2.33^{bc}	2.00^{c}	0.46	0.009	0.67-2.07
Basophil (%)	0.33	0.33	0.33	0.00	0.00	0.67	0.29	0.56	0.36-1.12

^{a,b,c}Means in the same row with the different superscript are significantly different at (p>0.05).

same trend as the PCV. The WBC highest (p<0.05) value was recorded by NB chicks fed LCP diet (16683.3x10^{3}µl) and similar to all other groups of chicks of both strains except for IB fed LCP diet that recorded the lowest value of 15266.7 × 10^{3}µl. The lymphocytes (67.00%) and eosinophils (4.33%) values were highest in IB fed with NCP diet while NB on LCP diet showed the lowest (55.00 and 2.00% respectively). Significantly highest (p<0.05) value of monocytes was observed in IB chicks on LCP diet (4.33%) and similar in values recorded by NB chicks on NCP (4.00%) HCP (4.33%) and LCP (3.67); the lowest value was noted in IB chicks fed HCP diet (2.33%). However, the RBC values were not significantly (p>0.05) influenced by the Strain x calorie protein ratio interaction. Strain effect on haematology is shown in Table 7. The PCV, WBC, neutrophils and monocytes in NB pullet chicks have significantly higher (p<0.05) values than the IB whereas the lymphocytes and eosinophils values were higher in IB chicks. However, the haemoglobin concentration (Hbc), RBC, monocytes and basophils values were not affected (p>0.05)

Calorie protein ratio effect did not significantly influence (p>0.05) all the serum indices analysed (Table 8) except aspartate enzyme which was highest for pullet chicks fed HCP ratio diet (68.77 µl). Birds fed diets containing NCP and LCP diets had similar but lower values (61.52µl and 57.97 µl respectively). Strain effect on the serum indices were not significant at all (p>0.05). The strain x calorie protein interaction (Table 9) significantly influence (p<0.05) the serum indices such as creatinine, aspartate and urea values. Isa Brown and Nera Black pullet chicks fed HCP and LCP diets respectively indicated similar but highest (p<0.05) serum aspartate concentrations of 88.15µl and 80.87 µl while IB chicks on LCP ratio had the lowest value (42.17 µl). Highest (p<0.05) creatinine value of 0.83 g/dl was observed in NB pullet chicks fed NCP ratio diet while the IB chicks on same diet NCP ratio recorded the lowest (0.62 g/dl). The urea values followed the same trend as obtained for creatinine. Strain effects on serum indices were not significant among the strains (Table 10).

DISCUSSION

The effect of calorie protein ratio in the diet of the two

Table 7. Strains effect on haematology of pullet chicks.

Parameter	Strains		SEM	p-value	Range
	ISA brown	NERA black			
PCV (%)	25.67^{b}	26.78^{a}	0.24	<0.0001	22.9-40.7
HBc (g/dl)	8.58	8.41	0.17	0.56	7.49-12.2
RBC (x10^{6}µl)	3.43	3.51	0.13	0.71	1.58-3.82
WBC (x10^{3}µl)	15550.0^{b}	16247.8^{a}	192.79	<0.0001	9.20-28.6
Lymphocytes (%)	66.44^{a}	49.78^{b}	1.11	<0.0001	5.91-18.4
Neutrophils (%)	29.67^{b}	40.56^{a}	1.03	<0.0001	2.23-6.92
Monocyte (%)	3.33^{b}	4.00^{a}	0.21	<0.0001	0.04-0.12
Eosinophils (%)	3.11^{a}	1.89^{b}	0.27	0.0001	0.67-2.07
Basophils (%)	0.33	0.22	0.17	0.94	0.36-1.12

^{a,b,c}Means in the same row with the different superscripts are significantly different at (p<0.05).

Table 8. Effect of calorie-protein ratio on serum.

Parameter	Calorie: protein ratio			SEM	p-value	Range
	NC:P	HC:P	LC:P			
Glucose (mg/dl)	211.73^{b}	178.00^{c}	313.45^{a}	5.30	0.008	152-182
Calcium (mg/dl)	21.98^{a}	19.05^{b}	17.93^{c}	0.84	0.0034	9.00-23.7
Phosphorus (mg/dl)	6.78^{b}	9.65^{a}	6.15^{b}	0.55	0.009	6.20-7.90
Cholesterol (mg/dl)	134.74^{a}	132.61^{b}	126.15^{b}	1.41	<0.0001	52.0-148
Albumin (g/dl)	3.01	3.06	3.01	0.17	0.72	3.50-5.50
Total protein g/dl)	4.53	4.19	4.56	0.27	0.61	6.20-8.00
Creatinine (mg/dl)	0.73	0.73	0.68	0.03	0.51	0.90-1.85
Aspartate (LU/L)	57.97^{b}	68.77^{a}	61.52^{ab}	2.55	<0.0001	88.0-208
Urea (mg/dl)	**5.34**	**4.86**	**4.90**	**0.44**	**0.71**	**1.50-6.30**

^{a,b,c}Means in the same row with the different superscript are significantly different at (p>0.05).

Table 9. Interaction effect of strains and calorie-protein ratio on Serum.

Parameter	ISA brown			NERA black			SEM	p-value	Range
	NC:P	HC:P	LC:P	NC:P	HC:P	LC:P			
Glucose (mg/dl)	198.81^{d}	160.68^{e}	272.34^{b}	224.66^{c}	195.32^{d}	354.35^{a}	7.49	0.008	152-182
Calcium (mg/dl)	18.27^{b}	12.44^{c}	16.78^{b}	25.69^{a}	25.67^{a}	19.08^{b}	1.19	0.0034	9.0-23.7
Phosphorus (mg/dl)	6.20^{b}	7.31^{b}	5.30^{b}	7.35^{b}	12.00^{a}	7.00^{b}	0.78	0.009	6.20-7.90
Cholesterol (mg/dl)	128.69^{d}	159.67^{a}	103.43^{e}	140.79^{c}	105.55^{e}	148.78^{b}	1.99	<0.0001	52.0-148
Albumin (g/dl)	3.09	2.97	2.83	2.93	3.16	2.72	0.23	0.73	3.50-5.50
Total Protein (g/dl)	4.72	4.22	4.37	4.33	4.16	4.75	0.38	0.61	6.20-8.00
Creatinine (mg/dl)	0.62^{b}	0.72^{ab}	0.71^{ab}	0.83^{a}	0.74^{ab}	0.66^{b}	0.05	0.04	0.90-1.85
Aspartate (LU/L)	61.90^{b}	88.15^{a}	42.17^{c}	54.05^{b}	56.38^{b}	80.87^{a}	3.61	<0.0001	88.0-208
Urea (mg/dl)	3.71^{c}	5.01^{abc}	5.96^{ab}	6.95^{a}	4.70^{bc}	3.85^{c}	0.29 ()	0.005	1.50-6.30

^{a,b,c}Means in the same row with the different superscript are significantly different at (p>0.05).

strains of pullet chicks showed that low calorie protein ratio diet (LCP) supported lower feed intake and better body weight gain whereas high calorie protein ratio diet (HCP) showed poor body weight and higher feed intake. This implies that lower calorie protein ratio diet was better utilized by the pullet chicks than the high calorie protein ratio (HCP) and the normal calorie protein ratio (NCP) diets (Dairo et al., 2010). This finding is also consistent

Table 10. Strains effect on serum.

Parameter	Strains		SEM	p-value	Range
	ISA Brown	NERA Black			
Glucose (mg/dl)	210.61[b]	258.11[a]	4.33	<0.0001	152-182
Calcium (mg/dl)	15.83[b]	23.48[a]	0.69	<0.0001	9.0-23.7
Phosphorus (mg/dl)	6.27[b]	8.78[a]	0.45	<0.0001	6.20-7.90
Cholesterol mg/dl)	130.60	131.71	1.15	0.52	52.0-148
Albumin (g/dl)	2.96	2.93	0.14	0.72	3.5-5.5
Total protein (g/dl)	4.43	4.42	0.22	0.61	6.2-8.0
Creatinine (mg/dl)	0.68	0.74	0.03	0.51	0.90-1.85
Aspartate (LU/L)	61.74	63,77	2.08	0.66	88.0-208
Urea (mg/dl)	4.90	5.17	0.36	0.77	1.50-6.30

[a ,b ,c]Means in the same row with the different superscript are significantly different at (p>0.05).

with the reports of Aftab et al*.* (2006), and Khan et al. (2011) who investigated the feeding of low calorie protein ratio diets with adequate lysine and methionine supplementation to broiler chickens. The energy in the LCP diets supported adequate consumption of the needed energy for body growth with efficient utilization of the protein. The birds consumed less to produce better body gain whereas pullet chicks on the HCP consumed more to meet energy needs which agreed with earlier report of previous workers that birds eat to meet their energy need (Golian and Moaurice, 1992; Leeson et al*.*, 1993). It should be noted as well that increasing the energy of the diets did not profoundly support body weight gained of pullet chicks in this study which is contrary to the findings of Jafarnejad and Sadegh (2011) who reported an increased in body weight gain of broilers having access to feed with unlimited fat than those that did not have in their diet. Though the component of the experimental diets did not contain vegetable oil, energy increase in the diet of the chicks could be sourced from other feed ingredients. It is also contrary to the report of other workers who found that dietary energy did not influence the body weight gain (Summers et al*.*, 1992; Leeson et al., 1996). This trend was also observed in the poor values of the feed conversion and protein efficiency ratio recorded as the energy in the diets increased for the different groups of chicks fed HC:P and NC:P.

Strains have significant effect on the performance of the chicks. In this study, Nera Black (NB) was observed to respond with better performance indices as the calorie protein ratio in the diet fluctuates. This might have been genetic which tend to agree with the reports of Sahota et al*.* (2003) and Anjum et al. (2012) that breed improvement could actually affect production performance of local breed of Dessi chicken in Pakistan. Nera Black used in this study may have been developed over years to effectively adjust to variation in dietary energy and protein contents in the tropical conditions.

Strain x Calorie protein ratio interaction had profound effect on the growth performance of the two strains investigated in this work. There appeared to be an inverse relationship of the effect on the average feed intake and the average daily body weight gain. Nera Black pullet chicks had significantly better impact of the interaction than the Isa Brown strain it might not be unconnected to some physiological changes which perhaps help the NB to respond positively than IB. Nera Black strain may have developed some physiological responses through some biochemical processes that may have enhanced their basal metabolic rate, physical activity or regulation of thermogenesis with overall consequential better performance (Gabarrou et al., 1997; Decuypere and Buyse, 2006). Research has further supported this view though the physiological uncoupling protein that regulates energy balance and thermogenesis in breeds of chicken with genetic difference might be responsible for the observation in this study (Raimbault et al., 2001; Li et al., 2013)

The various effects have been noted to have the same trend on the observations recorded for haematology and serum parameters. It is noted that Nera Black pullet chicks across the indices evaluated demonstrated better responses to the various interactive effects which agreed with reports from other investigators (Dairo et al*.*, 2010)

In conclusion, low calorie protein ratio diets of pullet chicks appear to be a better option for optimum performance of pullet chicks. There is also strain effect on the utilization of the diet. In this study, Nera Black performed optimally than Isa Brown. Therefore adequate consideration must be given to the energy and protein content to obtain a good calorie protein ratio in the pullet chicks' diet to promote the desired objective in production.

CONFLICT OF INTERESTS

The study was carried out without any conflict of interest as approved by the Departmental and University Ethics Committee.

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Full Length Research Paper

Moving beyond manual software-supported precision irrigation to human-supervised adaptive automation

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This paper "looks across the river" to explore computer engineering applied within agriculture, particularly precision irrigation. It begins with work by the United Nations Food and Agriculture Organization (FAO). They developed guidelines for estimating a crop's water requirements. These guidelines describe a set of equations (Penman-Monteith form) drawn from the physics of evapotranspiration. The equations estimate water loss based on information specific to the crop, soil, terrain, and weather conditions. Many good papers have been published on applications of the hand-held calculator produced from those equations. This present paper addresses the gap between software-supported manual implementation of FAO's equations and full automation. The project reported within transitions theory to practice by creating a proof-of-concept for an adaptive automation process that combines an embedded version of FAO's equations with automated feeds of weather data and connectivity with irrigation controllers. The result is a prototype for an adaptive human-supervised fully-automatic approach to irrigation based on estimated crop moisture needs. With precision irrigation, farmers seek to cope with drought by minimizing water use without devaluing the crop. This present work is another effort in that vein..

Key words: Precision irrigation, distributed systems, water conservation, evapotranspiration, Penman-Monteith, adaptive automation, precision agriculture.

INTRODUCTION

The project described in this paper addresses the gap between software-supported manual implementation of Food and Agriculture Organization (FAO)'s evapotranspiration equations (Allen et al., 1998) and full automation in an adaptive human-supervised context. Precision irrigation is a component of precision agriculture (precision farming), a field of work that combines agricultural knowledge with other fields such as computer engineering, geographic information systems, remote sensing, and meteorology. The main point is to improve or, at least maintain, crop value while using fewer resources such as land, pesticides, water, and fertilizers. It does so while retaining nutrition and without resorting to the risks of genetic mutation.

Given the considerable literature in precision agriculture (Brase, 2006; Lal and Steward, 2016), it is clear that computer engineering can help create adaptive human-supervised automated-control of irrigation systems. Such

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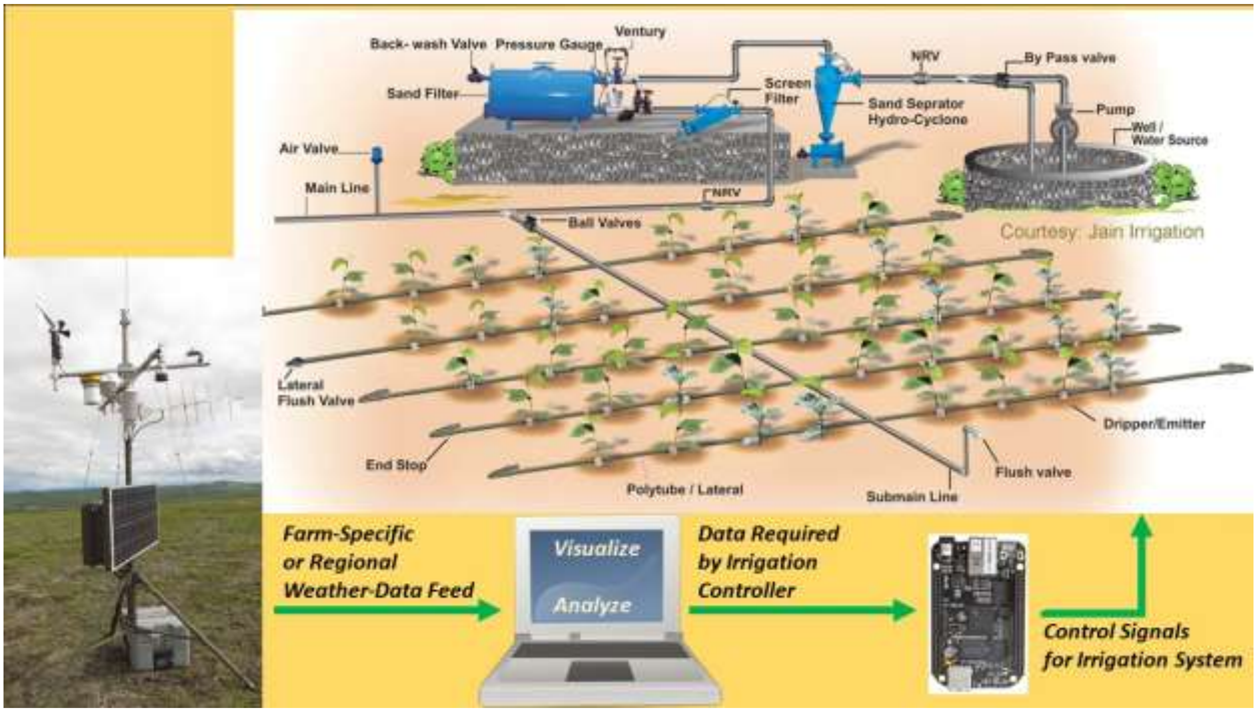

Figure 1. General vision for human-supervised fully-automated irrigation system[i].

control mechanisms have the potential to aid countries stricken by drought as they move beyond their dependence on direct-rain for watering crops. This could extend opportunities to grow crops outside the rainy season, while still not over-farming the land. Precision agriculture's positive impact on Africa has been noted in Shimeles et al. (2018), Ncube et al. (2018), and Jacobs et al. (2018).

Besides growing seasons limited by direct-rain irrigation, drought in many nations requires careful use of water. This leads naturally to control over irrigation so that crops are not over-watered or under-watered. Precision irrigation seeks to improve over methods that rely on fixed schedules and fixed volumes. Based on plant, soil, terrain, and ambient weather conditions, measures are taken to estimate a crop's water needs, and to irrigate on that basis. In the same way that crop health cannot always be estimated by visual observation, the same is true of a crop's water need. By the time the crop or land shows visual signs of dryness, the time when irrigation should have been applied is past. The project reported in this paper makes use of weather data and FAO's evapotranspiration equations to demonstrate an approach to limiting the amount of water drawn for irrigation. The author speaks to how the controller might be built, and discusses what this project has accomplished so far in that regard.

Figure 1 illustrates the general vision. Combining soil, terrain, and plant type, the plant's moisture needs, and actual rainfall, evapotranspiration calculations give an estimate of water loss and, thus, water needs. From there, a decision is made on activating the irrigator for some length of time at a given volume.

RELATED WORK

A number of good papers report on the use of evapotranspiration to reduce irrigation compared to standard schedule/volume watering. These make use of different manual controllers and a hand-held ETo (FAO, 2009). Proprietary irrigation controllers are generally designed for a particular crop, while supporting some variants. The UN's hand-held calculator yields variable-crop capabilities but is not designed to be integrated into an irrigation system so that a fully-automated mechanism can be realized.

Tolbert et al. (2016) worked with flatwood soils and sandy soils. They evaluated evapotranspiration (ET) control and soil-moisture control systems (SMS), with and without careful training of users. Turfgrass was the crop in question. The results were compared to cumulative irrigation with and without consideration of weather. They found that ET and SMS provided essentially equal results. Both were statistically beneficial when compared with conventional volume/schedule watering. A great deal of additional benefit was derived from careful training of users of SMS and ET controllers.

Goodman (2010) took an excellent step toward fully-automated human-supervised irrigation control based on evapotranspiration. He discussed and demonstrated the solution to myriad problems one should expect to encounter in the design and development of such systems. Like Tolbert et al. (2016), they addressed Turfgrass since landscaping is a major use of water in the USA. His evapotranspiration equation parameters are drawn from an online database provided by the State of California, USA. He showed that the target system can be developed using existing technology.

Chin and Auda (2017) introduced Internet of Things (IoT) technology to support a general ability to monitor and affect crops. Their work greatly expands one's vision of what can be accomplished using cloud-based technology and appropriate sensors. Their paper also addresses interfaces that support human supervision so that, while full automation is achieved, computer systems are not totally autonomous.

Yihun (2015) showed that diverted-water irrigation enables Teff production beyond the rainy season (An important point since most Teff production in Ethiopia depends on rainfall). He also developed values for Kc, an important parameter in evapotranspiration calculations. He focused on fine-textured and clay-loam soils, and showed how these values change as the crop grows.

Although beyond the scope of this paper, use of diverted-water irrigation by Yihun (2015) leads one to wonder if the land available for planting outside the rainy season could be expanded if water could be retained instead of being allowed to run off. Bladders developed by Yitbarek (2019) are an option, as are the rain-catch barrels of Munyaradzi et al. (2013a). One must be concerned with how to keep water containers full during the dry season. In Zimbabwe, it is common for trucks to deliver water. Water sources are an issue as well, especially in land-locked nations such as Ethiopia and Zimbabwe. One option is water desalination. Desalinated water could be imported from coastal nations. Technological development of desalination may be reaching the point of affordability, as suggested by Colagrossi (2019). Such matters are worth mentioning since irrigation requires water from somewhere and should not necessarily be limited to diverted natural sources or to rain, whenever rain happens to fall.

Araya et al. (2010) also developed values for Kc but employed a simpler approach than Yihun (2015). Similar to Tolbert et al. (2016), they found that trained users yield statistically significant benefit. In the case of the project reported by this paper, Kc values reported by Yihun (2015) and Araya et al. (2010) were employed to calibrate the FAO's evapotranspiration equations.

Precision irrigation has been found to be very beneficial for Ethiopian Teff crops (Yihun, 2015; Hilemicael and Alamirew, 2017). The thrusts in irrigation mentioned in this section are important since, currently, farming in Ethiopia is heavily dependent on direct rainfall (Kubo et al., 2012). With dependable irrigation and dependable water sources beyond direct rainfall, it may be possible to extend the time during which Teff can be grown, without over-farming the land. This has been demonstrated already in Ethiopia by a project that is collecting rainwater in bladders for use during periods of no-rain (Yitbarek, 2019). Literature found by the author on precision irrigation applied to Teff does not employ a fully-automated approach. By closing the gap between manual software-supported and fully-automated irrigation approaches it is possible that additional water savings could be achieved. This is something that would be beneficial to Africa and supportive of small farmers, thus adding to food security, especially if small farmers collaborate as part of a cooperative.

MATERIALS AND METHODS

Teff originated in Ethiopia and is that country's major crop and where most of the world's Teff is produced (Mottaleb and Rahut, 2018). As this research began, the author was a visiting Assistant Professor of Computer Science teaching at University of Gondar, Ethiopia, ICT Directorate (Information and Communication Technology). This led to the use of that crop as a means of discussing the broader issue of adaptive human-supervised fully-automated precision irrigation. Thus, evapotranspiration equations were calibrated for Teff. There have been several successful precision irrigation applications in Ethiopia for Teff. These rely on evapotranspiration calculations using equations developed by FAO (Allen et al., 1998). The projects cited earlier performed calculations using an international-standard manual calculator produced by FAO (Raes, 2009). Such projects demonstrate the value of applying evapotranspiration considerations to Teff production in Ethiopia.

A problem with FAO's hand-held evapotranspiration calculator is that it does not lend itself to insertion within embedded systems. It would be difficult to employ within a broader range of standard industrial equipment. Therefore, the author began with the 375-page document produced by Allen et al. (1998) and cast evapotranspiration equations in an industrial-standard computer language, C++. This language, employed according to language standards, has proven to be fully portable across Windows and Linux operating systems.

The evapotranspiration equations for ETo and ETc have several parameters. Each parameter is calculated by its own sub-equation, or looked up in a table relative to the crop, soil, and terrain. The work by Allen et al. (1998) is replete with examples, calibration tables, and discussion. These were all employed during design and testing, parameter by parameter and equation by equation, to develop and test new software. Each sub-equation has its own example. These examples were used to assist in creating and testing software in a modular approach. The flow of calculations were were guided in Allen et al. (1998). The result is software that works exactly as specified for whatever calibration or weather input.

ETc is calculated as a modification to ETo for translation from the reference crop to a specific crop. In a study, Allen et al. (1998) give Kc values for numerous crops during various growth phases. These values were produced from various studies under different conditions. There are equations for modifying Kc values for specific conditions that can be applied under standard conditions. However, those equations were not applied in the present phase of the project reported here since Kc is not tabulated for Teff and the papers giving Kc values resulted from specific conditions. The author assumed those conditions so that Kc was used directly, as reported.

Historical weather data was obtained from America's National Oceanic and Atmospheric Administration – National Center for

Environmental Information (https://www7.ncdc.noaa.gov/CDO/cdoselect.cmd?datasetabbv=GSOD&countryabbv&georegionabbv). However, weather data for Ethiopia is not complete. So, a test set for Gondar was constructed for one growing season from what data is available. This gives weather data for testing. If the project goes beyond proof-of-concept, it offers encouragement for producing reliable quality weather data.

For this prototype, physical implementation used a common Windows laptop and a BeagleBoneBlack-Industrial embeddable computer (https://beagleboard.org/black). The laptop, along with the community version of VisualStudio was used for writing and testing of all software, including that installed on the BeagleBoneBlack. The BeagleBone runs the Debian version of Linux and was the only thing purchased for this project, at a cost of $100US. It was chosen because it is a full-up Linux-based computer, contrary to other popular devices that are only microcontrollers. Microcontrollers are limited compared to computers but they do have their place in automation. The BeagleBone is open-source hardware, as are many microcontrollers. That means all construction plans for the hardware are freely available without license. In this case, the project purchased a ready-made industrial version. VisualStudio-Community is free, as is the Debian-Linux operating system. Windows is not free but that is normally a part of common laptops. It is interesting to note that the Windows side of the software could run on an inexpensive Linux computer. There are many ways to architect the hardware. In this case, Windows was chosen since that type of machine was already on hand. Plus, VisualStudio-Community is free and is an excellent software development environment. Generally, there are possibilities for moving to less expensive hardware as the transition from proof-of-concept to implementation proceeds.

Referring back to Figure 1, historical weather data takes the place of the weather station. The BeagleBone is the embedded computer, and the laptop is the laptop in the figure. This prototype did not connect to an irrigation system since that was not available. Instead, the laptop sends a message to the embedded computer, which then activates an LED to show that the signal was received. The LED remains on for as long as the message from the laptop indicates. How long the irrigator operates depends on the amount of water required and the amount of water the irrigator produces per unit of time. The program initializes an amount of moisture available to the crop based on documented crop-moisture needs (It was assumed that the field was appropriately water upon planting). As the days progressed, calculated ETc was subtracted from the moisture available. Rain on that day was added. The difference between needed and actual moisture was made up by the irrigation message.

Kc was derived from a study by Araya et al. (2010). They give their measures of ETo and ETc. ETc = Kc × ETo, so Kc was not difficult to derive. Since that research was conducted under specific circumstances, the derived values for Kc were used without modification. Based on the Kc values relative to growth phase and growth phase determined relative to number of days after planting, an interpolation procedure calculates Kc.

General Kc values in Araya et al. (2010) do require modification for the situation at hand. That software is currently in production.

RESULTS AND DISCUSSION

ETo calculation results were compared to those produced by CropWat (http://www.fao.org/land-water/databases-and-software/cropwat/en). That tool appears to be using a simplified version of the calculations described by Allen et al. (1998). For instance, CropWat seems to use incoming solar radiation instead of net radiation. The result is that this project's software delivers results that are 2 to 4% lower than CropWat. This is expected since incoming solar radiation is always greater than net solar radiation (net = incoming – reflected).

ETc gives an estimate of moisture loss. There may be circumstances where some level of confirmation is needed. Munyaradzi et al. (2013a, b) and Marimbi et al. (2012) have demonstrated the use of inexpensive soil-moisture sensors in outdoor and greenhouse farms. Their results show that the amount of water can be lowered while avoiding over and under watering, and while maintaining or even improving the crop’s value. A concern is not only the cost of sufficient numbers of sensors but also the cost of communicating each sensor’s data. However, there is much potential for improving the economics of farming using their methods. In fact, many of the attributes considered in irrigation scheduling via soil-moisture sensing are the same as those considered in evapotranspiration. Thus, one easily sees the opportunity for a merger of technologies and approaches for precision irrigation.

A great deal of difficulty with weather data was encountered. While a historical database could be accessed, the data for Ethiopia is incomplete and spotty. This was overcome by constructing a dataset for a single planting season. However, this approach serves only for software testing. A reliable source of quality weather data is needed.

In the test case for the present prototype, ETc and that-day rain was employed to calculate the amount of water needing to be delivered by the irrigator. This may well cause overwatering if it were to rain within the next 24 h. But, without reliable and accurate weather data, how does one come to a useful prediction of rain? This is another encouragement for national weather services to produce the required observations. Once the data is in hand, physics-based or statistics-based next-day-rain predictions can be had. If the predictions are accurate, then one would not necessarily water immediately but only if no rain is predicted, or if predicted rain did not occur. This could lead to further water savings. For the project reported here, it is possible that a statistical prediction model could be created from historical weather data. The model could be updated as new data arrives.

As this is a data-driven application, the scalability of data gathering, processing, distribution, and storage is of concern. A preliminary review of the matter indicates that it is possible to set up an expandable highly-reliable system using respected open-source software.

Where reliable and accurate weather data is not available, the installation of a weather station is necessary. Other sources of weather data could be explored. A useful farm-specific weather station costs up to $1500US. There are other sources of weather data that are freely available, besides the one used by this project. Those should be explored and evaluated. Any installed weather station should become a feed into databases that are freely accessible. Should remotely-accessible public systems be necessary, companies such as RackSpace (https://www.rackspace.com) and DigitalOcean (https://www.digitalocean.com) provide hosting for portable software systems. Respected open-source cloud software and other tools can be readily installed and operated. It is not necessary to use restrictive hosting services that prevent portability from one system to another.

Although mentioned last, of greatest importance is collaboration and testing with agriculturalists who are actively dealing with issues of drought. Computers are enabling tools but they are no substitute for experience in the topic area to which they are applied. For example, in the case of precision irrigation, tables of Kc assume the crop is in a given growth phase at a given number of days after planting. But, what growth stage is the crop actually in at any particular time? That is something that an agriculturist must answer. Computers and simulations, even given hordes of real-time plant images and data can only offer an estimate, a best-guess. They are not intelligent. They are just boxes filled with on/off switches. The intelligence lies between the ears of agriculturalists.

Conclusions

By combining research in agriculture and computer engineering, it is possible to embark on a new thread in precision irrigation that goes beyond manual software-supported methods. This thread holds great promise of creating an open-source hardware/software capability that is implementable by small farmers and farming communities if reliable and complete weather data can be achieved. Results in this project to date demonstrate that the technology exists for transitioning research into practical application. There are also possibilities in Controlled Environment Agriculture, an effort to bypass the issues of seemingly random rain and other environmental issues. Bethke and Lieth (2020) provide a broad introduction to that topic.

Water is an essential resource for farming and food security. Drought, or at least insufficient water, is common in Africa and other parts of the world. This project represents another thrust in minimizing water use while still maintaining or even improving crop value. It builds on previous results achieved in Africa and elsewhere. There is much encouragement to continue in this vein.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Effect of sugarcane bagasse ash and manure amendments on selected soil properties in Western Kenya

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This research determined the effects of incorporating sugarcane bagasse ash and cattle manure on soil pH, available P, and cation exchange capacity (CEC) during a 2 seasons' field experiment in Kakamega County of Western Kenya. The experiment used a Randomized Complete Block Design, 3 replications, and a 3 × 3 factorial arrangement of treatments. Sugarcane bagasse ash and cattle manure application showed highly significant effects on soil properties at P≤0.01. The combined application of 5 t ha^{-1} sugarcane bagasse ash with 5 t ha^{-1} cattle manure raised soil pH by 0.18, and with 10 t ha^{-1} manure by 0.17. These increments were higher than the positive control (2 t ha^{-1} lime alone), that raised soil pH by 0.03, while negative control (no amendment) decreased soil pH by 0.01 at the end of the 2nd season. Soil available P increased by 6 ppm due to 5 t ha^{-1} cattle manure and by 4 ppm due to 5 t ha^{-1} sugarcane bagasse ash. Soil CEC increased due to high application rates of cattle manure at the end of the second season. This study concluded that, the incorporation of sugarcane bagasse ash and cattle manure increased soil pH, available P and CEC.

Key words: Available P, bagasse ash, cation exchange capacity (CEC), cattle manure, soil pH, Western Kenya.

INTRODUCTION

Soils in Kakamega County, Western Kenya are predominantly Acrisols, Nitisols and Ferralsols (Jaetzold et al., 1982; NAAIAP, 2014). These soils are strongly weathered, with low pH, available P and cation exchange capacity (CEC) (IUSS Working Group WRB, 2015). The fixation of P in acid soils in the form of Al and Fe phosphates renders it unavailable for uptake by plants (Zhu et al., 2017). These conditions are further aggravated by continual cultivation in small holder farms without adequate replacement of nutrients. The use of inorganic fertilizers and lime to amend soil acidity and improve soil chemical properties is still low with about 7% of the farmers in Western Kenya applying lime (Kenya Markets Trust, 2019). Sugarcane bagasse ashes (SBA)

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Table 1. Basic soil characteristics (0-30 cm).

Soil property	Value
Soil texture	Clay loam
Sand (%)	42
Silt (%)	20
Clay (%)	38
Bulk density (gcm^{-3})	1.4
pH 1:2.5 (Soil water ratio)	5.39
Organic carbon (%)	1.93
Total N (%)	0.18
Available P (ppm)	25
CEC (meq 100 g^{-1})	20

from sugarcane mills in Western Kenya and decomposed cattle manure have the potential to improve soil properties. They are locally available and can provide an alternative for disposal of SBA in a useful way.

Bagasse ash contains micronutrients, secondary macronutrients (Mg and Ca) and primary macronutrients P and K (Khan and Qasim, 2008; Huotari et al., 2015; Benbi et al., 2017; Hale et al., 2020). The major role of Ca in soils and plants in addition to being an essential nutrient is to exclude or detoxify other elements such as Al and Mn present in acid soils (Fageria and Moreira, 2011). Application of manure can result to improved soil physical, chemical and biological properties (Thind et al., 2016). This study determined the effects of SBA and decomposed cattle manure on soil pH, available P, and CEC under field conditions.

MATERIALS AND METHODS

The study site

This research was conducted in Kakamega County of Western Kenya; 34° 36' E and 0° 15' N, altitude 1377 m above sea level (NAAIAP, 2014). The rainfall in this area ranges from 1280 to 2214 mm, and a temperature range of 18 to 29°C in a year (Jaetzold et al., 1982; NAAIAP, 2014). The major soils are Acrisols, Ferralsols and Nitisols, with soil pH ranging between 4.18 and 6.09 (Jaetzold et al., 1982; NAAIAP, 2014). This area has a relative humidity of 67% and undergoes intensive maize cultivation (NAAIAP, 2014). The field experiments included the cultivation of maize (*Zea mays* L.) during the short rain season; September to November, 2019 and long rain season; March to July of 2020.

Experimental design and field layout

The study used a randomized complete block design, with a 3 × 3 factorial arrangement of treatments, and 3 replications. It included 2 factors: cattle manure at the rates 0, 5, and 10 t ha^{-1} and soil conditioner at 0 and 5 t ha^{-1} sugarcane bagasse ash, and 2 t ha^{-1} lime. Plots that received 2 t ha^{-1} of lime were considered as positive controls, while plots that did not receive any amendment were negative controls. Plots of sizes 5 m × 4 m used during this field trials, received the treatments at random.

Soil and manure sampling

The sampling of soil, preparation of samples, and storage, for physical and chemical analyses followed procedures described by Anderson and Ingram (1993). Decomposed cattle manure was collected from Bukura Agricultural College in Western Kenya. The cattle manure was decomposed using composting method, and this followed procedures described by Rynk et al. (1992). The lime was sourced from Omya International AG Baslerstrasse, 42 4665 Oftringen Switzerland www.omya.com.

Analysis of soil physical and chemical properties

Soil texture was determined by Hydrometer method, and soil bulk density by coring method, as described by Okalebo et al. (2002). Soil pH (soil: water ratio of 1:2.5) was measured using a pH meter (Make: Jenway, UK; model: 3510 pH meter) (Mangale et al., 2016). The available soil P was determined by Mehlich Double Acid Method (Mangale et al., 2016); and soil CEC by the ammonium acetate method as described by Anderson and Ingram (1993).

Total nitrogen was determined by Kjeldahl method (Page et al., 1982) and total organic carbon, by Walkley-Black method, following the procedures of Anderson and Ingram (1993). The initial soil properties are presented in Table 1. The pH was low (medium acid) suggesting that H and Al ions toxicity were possible (FAO and ITPS, 2015; Jaiswal et al., 2018); and the soil deficient in nitrogen and P. Soil organic matter content required to be improved (Table 1).

Analysis of experimental soil amendments

The analysis of cattle manure and SBA for the chemical properties: pH, and total elements content, followed procedures and methods described by Okalebo et al. (2002) for plant tissue analysis. The characteristics of the amendments are shown in Table 2.

Land preparation and application of treatments

Land preparation was carried out in the short rain season using a tractor driven plough and harrow. In the long rain season land was prepared manually. The SBA was collected from West Kenya Sugar Company Limited. The bagasse ash was passed through a 2 mm sieve prior to its application in the field to enable a compatible mix with the soil particles. The bagasse ash, manure and lime were placed on top soil (15 cm depth) at planting according to treatments and mixed with soil thoroughly. The mixes were covered with light soil before placement of the seed to avoid seed burn. Maize was planted as a mono crop during the short and long rain seasons, at the spacing of 75 by 30 cm. Two seeds were planted per hill; later thinned to one seedling per hill two weeks after emergence, to give the recommended plant population of 44,444 plants per hectare.

Statistical analysis of data

Data were subjected to analysis of variance (ANOVA) using SAS software for windows 8.2 (TS2M0) 1999 – 2001 by SAS Institute Inc., Cary, NC, USA. Where the Fisher's protected F-test was significant, mean treatments were separated using Least significant difference (LSD) test at $P \leq 0.01$ level of significance. The statistical analyses and presentations for the data on soil parameters were done on the basis of the data collected for the two seasons.

Table 2. Characteristics of soil amendments (manure, bagasse ash and lime).

Sample description	Manure	Bagasse ash	Lime
pH-water	7.40	7.96	
N %	1.98	2.33	
P %	0.31	0.37	
K %	0.52	0.57	
Ca %	0.35	0.38	36
Mg %	0.23	0.25	0.6
Granulated Ca carbonate mm			2 - 6
Ca carbonate %			91
Mg carbonate %			2
Neutralizing value			52
Ca oxide %			51
Mg oxide %			0.9
H_2O %			< 2

Table 3. Interaction effect of manure and soil conditioner on soil pH during the short rain (2019) and long rain (2020) seasons at Kakamega, Western Kenya.

Treatment	Soil pH	Soil pH
	Season 1	Season 2
0 t ha^{-1} manure × 0 t ha^{-1} soil conditioner	5.38^{h}	5.38^{gh}
0 t ha^{-1} manure × 2 t ha^{-1} lime	5.41^{fg}	5.42^{f}
0 t ha^{-1} manure × 5 t ha^{-1} bagasse ash	5.48^{e}	5.50^{de}
5 t ha^{-1} manure × 0 t ha^{-1} soil conditioner	5.56^{c}	5.73^{b}
5 t ha^{-1} manure × 2 t ha^{-1} lime	5.73^{b}	5.85^{a}
5 t ha^{-1} manure × 5 t ha^{-1} bagasse ash	5.54^{c}	5.56^{c}
10 t ha^{-1} manure × 0 t ha^{-1} soil conditioner	5.41^{fgh}	5.42^{f}
10 t ha^{-1} manure × 2 t ha^{-1} lime	5.55^{c}	5.56^{c}
10 t ha^{-1} manure × 5 t ha^{-1} bagasse ash	5.53^{cd}	5.55^{c}
Standard error	0.01	0.01

Means within a column or row followed by same letter are not significantly different at LSD P≤0.01 level of significance.

RESULTS AND DISCUSSION

Effect of SBA and decomposed cattle manure application levels on soil pH in the field

The objective of this study was to determine the effect of sugarcane bagasse ash and cattle manure amendments on soil pH. This was achieved by laboratory analysis of soil samples from the field under maize cultivation before the beginning of the field experiment, at the end of the first and second seasons, then subjecting the data to statistical analyses respectively. The results of the study revealed highly significant interactions among season, manure and conditioners (lime and bagasse ash) on soil pH at P≤0.01. Highly significant differences in pH values between seasons were observed with combinations of 5 t ha^{-1} decomposed cattle manure and 2 t ha^{-1} lime, and application of 5 t ha^{-1} manure with no soil conditioner (Table 3). In these treatments, the soil pH values at the end of the 2nd season were significantly higher than values obtained at the end of first season (Table 3). The interaction of 5 t ha^{-1} manure with 2 t ha^{-1} lime significantly yielded the highest pH values in both seasons.

Treatment 5 t ha^{-1} bagasse ash when incorporated with 5 t ha^{-1} manure gave pH values that were not significantly different in the two seasons but were significantly higher than treatments with no soil amendments in both seasons (Table 3). The results show that the interaction of manure at the rate 0 t ha^{-1} with bagasse ash caused a significant increase of pH compared to its interaction with lime at the end of seasons 1 and 2. However, high improvement of soil pH was observed mostly when lime interacted with either 5 or 10 t ha^{-1} manure unlike bagasse ash.

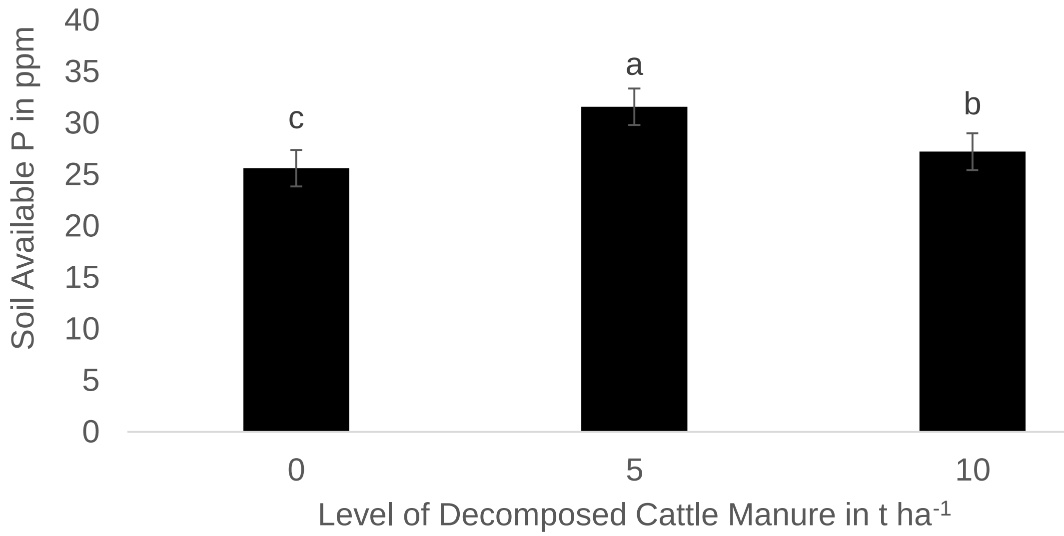

Figure 1. The main effects of manure application levels on soil available P in ppm during the short rain (2019) and long rain (2020) seasons at Kakamega, Western Kenya. The x-axis represents the treatments applied in the field under maize cultivation for 2 seasons. The 0 represents plots where 0 t ha^{-1} decomposed cattle manure was applied, 5 and 10 represent application of 5 t ha^{-1} and 10 t ha^{-1} decomposed cattle manure. The y-axis depicts mean values of available P in parts per million for the 2 seasons. The error bars represent the standard errors (SE). The letters a, b and c represent the means separation using the Least Significant Difference (LSD). Means represented by different letters are significantly different at $P \leq 0.01$. The available P in treatment 0 was 25 ppm; 5 t ha^{-1} 32 ppm and 10 t ha^{-1} 27 ppm at the end of the field experiments.

The initial soil pH value was 5.39, which was not conducive for crop growth due to toxicity of H^+ and Al^{3+} ions (Jaiswal et al., 2018). The application of manure combined with lime, manure only and manure combined with SBA significantly lowered soil acidity. The pH values of SBA and cattle manure were 7.96 and 7.40, respectively confirming their effects in raising soil pH. Liming in combination with farmyard manure is more efficient for acidity indicators than its application alone and reduces the amount of mobile Al to a level that is not toxic to plants (Karcauskiene et al., 2019). Lime (positive control) and manure contained 0.36% and 0.35% Ca and 0.6% and 0.25% Mg, respectively (Table 2). The reaction of lime with soil to release Ca and/or Mg ions into the soil solution leads to increase in soil pH and the reduction in exchangeable Al ions due to precipitation of H^+, Al^{3+}, Fe^{3+} and Mn^{4+} ions (Kisinyo et al., 2013). These amendments were reapplied in the second season, hence released bases over time. The results of this study concurs with research findings in the Nordic Countries where the application of ash at the rates 3 to 5 t ha^{-1} decreased soil acidity, increased base saturation and the total amount of nutrients (Huotari et al., 2015; Hale et al., 2020). Mineralization of manure over time also released basic elements into the soil. Manure used in the study contained 0.35% Ca and 0.23% Mg, respectively. The increase of soil pH in plots that received decomposed cattle manure after two seasons contrasts findings of a long-term field experiment where the stabilizing effect of farmyard manure (FYM) on soil pH was not proven. After 14 years of FYM application pH decreased at all the sites in the study (Vasak et al., 2015).

Effect of SBA and cattle manure on soil available P and soil CEC in the field

The objective of this study was to determine the effect of sugarcane bagasse ash and cattle manure amendments on soil available P and CEC in the field. The main effect of cattle manure on soil available P was highly significant at $P \leq 0.01$. Plots that received 5 t ha^{-1} manure gave the highest improvements followed by 10 t ha^{-1} while 0 t ha^{-1} remained significantly lower (Figure 1). The main effect of soil conditioner on soil available P was significant at $P \leq 0.01$. The application of bagasse ash and lime under field conditions resulted in significant changes of soil available P, at $P \leq 0.01$ level of significance. Treatments that received 5 t ha^{-1} of bagasse ash gave the highest values for soil available P, followed by 2 t ha^{-1} lime whereas 0 t ha^{-1} treatment rate remained significantly the lowest (Figure 2).

Significant increases in soil available P with sole application of decomposed cattle manure and SBA can be attributed partly to dissolution of the precipitated soil P with rise in soil pH. Huotari et al. (2015) reported that as the soil pH approaches 5.5 to near neutral, the precipitated P in soils occurring in pH below 5.5 is

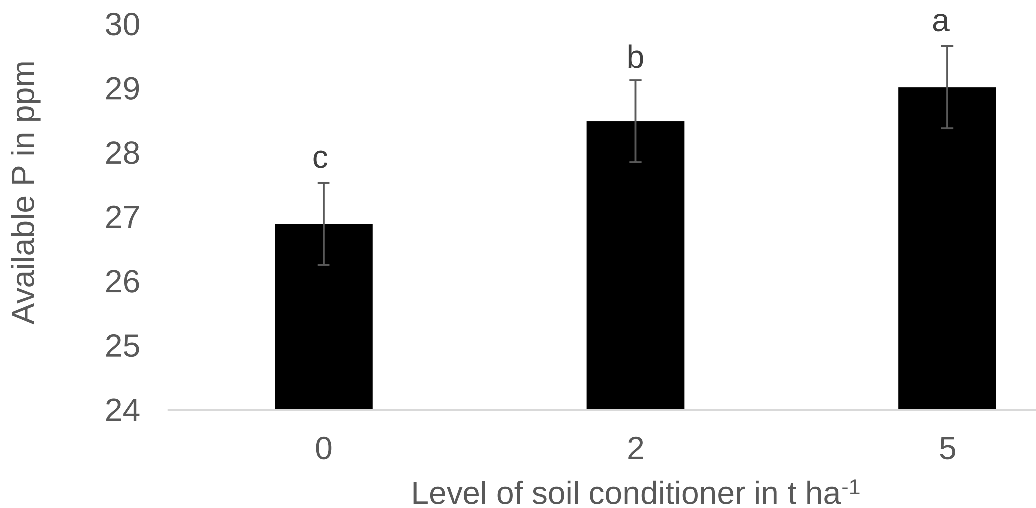

Figure 2. The main effects of soil conditioner application levels on soil available P in ppm during the short rain (2019) and long rain (2020) seasons at Kakamega, Western Kenya. The x-axis represents the treatments applied in the field under maize cultivation for 2 seasons. The 0 represents plots where 0 t ha^{-1} soil conditioner was applied, 2 represents 2 t ha^{-1} lime and 5 represents application of 5 t ha^{-1} sugarcane bagasse ash. The y-axis depicts mean values of available P in parts per million for the two seasons. The error bars represent the standard errors (SE). The letters a, b and c represent the means separations using the Least Significant Difference (LSD). Means represented by different letters are significantly different at P≤0.01. The available P in treatment 0 was 27 ppm; 2 t ha^{-1} lime was 28 ppm and 5 t ha^{-1} sugarcane bagasse ash was 29 ppm at the end of the field experiments.

released and hence becomes available. Additionally, both manure and SBA had adequate total P; 0.31 and 0.37%, respectively which improved the soil available P pool. This study found that application of manure at the rate 5 t ha^{-1} caused highest soil available P improvements followed by 10 t ha^{-1} and lastly no amendment. This could be possible because higher quantities of manure would require more time for mineralization to take place and nutrients to be released. This is in contrast with the findings of Lemanowicz et al. (2014) who found that the amount of available P in soil increased with increase in the amount of organic fertilizers (manure and slurry) applied. Bagasse ash significantly increased available P compared to liming and no amendment application. This agrees with findings by Hale et al. (2020) who reported that ash increased soil available P more than biochar, inorganic fertilizers and treatments with no amendment. Although the average available P was increased from 25 to 29 ppm, it is slightly above the adequate range. Results show that the main effect of season was significant at P≤0.01. The CEC was higher at the end of the 2nd season as shown in Figure 3.

The main effect of manure on soil cation exchange capacities was significant (P≤0.01). The CEC was highest at the highest rate of decomposed cattle manure applied. Treatments with no manure and 5 t ha^{-1} manure, had the lowest values (Figure 4). The main effect of soil conditioner on soil cation exchange capacities was significant (P≤0.01). Significantly higher CEC resulted from the application of bagasse ash. There was no significant difference in soil CEC values between the application of lime and nil application of any amendment (Figure 5).

The CEC of soil increased due to application of decomposed cattle manure at high rate (10 t ha^{-1}). Manure adds organic matter to soil and releases basic cations into the soil solution over time. Changes in CEC were not visible during the first season but increases were observed during the second season. The decomposed cattle manure and ash had been reapplied at the planting of second season. Despite CEC being an inherent soil property, it is highly influenced by the content of organic matter of a soil (FAO and ITP, 2015). This implies that soils with low organic matter content are likely to have low CEC as seen in the highly weathered soils like the Acrisols and Ferralsols and can be improved by increasing the organic matter content. Ingerslev et al. (2014) similarly reported that soil CEC and base saturation significantly increased in plots treated with ash, as a result of increase of magnesium and calcium ions at 10- 75 cm soil depth.

Conclusions

The application of amendments caused significant increases in soil pH, soil available P and CEC, at the end of the 2nd season. To raise soil pH to the optimum for

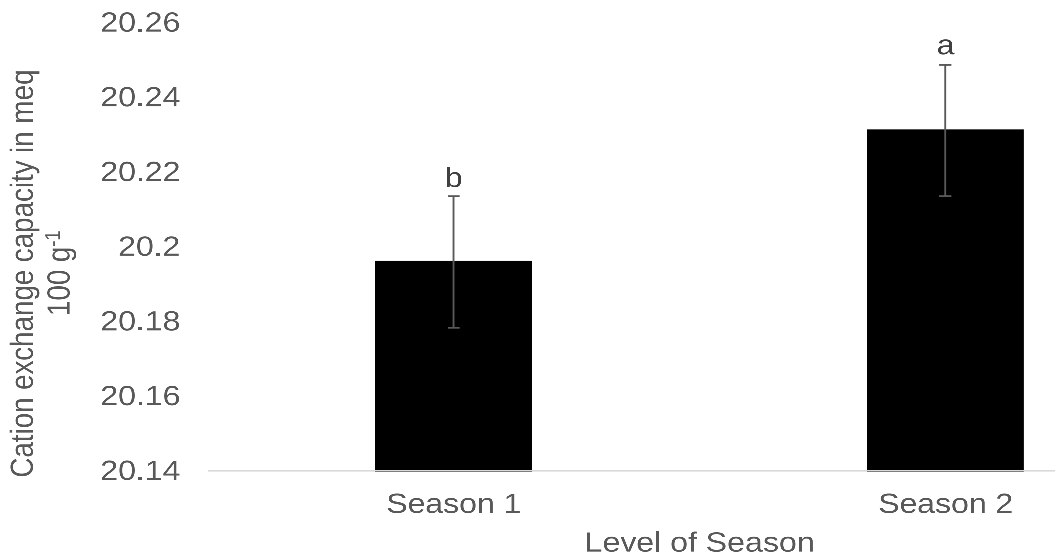

Figure 3. Main effect of season on soil CEC in meq 100g^{-1} during the short rain (2019) and long rain (2020) seasons at Kakamega, Western Kenya. The x-axis represents the levels of seasons. Season 1 represents the short rain season from September to December 2019 and season 2 represents the long rain season from March to July 2020. Treatments were applied in the field under maize cultivation for the 2 seasons. The y-axis depicts mean values of CEC for each of the two seasons. The error bars represent the standard errors (SE). The letters a, and b represent the means separations using the Least Significant Difference (LSD). Means represented by different letters are significantly different at P≤0.01. The mean CEC was 20.19 ppm at the end of season 1 and 20.23 at the end of season 2.

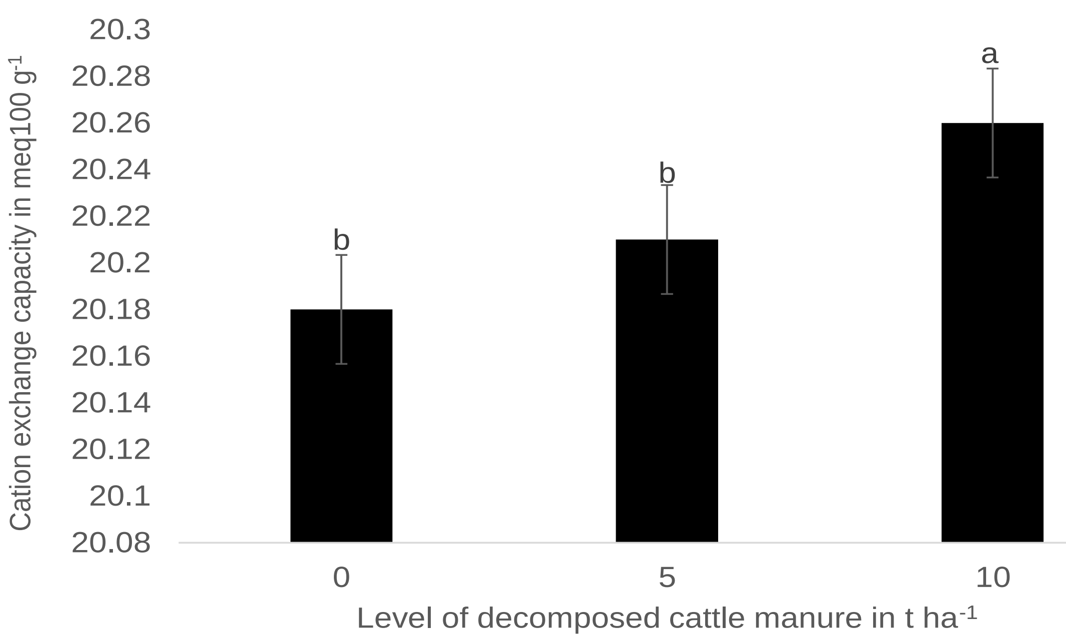

Figure 4. The main effects of manure application levels on soil CEC in meq 100g^{-1} during the short rain (2019) and long rain (2020) seasons at Kakamega, Western Kenya. The x-axis represents the treatments applied in the field under maize cultivation for 2 seasons. The 0 represents plots where 0 t ha^{-1} decomposed cattle manure was applied, 5 and 10 represent application of 5 t ha^{-1} and 10 t ha^{-1} decomposed cattle manure. The y-axis depicts mean values of CEC for the two seasons. The error bars represent the standard errors (SE). The letters a, and b represent the means separations using the Least Significant Difference (LSD). Means represented by different letters are significantly different at P≤0.01. The mean CEC value in treatment 0 was 20.18; 5 t ha^{-1} was 20.21 and 10 t ha^{-1} was 20.26 meq 100 g^{-1} at the end of the field experiments.

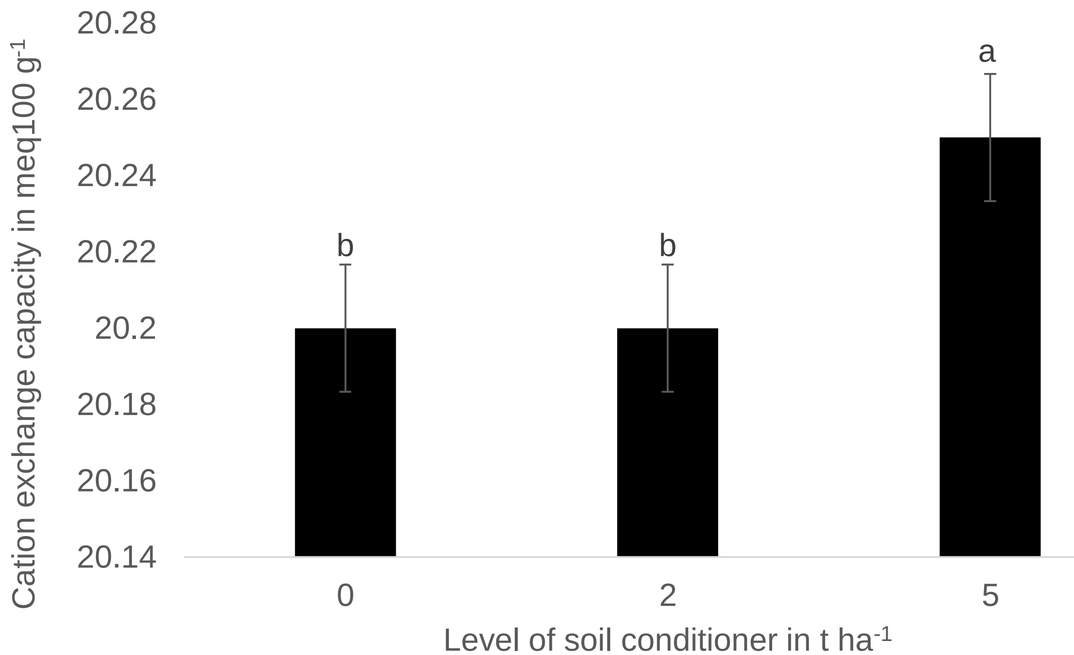

Figure 5. The main effects of soil conditioner application levels on soil CEC in meq $100g^{-1}$ during the short rain (2019) and long rain (2020) seasons at Kakamega, Western Kenya. The x-axis represents the treatments applied in the field under maize cultivation for 2 seasons. The 0 represents plots where 0 t ha^{-1} soil conditioner was applied, 2 represents 2 t ha^{-1} lime and 5 represents application of 5 t ha^{-1} sugarcane bagasse ash. The y-axis depicts mean values of CEC for the two seasons. The error bars represent the standard errors (SE). The letters a, and b represent the means separations using the Least Significant Difference (LSD). Means represented by different letters are significantly different at $P \leq 0.01$. The CEC in treatments 0 was 20.2; 2 t ha^{-1} lime was 20.2 and 5 t ha^{-1} sugarcane bagasse ash was 20.25 meq 100 g^{-1} at the end of the field experiments.

crop production, a combined application of decomposed cattle manure and lime at the rates 5 t ha^{-1} manure and 2 t ha^{-1} should be the first choice. The 2nd alternative should be the application of 5 t ha^{-1} decomposed cattle manure alone or in combination with 5 t ha^{-1} SBA. To improve soil available P, 5 t ha^{-1} SBA or 5 t ha^{-1} well decomposed cattle manure and lime at 2 t ha^{-1} should be the best choice. On the other hand application of manure at high rates such as 10 or 5 t ha^{-1} SBA is recommended if improvement of soil CEC is the main objective.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Demographic factors and perception in rhizobium inoculant adoption among smallholder soybeans (*Glycine max* L. Merryl) farmers of South Kivu Province of Democratic Republic of Congo

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The use of rhizobium inoculants fertilizer in soybean production has been practiced for over a century all over the world, but in Africa, the technology is relatively new. Rhizobium inoculants have been disseminated in Eastern Democratic Republic of Congo (DRC) by Nitrogen 2 Africa (N2AFRICA) project of CIAT and later IITA since 2010. However, demographic factors and perception in rhizobium adoption remain unknown. We assessed the demographic factors and perception in rhizobium inoculant adoption among 193 smallholder soybeans farmers of South Kivu Province of DRC. The information was collected in September 2018 and included farms and farmers socio-economic characteristics and farmer's adoption and perception of rhizobium inoculants. We used Probit model to assess the factors that are likely to influence the adoption and measured the perception using 5-point Likert-type scale. Results indicated that the adoption of rhizobium inoculants was very low in South Kivu (21%) and was highly influenced (P<0.01) by gender of the household head, farmer's location, education type of household head, the knowledge of nodules roles and the household income. The perception of inoculant by farmers also highly influenced its adoption. Furthermore, farmers strongly perceive rhizobium as an affordable nitrogen source for enhancing soybeans productivity but less available in the market. More effort is needed in farmers' education about BNF to improve adoption of inoculants.

Key words: Adoption, perception, smallholder's farmers, Biofix, Soybeans, N2 Africa, rhizobium inoculants.

INTRODUCTION

The Democratic Republic of Congo is among the biggest countries in Africa and offers great potential for increased

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agricultural productivity (Lecoutere et al., 2009). Currently, its productivity is among the lowest in Africa and in the world (FAO, 2018) due to declining soil fertility (Pypers et al., 2011), and aggravated by lack of specific information on soil management and sustainability at farm level (Bashagaluke et al., 2015). Most crops; cereals and legumes, are cultivated without application of fertilizers and hence low yields (Lambrecht et al., 2016).

Soybean (*Glycine max* (L.) Merrill) is one of the most important legume crops (Hartman et al., 2011) cultivated in South Kivu province of Democratic Republic of Congo for its diverse uses (Bisimwa et al., 2012). This crop has been promoted since 1985 by humanitarian organization and United Nations agencies such as FAO, to address the issues of malnutrition induced human diseases following the political strife of 1985 (Kismul et al., 2015). Its cultivation has increased as a result of its utilization in public schools and hospitals to prevent and cure the wasting effects of malnutrition (Bisimwa et al., 2012; Kismul et al., 2015), in household (Pypers et al., 2011; de Jager et al., 2019) and in livestock especially in poultry production and aquaculture (Khojely et al., 2018). Despite its importance, the potential productivity of this crop is challenged by poor soil fertility and low accessibility to mineral fertilizers by poor-resources farmers (Khojely et al., 2018; Pypers et al., 2011); hence reported yield is very low (0.51 t/ha) (FAO, 2018) compared to potential yield of 3t/ha (Salvagiotti et al., 2008). The use of organic fertilizers to alleviate this problem is constrained by their very limited availability leading to a very low utilisation per unit area (Lambrecht et al., 2016). The mineral fertilizers are also very expensive to farmers. Odame (1997) estimated that a farmer must sell about 10 kg of maize or 5 kg of common bean to buy 1 kg of N or P in the form of mineral fertilizers.

Fortunately, soybean is able to fix its own nitrogen from atmosphere in symbiosis with rhizobia bacteria by the process called Biological Nitrogen Fixation (BNF) (Collino et al., 2015; Giller et al., 2011; Hungria et al., 2005; Dakora and Keya, 1997). By BNF process, soybean crop can fix up to 80% of its nitrogen needs and thus alleviate the need of applying mineral fertilizers that are neither available nor affordable by smallholder's farmers (Chianu et al., 2011). Many soils contain *Rhizobia,* but often in small populations and they are less effective and mostly non-compatible to soybeans (Abaidoo et al., 2007). This requires inoculation with a highly effective and competitive Rhizobia strain in high quality formulations. Two approaches were used by international organization to address the problem of low yields of soybean in Africa. First, breeding for development of soybean cultivars that can nodulate freely with native rhizobia population (Mpepereki et al., 2000; Tefera, 2011). Second, introduction of inoculants containing highly effective rhizobia strains (van Heerwaarden et al., 2018).

Therefore, rhizobium inoculants fertilizers were introduced among smallholder's farmers of South Kivu by the N2 Africa project of International Institute of Tropical Agriculture(IITA) and partners' organizations, first in 2010 (Chianu et al., 2011; van Heerwaarden et al., 2018). The introduced commercial formula was the BIOFIX®. This inoculant is produced in Kenya and was initiated as part of the Microbial Resources Centre Network (MIRCEN) that was established by the University of Nairobi (Mutuma et al., 2014; Chianu et al., 2011). This product is licensed and marketed by MEA Limited, which started its production in 2010 (Ampadu-Boakye et al., 2017). Yield increase was observed in soybean inoculated by this inoculant in many countries (Waswa et al., 2014; Ulzen et al., 2016; Van Heerwaarden et al., 2018; Thilakarathna et al., 2019).

BIOFIX® for soybean contains the *Bradyrhizobium japonicum* strain USDA 110, a widely used industry standard concentrated at $>10^9$ Rhizobia g^{-1} in an organic carrier material (Ulzen et al., 2016). This is one of the main legume inoculants commercially available in East Africa and is steadily being promoted among farmer groups of many countries assisted by many organizations such as N2 Africa (Chianu et al., 2011; Karanja et al., 1998; Wafulah, 2013; Farrow et al., 2016). Whereas Woomer et al. (1997) and Odame (1997) identified low farmers' awareness and inoculants unavailability as an important constraint to its adoption, the inoculant adoption and profitability assessed in other countries (Getachew, 2016; Mutuma et al., 2014; Nekesah, 2017; Ulzen et al., 2016); there is no information on demographic factors in rhizobium inoculant adoption among smallholder soybeans farmers in South Kivu Province of D.R Congo. Furthermore, previous conducted studies did not assess the perception of smallholder's farmers of the inoculants products since the adoption largely depends on perceptions (Negatu and Parikh, 1999; Ojiako et al., 2007). Therefore, the objective of this study is to assess the demographic factors and perceptions that are likely to influence the adoption of rhizobium inoculants among soybean smallholder's farmers of South Kivu Province of Democratic Republic of Congo.

METHODOLOGY

Study area

This study was conducted in South Kivu Province of Democratic Republic of Congo, targeting three villages namely Lurhala, Kalehe and Kamanyola where N2 Africa project of IITA has disseminated BNF technologies including rhizobium inoculants (Chianu et al., 2011). South Kivu Province is located in the Eastern part of Democratic Republic of Congo between 1° 36' and 5° South latitude and 26° 47' and 29° 20' East longitude (Pypers et al., 2011). The province of South Kivu has an area of 69,130 Km^2 and its population is currently estimated at 3,500,000 peoples with an average density of 50.6 inhabitants per km^2 (DSRP, 2011).

The area is recognized as a high humid forest zone depicted by high vegetation diversity (Potapov et al., 2012); highlands and soils are mostly infertile Dystric or Humic Nitisols or Humic Ferralsols (van Engelen et al., 2006). This region has a tropical climate with an average annual rainfall of 1500 mm and average temperature of 18°C (Nash and Endfield, 2002). The main activity in the region is agriculture with most cultivated crops including banana, cassava, beans and traditional livestock comprising cattle, sheep, goats, chicken and pigs (Maass et al., 2012).

Sampling and data collection

The survey was conducted in two stages; a pre-survey (conducted from 23rd to 25th June 2018) was done in consultation with N2 Africa country coordinator and field specialist to determine the villages where inoculant product was promoted. From this stage, three villages were purposively selected namely Lurhala, Kalehe and Kamanyola and the sampling frame determined. At the second stage, two lists of soybeans farmers; (i) participating and (ii) not participating in the N2 Africa project were drawn in each village with the help of the farmer's group contact person and N2 Africa project field technician. Lastly, a random equal number of farmers were drawn from the two lists to participate in the survey conducted from 1st to 30th September 2018. From this process 200 farmers were selected but only 193 respondents were considered as they met the requirements of the survey. The true sample size was determined as guided by Murongo et al. (2018).

Data were collected through personal interviews, using pretested questionnaires. Information collected for demographic factors in inoculants adoption included farmers' characteristics (gender, education, household size and management, etc.), farm characteristics (farm size, number of cultivated land, etc.), institutional factors (group membership, credit access etc.) and capital endowment. Concerning perception of inoculants product, farmers were asked about their perception on the importance of soybean, the effectiveness of rhizobium inoculant in improving soybeans productivity, its availability, its accessibility and affordability. The market prices were used to estimate the cost of farm inputs and value of outputs in order to compute the gross margin.

Analytical framework

Technology adoption can be modeled using a utility maximization problem (Sidibé, 2005). A farmer will only adopt a new technology, for example an improved crop variety or fertilizer, when the utility he derives from this technology (U_n) is greater than the utility of a traditional technology he had been using (U_t) (Mercer, 2004). The utility derivable from the new technology is considered as a vector of several factors ranging from farm observed characteristics (e.g., farm size) to perceived technology characteristics (X_i) through institutional factors (e.g., distance to the market, membership to farmers' organizations), farmer characteristics (e.g., gender of the farmer, age) and a disturbance term with mean zero (Sattler and Nagel, 2010). Perceived technology characteristics, or perceived varietal attributes under crop technology adoption, are also function of subjective and/or objective characteristics of the technology itself, but also farm and farmer-specific characteristics (Mariano et al., 2012). Thus, a given farmer, in the adoption process, will always consider the benefits and losses (both economic and social) of the new technology and eventually chooses the technology (*T*) that promises higher utility compared to the traditional technology.

Suppose an individual household's utility of adopting a new technology, depending on a vector of social, economic and physical factors (*X*), denoted by $U_n(X)$, and the utility of remaining with the traditional technology denoted by $U_t(X)$, then the utility models associated with adoption of the old and new technologies can be apprehended through a linear relationship:

$$U_n(X) = \theta_n' X + E_n \tag{1}$$

$$U_t(X) = \theta_t' X + E_t \tag{2}$$

Where $\theta_n' X$, $\theta_t' X$ and E_n, E_t are response coefficients and disturbances associated with adoption of the new and old technologies respectively.

Under the adoption framework, the state of mind of the farmer is not observable but can only be seen through outcome of a decision-making process and this allows the classification of farmers into two groups: adopters and non-adopters. The adoption process can thus be modelled using a latent variable (Horrace and Oaxaca, 2006) denoted by (y^*). In our case, it measures the difference between the utility derived from the new technology and that of the old technology $[U_n(X) - U_t(X)]$. This variable can take both positive and negative values depending on whether the utility of the new technology outweigh that of the old technology and vice versa. So, in the real world, the outcome variable (Y)will take the value of 1 if the farmer adopted or is willing to adopt the new technology and 0 otherwise. Mathematically, the probability that a given farmer will adopt the new technology considering the explanatory factors can be expressed as follows:

$$\begin{aligned} P(Y = 1) &= P(U_n > U_t) \\ &= P(\theta_n' X + E_n > \theta_t' X + E_t) \\ &= P[X(\theta_n - \theta_t) > E_t - E_n] \\ &= P[X\theta > E] \\ &= F(X\theta) \end{aligned} \tag{3}$$

Where P is the probability function, $\theta = (\theta_n - \theta_t)$, a vector of unknown parameters to be estimated and which can be interpreted as net influence of explanatory variables on technology adoption; $E = (E_t - E_n)$ a random disturbance term; and $F(XB)$ the cumulative distribution function of F evaluated at XB.

The parameters of such model can be estimated using maximum likelihood technique due to the non-linearity nature of the model (probabilistic model). Several empirical models can be used to map the relationship between the dependent variable and the independent variables. These include the Linear Probability Model (LPM) (Horrace and Oaxaca, 2006), logit and probit models (Briz and Ward, 2009). One of the major flaws of the LPM model comes from its estimation technique. It uses ordinary least squares (OLS) to estimate parameters of a binary-outcome variable. The predicted probability for such model may also go beyond 1 or below 0, violating basic principles of probability (Horrace and Oaxaca, 2006). This has made the model less used in studying technology adoption in empirical studies. Therefore, Logit and Probit are suitable for the current situation because they analyze better dichotomous outcome (Woodridge, 2002) but the choice between them has always been subject to several controversies. Cakmakyapan and Goktas (2013), for example, conducted a series of simulation in order to determine in which situation each model would be the most appropriate. Considering three cases from the variance and covariance matrix, namely "high", "low" and "no", they found that though both models were similar and could be used interchangeably. According to Zamasiya et al. (2014), the logit model seemed more appropriate in larger sample sizes (500, 1000) as compared to the probit model. In the current study, Probit model was used to identify determinants of adoption of rhizobium inoculants among soybean farmers. Farmers' perception towards rhizobium inoculants was measured using 5-point Likert-type scale (Preston and Colman, 2000; Bagheri, 2010;

Li, 2013). XL Stat software version16 was used for descriptive statistics and the statistical package R, version 4.1 for regression analysis. The Principal Component Analysis (PCA) was used to isolate factors and only significant variables toward adoption and perception were included in the regression analysis. Hosmer-Lemeshow test was performed to measure model goodness-of-fit (Fagerland and Hosmer, 2012).

RESULTS AND DISCUSSION

General characteristics of soybean farmers

The mean age of soybean farmers of South Kivu was 46 years (Table 1) with most of farmers being within productive age (more than 46 years old). This result shows a low involvement of the youths in soybean production, consequently, there is need to encourage youth involvement. This may be due to the fact that soybean is a crop cultivated for both nutrition security and cash income generation of the household; which is an elders' concern, on one hand. On the other hand, this can be explained by the fact that youths are not interested in performing various agriculture related activities. This result is consistent with Zamasiya et al. (2014) and Ojiako et al. (2007) who found that most soybean farmers are within productive age (43-50years).

Of the interviewed farmers, 68.7% were men while 31.2% were women. Men are mostly represented in the soybean culture in the study area, because this crop is becoming a cash crop in South Kivu due to the increasing market opportunity; men are mostly interested in such crops. These findings are in discordance with Mutuma et al. (2014) who found that in Kenya women are more involved in soybeans culture than men. This discordance is noted probably because the market opportunity for soybean in Kenya is not that considerable compared to D.R.Congo, where soybean crop is used like medicinal food to cure malnutrition diseases (Bisimwa et al., 2012).

The education type among soybeans farmers was mostly formal education (Table 1) with mean of 5 years spent in school (data not presented). The low education status is explained by the less access to education in rural area due to poverty. A study conducted by Mariano et al. (2012) also reported a low education status of farmers in Philippine and the same study demonstrated the negative influence of this low education on adoption of modern rice technologies. Most of the interviewed farmers had a mean of 26 years of experience in growing soybean (data not presented). The most practised religion was Catholicism (72.9%) followed by Protestantism (23.9%). The main source of income in the study area was the sale of agricultural products (88.4%) followed by small trade (6.8%). The household income was controlled mostly by both conjoint (45%) followed by the husband alone (23%) and was in the range of 50-100 US dollars (29%). Only few households (28%) received a mean credit of 128 USD and many households (68.7%) were members of farmer's group (data not presented).

The mean number of fields allocated to soybean was 2 fields per household with mean area under soybean crop of 0.46 ha (data not presented). This farm size is above 0.1ha, which is the approximate farm size usually allocated to legumes in Sab-Saharan Africa (Chianu et al., 2011) showing the importance of soybeans in this part of Africa.

Comparative characteristics of soybean inoculants users and non-users

The number of soybean inoculants users was 41 against 152 of non-users (Table 2) showing an adoption rate of 21%. The users of soybean inoculants had more access to credit than non-users (P<0.01), they were more involved in groups and had stayed longer in groups than non-users (P<0.01). In addition, many of them were beneficiary of development or humanitarian projects (P<0.01). On the other hand, users of soybean inoculants had more awareness on roots nodules roles (P<0.01) and were in contact with organization promoting inoculants (P<0.01). These results were expected and showed that inoculants users have more access to information, and this increases their chance to adopt new technologies.

This corroborates findings of past studies (Getachew, 2016; Mutuma et al., 2014; Nekesah, 2017) who stated that projects that promote use of new agricultural technologies are important in facilitating their adoption. Katungi and Akankwasa (2010) also found that farmers who participate more in community-based organizations are likely to engage in social learning about the technology hence raising their likelihood to adopt the technologies. These finding imply that structuration of farmers in groups is important for better understanding and utilization of new technologies.

Factors influencing inoculants adoption

The location, gender, education, knowledge of root nodules, household income and perception of rhizobium inoculant were significant in explaining adoption of rhizobium inoculants in the study areas (Table 3). Farmers located in Lurhala were more likely to adopt Rhizobium inoculants than those located in Kamanyola. This was expected and may be due to the fact that soil conditions vary among these villages. Lurhala, for instance, is characterized by highlands and less fertile soils compared to Kamanyola, which is a plain with moderate fertility soils (Pypers et al., 2011). The observed higher adoption in Lurhala may be because farmers in the area are in need of an affordable source of fertilizer to increase soybeans yield because of lower soil fertility status. This finding corroborates Mutuma et al. (2014)'s findings to the effect that farmers in Bondo were more likely to use inoculants than Mumias and Bungoma because of low soil fertility status.

Table 1. General characteristics of soybean farmers.

Factor	Category	Frequency	Percent
Mean age	<18	1	0.5
	18-25	24	7.2
	26-35	36	18.7
	36-45	27	27.6
	>46	89	45.8
Gender of the farmer	Male	126	68.7
	Female	67	31.2
Type of Education	Formal	139	72.4
	Non formal	14	7.3
	Any	39	19.8
	Other	1	0.5
Religion	Catholicism	140	72.9
	Jehova Witness	2	1
	Protestantism	46	24
	Adventist	4	1.6
	Traditional	1	0.5
Household management	Husband is the head	42	22.1
	Wife is the head	45	23.7
	Conjoints	87	45.8
	Another person	16	8.5
Montly income interval	<30$	27	17.3
	30-50$	41	26.3
	50 -100$	46	29.5
	100 -200$	33	21.2
	200 -300	8	5.1
	>500	1	0.6
Source of income	Sale of agricultural products	169	88.5
		2	1
	Small trade	13	6.8
	Employees	2	1
	Other	5	2.6

Gender of the household head had unexpectedly a negative effect on the adoption of rhizobium inoculants fertilizer meaning that when a household is men headed, he is not likely to adopt the rhizobium inoculant. The higher adoption of women may be due to the fact that women have higher accessibility to products compared to men; they can even get price reduction when purchasing. This observation is in contradiction of the finding of Nekesah (2017) who found that male farmers are more likely to adopt inoculants fertilizers because they can leverage on their equity capital with which to purchase external farm inputs than women. Our study findings were in discordance perhaps because at the beginning of the project, inoculants were distributed for free by organization promoting it and thereafter they remained cheap and very accessible to farmers (Ampadu-Boakye et al., 2017). Women are usually more considered for donation compared to male. However, these findings are in agreement with Zamasiya et al. (2014) who found that a female-headed household is likely to adopt new technologies related to legumes because legumes are usually considered as female crop.

The type of education, also, unexpectedly negatively affects the use of inoculants meaning that farmers with

Table 2. Characteristics of soybean inoculants users versus non-users.

Variable	Overall sample	Users	Non-users	Mean/proportion difference
Age	46	46	46	-0.28
Gender		0.425	0.51	0.093
Education level	5.86	5.57	5.97	0.40
Experience in agriculture	26.48	25.75	26.74	0.995
Household head	7.81	8.4	7.6	-0.8
Household workers	3.16	3.38	3.07	-0.31
Credit access	0.3	0.5	0.22	-0.27***
Credit amount	11478.4	17640	6549.12	-11090.88
Group membership	0.73	1	0.63	-0.36***
Duration in farmer's group	7.09	9.87	5.67	-4.21***
Project beneficiary	0.52	0.87	0.39	-0.48***
Number of cultivated land	2.72	2.97	2.60	-0.36
Knowledge of root nodules	0.50	0.75	0.401	-0.35***
Contact with inoculant promotors	0.47	0.81	0.30	-0.51***
Total number of farmers (N)	193	41	152	

*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

informal education were more likely to adopt inoculants fertilizers compared to those with formal education. This may be due to the fact that farmers who went through informal education undertook technical studies including short trainings in agricultural techniques organized by extension workers in rural areas. These findings are consistent with numerous authors (Šūmane et al., 2018; Mignouna et al., 2011; Namara et al., 2013). These authors stated that informal knowledge and learning is a valuable resource that can reorient modern agriculture towards more sustainable and resilient paths of development because this type of learning addresses the knowledge and learning needs of farmers. The awareness of roots nodules positively affected the adoption of inoculants. This was expected because being aware of the existence of root nodules in leguminous plants, knowing their role in nitrogen fixation and perceiving that the nodules are beneficially enhanced by inoculant use increase the decision of using inoculants. This was also observed by Mutuma et al. (2014) and Nekesah (2017).

Household income positively and significantly ($P<0.01$) affected the adoption of soybean inoculants. This is because when farmers are getting more income from farm crop, they take a risk and responsibility about a new technology. Duressa (2015) also reported that farm income has significant and positive effect on adoption of technologies. Households with relatively higher level of income are more likely to purchase or exchange improved technologies.

Furthermore, farmers' perceptions of rhizobium inoculants also played a key role in adoption of the latter. Perceiving that inoculant's price is affordable by farmers negatively affected its adoption meaning that cost is not the most important factor for adoption of inoculant. This might be due to the fact that when a technology is perceived to be affordable, its efficacy is questionable. These results are consistent with Sattler and Nagel (2010) in the study factors affecting farmers' acceptance of conservation measures in Germany; costs were not the most important factor for adopting conservation measures. Other factors, like effectiveness, associated risks, or time and effort necessary to implement a certain measure were more important.

However, perceiving that rhizobium inoculant is effective and available at sale points was more important for its adoption in our study area. This is due to the fact that the inoculation technology has been subject to intense promotion among farmers under Integrated Soil Fertility Management (ISFM) as one of soil fertility replenishment technologies that are suitable for different types of resource-poor farm households (Sanginga and Woomer, 2009). These findings agree with Farrow et al. (2016) who reviewed the literature on factors affecting inoculants adoptions. He mentioned that the most commonly mentioned factors affecting the adoption of inoculants as one of legume technologies were the biophysical relevance of the technology (such as suitability for the agro-ecological zone), followed by the effectiveness and availability of the technology.

Diagnostic tests through Wald statistic showed that the model is globally significant, justifying the use of the selected covariates to predict the response variable. As for the reported pseudo R2, its value of 0.56 indicated that the retained variables (the location, gender, education, knowledge of root nodules, household income and perception of rhizobium inoculants etc.) are useful in predicting adoption of rhizobium inoculants (Table 3). To measure goodness-of-fit, other statistical tests such as the Hosmer-Lemeshow test was performed. Results

Table 3. Factors affecting adoption of rhizobium inoculants.

Variable	Adoption coefficients	Probability	Marginal effects	Probability
Gender	-1.049 (0.423)**	0.013	-0.167(0.0654)**	0.011
Age	-0.0268(0.0177)	0.129	-0.00425(0.00278)	0.126
Type of education	-0.841(0.431)*	0.051	-0.134(0.0679)**	0.049
litteracy	1.224(0.812)	0.131	0.194(0.129)	0.132
Farming experience	-0.00137(0.0161)	0.932	-0.000218(0.00255)	0.932
Religion	-0.125(0.419)	0.764	-0.0198(0.0659)	0.764
Household size	0.0791(0.0518)	0.127	0.0126(0.00813)	0.123
Credit access	0.262(0.407)	0.521	0.0415(0.0653)	0.525
Membership to farmer organization	0.519(0.411)	0.207	0.0824(0.0643)	0.200
Knowledge of roots nodules	3.011(0.529)***	0.000	0.478(0.0653)***	0.000
Contact with extension services	0.627(0.414)	0.130	0.0995(0.0643)	0.122
Income variable				
30-50	1.119(0.554)**	0.043	0.170(0.0830)**	0.041
50$ -100$	1.341(0.548)**	0.014	0.207(0.0783)***	0.008
100-200	0.947(0.575)*	0.099	0.142(0.0844)*	0.092
200-300	0.310(0.971)	0.750	0.0433(0.138)	0.754
Location variable				
Kamanyola	-0.902(1.169)	0.441(0.000)	-0.125(0.134)	0.353
Lurhala	1.722(0.396)***		0.279(0.0564)***	0.000
Perception variable				
Affordable price	-1.604***(0.459)	0.000	-0.255***(0.0680)	0.000
Inoculants accessibilité	-0.519(0.633)	0.412	-0.0824(0.100)	0.411
Inoculants effictiveness	1.307***(0.483)	0.007	0.207***(0.0720)	0.004
Availability at sale points	0.901*(0.474)	0.057	0.143*(0.0738)	0.053
Inoculant not important for soy	0.461(0.430)	0.283	0.0732(0.0686)	0.286
Soybean importance	-0.0152(0.426)	0.972	-0.00242(0.0677)	0.972
Constant	-2.276(1.093)**	0.037		
Wald $chi^2(24)$	81.39			
Prob>Chi^2	0.0000			
Pseudo R^2	0.5678			
Observations	140		140	
Robust standard errors in parentheses				

*** p<0.01, ** p<0.05, * p<0.1.

$(\chi^2 = 4.94, P - value = 0.7635)$ showing that the used Probit model fitted well the data. As for multicollinearity test, Variance Inflation Factors (VIF) reported figures less than 5 for most of the variables; this implies low level of multicollinearity among variables. Robust standard error was used to control the problem of heteroskedasticity and possible sample selection-bias in the data. And at last, a link test was performed for model specification and possible omitted-variables problem. The result of the test indicated that the model was well specified and is not suffering from any omitted-variable problem.

Farmers' perception of rhizobium inoculants adoption

Inoculants users strongly agreed (65%) that soybean is an important crop, strongly agreed that inoculant improves soybean's yield (50%) and agreed that rhizobium inoculant is available at sale points. Inoculants users were not sure (21% agreed, 21% moderately agreed and 21% disagreed) on the importance of rhizobium inoculants for soybeans production (Figure 1). However, inoculants users strongly agreed that inoculants price is affordable with the majority of farmers' users of inoculants stating that the sales points of inoculants are inaccessible.

Concerning inoculants non-users; they also strongly agreed that soybean is an important crop, moderately agreed that inoculation can promote soybeans production, moderately agreed or disagreed (37, 37% respectively) on inoculants availability (Figure 2). In addition, they agreed that inoculants are not important for soybean's

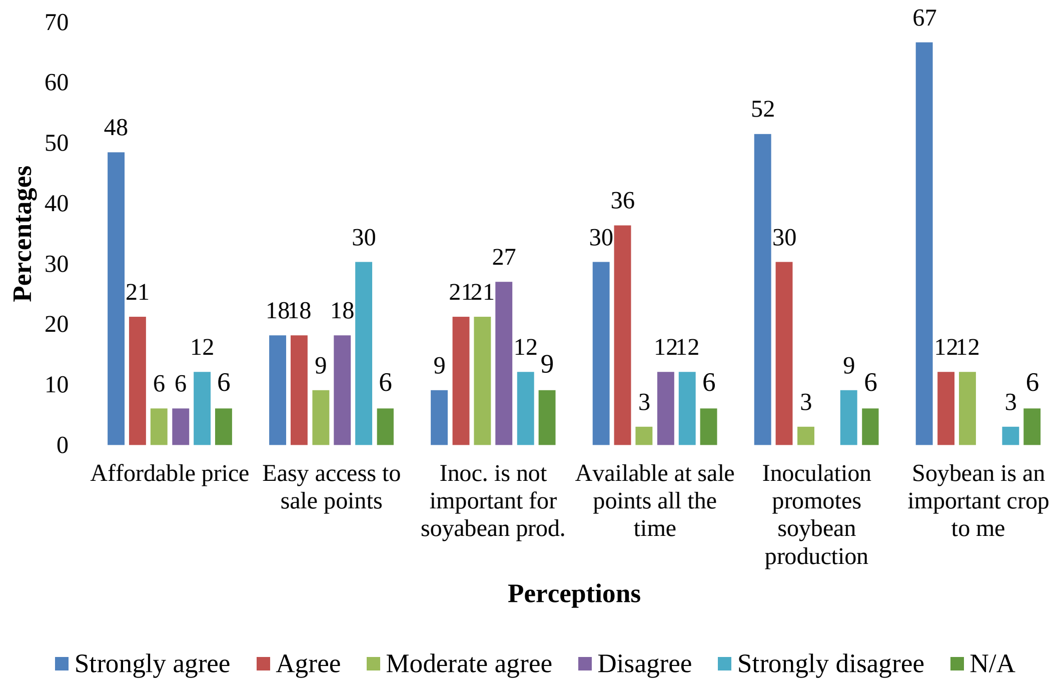

Figure 1. Perception of inoculant by users.

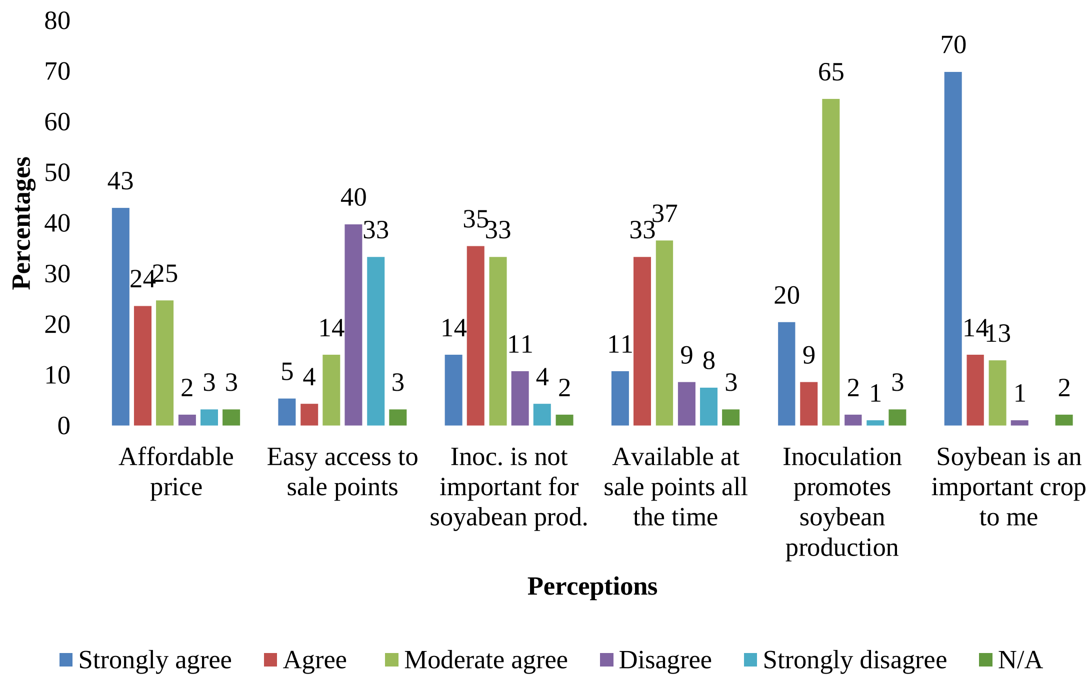

Figure 2. Perception of inoculant by non-users.

production and disagreed on inoculants' easy access. However, most of them strongly agreed that inoculants' price is affordable.

Inoculants users and non-user farmers strongly agreed that soybean is an important crop. This is explained by the fact that soybean in South Kivu is being used in households for malnutrition fighting and for cash income generation due to the presence of markets. This is in agreements with many authors. For example Khojely et al. (2018), Hartman et al. (2011) and Murithi et al. (2016) who stated that soybean is becoming an important and popular crop in Sub-Saharan Africa. Soybean plays a role in food and nutrition security (Owino et al., 2011; Bahwere et al., 2016; Rossi et al., 2005), in cash income generation (Bangsund et al., 1999), in animal nutrition (Huang et al., 2014; Yuan et al., 2016) and in soil fertility improvement (Sanginga, 2003; Miransari et al., 2013). This suggests that effort should be done to promote the productivity of this crop.

Inoculants users strongly agreed that inoculation promotes soybean production whereas the non-users only agreed moderately. This may be explained by the higher contact of inoculants users with organizations promoting inoculants and their long duration in farmers groups. This facilitates their easy access to information and evaluation of new technologies. The less agreement of non-users is explained by their less education on inoculation. In addition the response of soybeans to inoculation varies and depends on many factors. The importance of them include the number and quality of indigenous rhizobia, water stress (Serraj et al., 1999; De Vries et al., 1989; Sinclair et al., 1987; Ryan and Spencer, 2001), high temperature (Michiels et al.,1994), soil acidity (Giller, 2001) and salinity (Delgado et al., 1994) and nutrient deficiencies (Cassman et al., 1981). Marufu et al. (1995) observed that farmers' education on inoculation is a major driving force for the adoption of inoculants. Organizations promoting inoculants and extension services should determine the need to inoculate a certain area before the implementation of demonstration trials for good perception and high adoption of the product.

Concerning the inoculants availability at sale points, inoculants users agreed that this product is available in the market while in non-users group, the same number of farmers either agreed moderately or disagreed. This shows a moderate availability of inoculants, which may be owing to the fact that this product was produced under a project by, limited number of technicians who could produce only limited quantity of inoculants (Ampadu-Boakye et al., 2017). A study on farmers' inoculants adoption conducted in Zimbabwe demonstrated also a less availability of inoculants (Bala, 2008). These findings are in agreement with other studies that demonstrated a very low access to inoculants as major constraint to its adoption (Odame, 1997; Woomer et al., 1997; Kipkoech et al., 2007).

However, the two groups strongly agreed that the price of inoculants is affordable. This is in agreement with other studies (Mutuma et al., 2014; Nekesah et al., 2017). Chianu et al. (2011) argued that a 100 g-packet of inoculant is sufficient to inoculate 15 g of seeds and enough to plant 1 acre costs of only 1.2 US dollars while inorganic nitrogen fertilizer in form of Calcium Ammonium Nitrate needed for the same size of plot costs 34 US dollars. This shows that rhizobium inoculant is cheaper compared to inorganic N fertilizer 28 times and should be promoted among smallholders 'farmers.

Conclusion

Demographic factors that affect the adoption of rhizobium inoculants in South Kivu Province of Democratic Republic of Congo include farmers' location, gender of household head, type of education, awareness of nodules roles on legumes and household income. However, farmers perceive rhizobium inoculant as an affordable source of Nitrogen for soybean but less accessible. Much effort is needed in extension services strengthening to ensure advanced farmers 'education about inoculation and rhizobium inoculant promotion. Local private firms and agro dealers involvement is important for more availability and accessibility of the product.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Pesticide use in vegetable production in rural Uganda - A case study of Kabale District, South western Uganda

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A study to investigate commonly grown vegetables, commonly used pesticides, and pesticide use practices was conducted in Kabale District, in South-western Uganda. This is because indiscriminate pesticide use and poor application practices can leave pesticide residues in food rendering it unsafe for consumption. The study revealed extensive pesticide application in *Brassica oleracea; var. capitata* (cabbage), *Brassica oleracea; var. botrytis* (cauliflower), *Solanum lycopersicum,* (tomato) and *Beta vulgaris* (beet root). Information obtained using interviews revealed that 16.5% of the traders in Kabale Municipality sold pesticides and 70% of the farmers in the major vegetable growing subcounties of Kaharo, Kyanamira and Kamuganguzi sprayed their vegetables with pesticides. Only 18% of the interviewed farmers could interpret instructions on pesticide container or bag labels correctly. All farmers (100%) had never attended any training on pesticide use. Cypermethrin, dimethoate, dichlorvos, metalaxyl, profenofos, malathion and mancozeb were mentioned as commonly used pesticides in vegetables grown in the district. Some of the farmers (42%) used mixed different pesticides in the vegetables. Limited knowledge about pesticide application, inability to interpret instructions, non-observance of pre-harvest intervals, mixing pesticides and lack of training on pesticide use contribute to pesticide use malpractices which may put farmers' health at risk and reduce food quality. Therefore, there is need to address the identified knowledge gaps on safer pesticide application in order to attain safe agricultural productivity for sustainable food security, safeguarding human health and community development in Kabale District, Uganda.

Key words: Pesticides, vegetables, pesticide use practices, Kabale District, Uganda.

INTRODUCTION

Rapid human population growth has increased food demand worldwide (Jallow et al., 2017) requiring agricultural intensification (Majeed, 2018); however; food loss due to pests is still a challenge (Zanella et al., 2012; Munawar and Hameed, 2013). Pests destroy 30 - 48% of world's food yields annually; for example, in 1987 one third of the potential world crop harvest was lost to pests (Tano, 2011). Crop yield loss is a food security threat (Munawar and Hameed, 2013) which is further enhanced by pests and pathogens. To reduce the food loss as a

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result of pests, chemical pesticide use has been intensified; although, indiscriminate pesticide use can harm humans and the environment (Majeed, 2018).

Indiscriminate chemical pesticide use or haphazard application in food crops may lower food quality, reduce yields, risk consumers' and farmers' health, and affect prices, in addition to polluting the environment. Thus, pesticide use malpractices may reduce the contribution of food production to gross domestic profit (GDP). Proper pesticide application practices and reduced chemical pesticide use is beneficial to everyone and the environment (Bon et al., 2014). Hence, there is need for proper regulation of pesticide use and caution about malpractices.

Non-chemical pest management methods such as biological and mechanical control (nets and traps) have shown promising results in various studies from African countries (Bon et al*.,* 2014; Vidogbena et al*.,* 2015). However, a knowledge gap about their use and efficacy still exists especially in small scale farming; for example, in small scale vegetable production; thus farmers still heavily rely on the use of chemical pesticides for control of pests.

Pesticides are generally described as insecticides e.g. organophosphates, organocarbamates, organochlorines, pyrethrins and pyrethroids; fungicides for example thiocarbamates and dithiocarbamates (Fouche et al*.,* 2000; Fait et al*.,* 2001; Fenik et al*.,* 2011). In vegetable production, different pesticides can be used depending on plant species and pests (Schwinn, 1988; Özkara et al*.,* 2016). Some of the commonly grown vegetables across Africa include bottle gourd (*Legenaria vulgaris*), cabbage (*Brassica oleracea var. capitata*), cauliflower (*Brassica oleracea*), carrot (*Daucus carota*), egg-plant (*Solanum aethiopicum*), spinach (*Spinacia oleracea*) and tomato (*Lycopersicon esculentum*) among others (Ogwu et al., 2016). Similarly, commonly used pesticides in vegetables worldwide include dichlorvos, cypermethrin, malathion, profenofos and metalaxyl among others (Fenik et al. 2011). According to Oesterlund et al. (2014), frequently used pesticides in Uganda belonged to World Health Organization (WHO) class II.

There is widespread pesticide use in most developing countries (Alavanja, 2009; Popp et al*.,* 2013); however, indiscriminate application raises concern over food safety (Perez et al*.,* 2015). Health consequences of excessive pesticide use on consumers' and farmers' safety and the environment require governments to revise pesticide residue standards in food stuffs (Okello and Swinton, 2011). Pesticide use malpractices are a food safety challenge; for example, farmers may not always follow appropriate pesticide use methods like pre-harvest intervals (Miah et al*.,* 2014); yet there is limited information on pesticide use practices in developing countries in sub-Saharan Africa for example in Uganda. Poor pesticide use practices may be attributed to lack of knowledge about the side effects of pesticide use and failure to follow instructions on pesticide usage (Bon et al*.,* 2014). Common malpractices include use of unregistered pesticides, inappropriate dosage, non-compliance to pre-harvest intervals, use of banned pesticides, inappropriate application techniques, pesticide/crop mismatch, use of a mixture of different pesticides in a single spray, insufficient personal protection equipment and unsafe pesticide handling practices (Ngowi et al*.,* 2007; WHO and IPCS, 2010; Naidoo et al*.,* 2010; Marčić et al*.,* 2011; Nonga et al*.,* 2011). While information on pesticides use in Uganda is limited, most farming is done by small-scale farmers on a few acres of land per household often without appropriate application of pesticides (Salameh et al., 2004; Jors et al*.,* 2006). In the absence of appropriate handling of pesticides, the health of farmers and that of their families are at risk (Macfarlane et al*.,* 2008; Sam et al*.,* 2008; Williamson et al*.,* 2008).

In various African countries an average of 10 % of the food budget is spent on fruits and vegetables (Joosten et al., 2015). Vegetable consumption ensures adequate dietary supply of vitamins, minerals, water, and dietary fibre (Sinyangwe et al., 2016). An adult is recommended to consume 400 grams of vegetables daily for a healthy life (Smith and Eyzaguirre, 2007; JICA, 2016). To cope with the increasing vegetable demand, pesticides are used to increase productivity, protect nutritional integrity, facilitate storage to ensure year-round supplies, and provide attractive vegetable products (Chow, 2016). Therefore, this study investigated commonly grown vegetables, common pesticides used in vegetables, attitudes of farmers and traders on pesticide use and application practices in Kabale District, Uganda.

MATERIALS AND METHODS

Study area description

Kabale District is a highland district of Uganda in the South West of the Republic of Uganda. It is bordered with districts of Rubanda to the West, Rukiga in the North and East and the Republic of Rwanda to the South (Figure 1). Kabale District is 402 km from the capital city Kampala, lying between 29° 45' and 30° 15' East longitude and 1° 00' and 1° 29' South of latitude (Langan and Farmer, 2014). The district has an estimated population of 212, 506. Out of these, only 49, 667 (23 %) stay in the municipality and the remaining 162,839 (77%) stay in the rural area. The people are predominantly from Bakiga tribe and a few Batwa (pigmies), Banyarwanda and Bahororo tribal clans. It is one of the most populated districts with projected population density approximated to be at 358 people per Km^2 (Uganda Bureau of Statistics, 2014). Kabale District comprises Kabale municipality (Northern Division, Central Division and Southern Division) and seven sub-counties including Rubaya, Kamuganguzi, Buhara, Maziba, Kaharo, Butanda and Kitumba (Figure 1).

Determination of sample size for interview

The study populations were composed of pesticide traders from

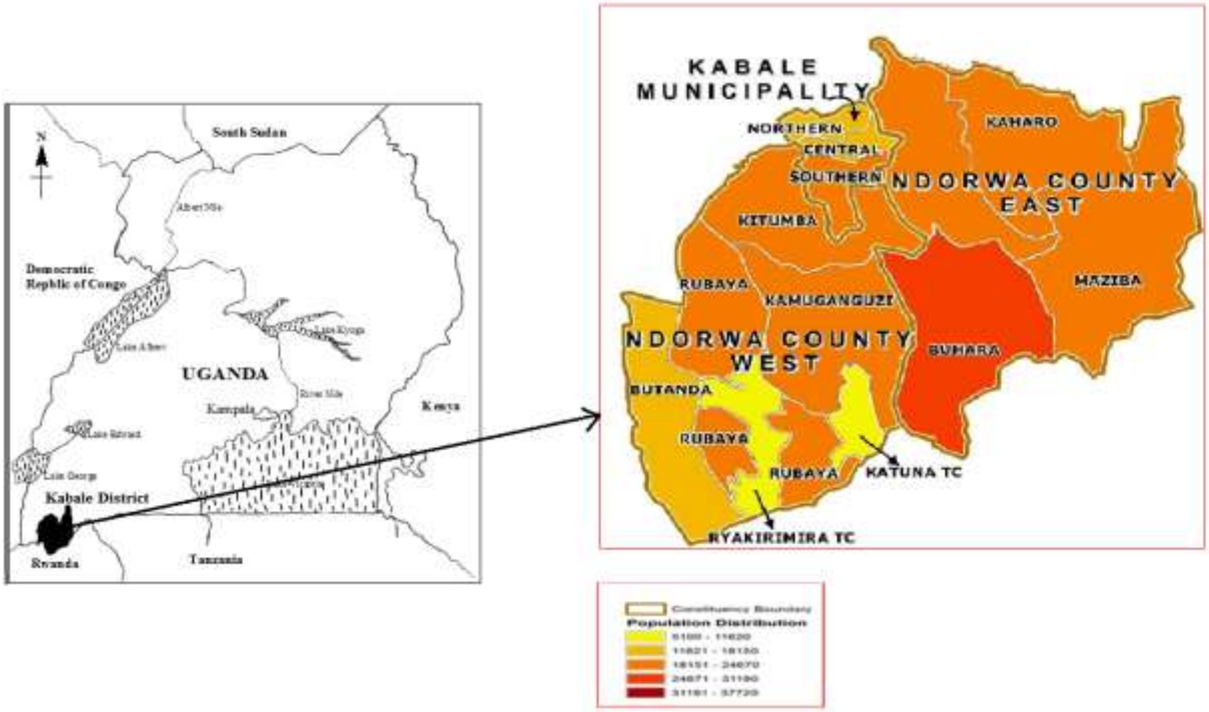

Figure 1. Study area.

Table 1. Number of Vegetable farmers in Kyanamira, Kaharo and Kamuganguzi Sub counties.

Sub-county	Estimate farmers
Kyanamira	4,292
Kaharo	4,064
Kamuganguzi	4,337
Total	12,693

Kabale town, the main commercial area and vegetable farmers from the district. According to Kabale District Agriculture Office the three sub-counties of Kaharo, Kyanamira and Kamuganguzi (Table 1) have majority of the vegetable farmers and they were selected for the study. Therefore, pesticide traders who operated from central market in Kabale Municipality and vegetable farmers in Kaharo, Kyanamira and Kyanamira sub-counties were interviewed in the survey. The sample sizes were determined using Krejcie and Morgan's Table (Krejcie ad Morgan, 1970) in both cases as shown in Table 2. Standardized interview questions were designed for both traders and farmers to ensure homogeneity in responses, that is, traders and farmers were asked predetermined questions related to pesticide use in vegetables grown in the district and their responses were recorded.

Determination of commonly grown vegetables, pesticide used and pesticide use practices in Kabale District, Uganda

This study was designed as a cross-sectional survey on vegetables grown; pesticides used in the vegetables and associated pesticide use practices in Kabale District, Uganda. The study was conducted using face-to-face interviews with traders and farmers. Data were collected based on responses to the interview questions which were designed in English, a language understood by majority of the traders but translation was done to *Rukiga language* for farmers who did not know English. The survey was conducted in April 2017. Pesticide traders considered in the study operated from central division where majority of the shops and central market were located in Kabale municipality.

The active ingredients present in the pesticides were determined by reading their names and quantities on the pesticide container labels. Respondents were interviewed on commonly grown vegetables, pesticides sprayed in the vegatables, the importance of pesticide use in vegetables, known adverse effects of pesticides, ability to interpret instructions on container labels, pre-harvest application intervals, pesticide mixing and trainings on pesticide use attended.

Data analysis

Responses to interview questions such as types of vegetables grown and sprayed, pesticides sold, pesticide use practices and

Table 2. Krejcie and Morgan Table

N	S	N	S	N	S
10	10	220	140	1200	291
15	14	230	144	1300	297
20	19	240	148	1400	302
25	24	250	152	1500	306
30	28	260	155	1600	310
35	32	270	159	1700	313
40	36	280	162	1800	317
45	40	290	165	1900	320
50	44	300	169	2000	322
55	48	320	175	2200	327
60	52	340	181	2400	331
65	56	360	186	2600	335
70	59	380	191	2800	338
75	63	400	196	3000	341
80	66	420	201	3500	346
85	70	440	205	4000	351
90	73	460	210	4500	354
95	76	480	214	5000	357
100	80	500	217	6000	361
110	86	550	226	7000	364
120	92	600	234	8000	367
130	97	650	242	9000	368
140	103	700	248	10000	370
150	108	750	254	15000	375
160	113	800	260	20000	377
170	118	850	265	30000	379
180	123	900	269	40000	380
190	127	950	274	50000	381
200	132	1000	278	75000	382
210	136	1100	285	100000	384

N is population size, S is sample size
Source: Krejcie and Morgan, 1970

effects were collected and tabulated. Frequencies of occurrence were determined using descriptive statistics. Active components of pesticides listed on labels were also tabulated and their frequency of occurrence was determined.

RESULTS AND DISCUSSION

Number of participants in the survey

The number of pesticide traders interviewed during the survey as per Krejcie and Morgan's Table (Krejcie ad Morgan 1970) was 200 out of total of 416 traders who operated in the central market in Kabale municipality. The number of vegetable farmers interviewed was 400 out of 12,693 farmers found in the three sub-counties of Kaharo, Kyanamira and Kyanamira (Table 1). Therefore, 200 traders and 400 farmers were selected at random and interviewed. These numbers provided a representative sample from which data was collected.

Commonly grown and pesticide sprayed vegetables in Kabale District, Uganda

The commonly grown and sprayed vegetables by the farmers in Kabale District are indicated in Table 3. Tomatoes appeared most frequently followed by cabbages, cauliflower, beetroot carrots and green pepper, egg plants. African egg plants and onions had the lowest frequency. These vegetables have a high demand for home consumption and sale.

Common pesticides sold and their active ingredients

The results obtained revealed that 33 traders (16.5 %),

Table 3. Commonly grown pesticide sprayed vegetables.

Types of vegetables	Frequency of occurrence based on farmers' responses
Tomatoes (*Solanum lycopersicum)*	360
Cabbages *(Brassica oleracea; var. capitata)*	244
Cauliflower (*Brassica oleracea; var. botrytis)*	168
Beet root (*Beta vulgaris)*	96
Carrots (*Daucus carota*)	60
Green pepper (*Piper nigrum L*)	60
Egg plants *(Solanum melongena)*	36
African egg plants *(Solanum aethiopicum)*	36
Onions *(Allium cepa)*	24

Table 4. Pesticide types present in shops and their active ingredients (a.i).

Pesticide class	Trade names	Amounts of a.i in each pesticide Kg^{-1}	Total frequency
Fungicides (systemic)	a, b, c, d, e,f, g	Mancozeb 640 g per.Kg^{1} + Metalaxyl 40 g per Kg	Fungicides (352)
	Osho mistress	Mancozeb 640 g.Kg^{-1} + Cymoxanil 80 g.Kg^{-1}	
Fungicides (non-systemic)	i,ii, iii, iv, v, vi vii.vii	Mancozeb 80%	
Insecticides (systemic)	α , β, γ	Dimethoate	
	A	Cypermethrin 4% + profenofos 40%	
	B	Cypermethrin 5%	
Insecticides	C	Cypermethrin 5%	Insecticides (400)
(non-systemic)	Dichlorvos	dichlorvos 100%	
	Malathion	Malathion 50%	

Trade names: Systemic fungicides: a, Ridomil; b, Eureka; c, Victory, d, [TATA]Master; e, Kingmill, f, Milraz; g, Osho Master; Non-systemic fungicides: I, Unizeb; ii, Mancodoze; iii,Mancozeb; iv, Sicozeb; v, Tridex; vi- Mancoera; vii, Oshothane; Systemic insecticides: α, Uthoate; β, Tagfor; γ, Sicothoate; Non-systemic Insecticides: A, Rocket; B, Supacyper; C, Cyperlacer.

out of the 200 traders originally selected for the survey, sold pesticides in their shops in Kabale District, Uganda. The common pesticides sold for use in vegetables belonged to two categories namely: insecticides such as pyrethroids, organochlorines, organophosphates and carbamates (53 %) and fungicides (47 %) as shown in Table 4. The findings of the study are in agreement with the results obtained by Ngowi et al. (2007). While some pesticides used in vegetables had different trade names, which could potentially confuse customers; the active ingredients present were similar and the most commonly used active ingredients either singly or in a mixture were mancozeb followed by metalaxyl, dimethoate, cypermethrin, dichlorvos, malathion and profenofos, respectively as shown in Table 4. It was also observed that majority of the pesticide container labels showed percentages of the active ingredients present but the percentage of dimethoate was missing on the container labels. This may affect proper application, thus manufacturers can be engaged to label more appropriately to provide farmers with correct information.

Application of pesticides to vegetables and pesticide use practices

During the interview, it was found that for those farmers who followed pesticide application guidelines, the pesticide was dissolved in water as per the guidelines of the manufacturer and sprayed using a knapsack sprayer. Various sprayers were used but the most common was the Bomba magoba, 10 - 20 L (China), distributed by Chemical Industries Limited, Kampala, Uganda.

Pesticides used in vegetables are commonly delivered in form of droplets from sprayers of different types of nozzles and spray bombs. Spray droplets need to be uniformly distributed on a target surface with minimum losses due to drift, evaporation or run-off in order to maximize spray efficiency. Poor spray application techniques may cause reduced pest control, yield reduction, wasted pesticides and lower returns to the grower. Thus, knowledge about droplet sizes, droplet density and water volume may lead to higher spray efficiency.

However not all farmers could read and interpret instructions on pesticide container labels. About 82% could not interpret instructions on labels of pesticide containers and only 18 % could easily follow instructions given on the pesticide container labels. This demonstrates the need for training and simplifying procedures on the labels so that they are easily understood. This challenge can further be addressed though publication of simple pictorial guides to help semi-illiterate farmers to avoid wrong reconstitution and application practices. Since haphazard pesticide application is detrimental, it is important to provide more farmer education for example to know when systemic pesticides non-systemic pesticides should be used, or when fungicides, insecticides or other pesticide categories are required depending on the mode of infection, pest and plant species.

Post spray waiting periods were haphazard, for instance, about 17.5% of the farmers harvested vegetables 1 h after pesticide spraying, 21% of the farmers after 3 h, and 32.5% after 6 h. 41.8% waited after 1 day of pesticide spraying to harvest vegetables, 4% waited 2 days while only 2 % of the farmers harvested vegetables after 3 days of pesticide spraying. Longer waiting period may allow pesticide degradation to less toxic levels. Non adherence to the pre-harvesting period waiting periods can be associated with accumulation of pesticide residues in vegetables. Therefore it is important to observe an adequate waiting period; moreover, many pesticides are systemic (Miah et al*.,* 2014). Harvesting vegetables after spraying on the same day is wrong – usually at least 3 days or more are needed depending on the vegetable type and pesticide used.

Farmers' responses showed that 42% mix different pesticides before use and 58 % do not mix pesticides. Some farmers mix two or more pesticides with a range of products having the same active ingredients in the same spray tank aiming at increasing efficacy. Similar practices were reported in Tanzania (Ngowi et al*.,* 2007; Mhauka, 2014); however, this is not recommended. Mixing of pesticides in the same spray tank can result in synergistic or antagonistic effects which are not well investigated. Pesticide mixtures can affect plant health, reduce yield and result in multiple pesticide residues in vegetables (Ngowi et al*.,* 2007; Moshi and Matoju, 2017) which can cause various health hazards in humans as well as high production costs. Furthermore, codes of best practices prohibit use of a mixture of pesticides unless advised by the manufacturer or inherent in the formulation (Ngowi et al*.,* 2016; Lekei et al*.,* 2014). Generally, pesticide mixing is one form of pesticide misuse that may lead to application of pesticide sprays with far higher concentrations of active ingredients than what is recommended for use at a time. Farmers should also be advised against pesticide mixing unless it is recommended by the manufacturer or technical professionals.

All the farmers interviewed had never attended formal training on pesticide use and these findings were similar to those obtained by Pujara and Khanal (2002) in their study among vegetable growers of Jaishidihi sub-catchment in Nepal. A low level of education and limited professional pesticide application training may lead to poor pesticide handling practices and contribute to increased risk of human exposure through occupation exposure and food consumption (Ngowi et al*.,* 2007; Nonga et al*.,* 2011; Marčić et al*.,* 2011; WHO and IPCS, 2010; Mdegela et al*.,* 2013). Therefore, there is a need for training not only farmers/field agriculture extension staff, but also pesticide sellers; provision of advice by using posters and distributing pocket books illustrated so that a farmer learns to spray downwind and avoid walking towards the spray etc. Farmers need to understand the use of personal protection equipment to avoid inhaling of pesticide sprays and unnecessary body contacts with pesticides.

Knowledge of effects of pesticides and prevention of exposure

Farmers responded that pesticides improve productivity in vegetable growing (90%), could also affect food quality (8%), contaminate non-target vegetation (2%) and surface water (6%). All traders and farmers stated various harmful effects associated with exposure to pesticides on human health (Table 5). The effects stated although reported elsewhere in literature (Grewal et al*.,* 2017) cannot be exclusively attributed to pesticide exposure in this study because general ill-effects were reported as the farmers were unable to associate a specific effect to a specific pesticide. There could be other contributing factors such as harsh environment or other diseases, thus more work can be done to interrogate these responses.

Prevention measures against effects of pesticides were generally well known to both pesticide sellers and vegetable growers as shown in Table 6. However, pesticide sellers mentioned many effects perhaps from experience and information sharing with their customers and/or manufacturers. Pesticide sellers may be prone to prolonged exposure to pesticides in their shops especially those that are highly volatile. Exposure may be enhanced during mixing or repackaging pesticides without personal protective equipment and proper guidelines. There is a need for more educational programs, mass sensitization perhaps through various media platforms to remind the population of the deleterious effects of pesticide exposure.

The impact of pesticides can be minimised by preventive measures such as rational use of pesticides, washing and proper processing of food products, practicing organic farming, use of natural pesticides and bio-pesticides, and strict implementation and amendment

Table 5. Responses on the possible adverse effects of pesticides on human health.

Signs of the Effects	Frequency	Percentage
Traders' responses		
Cancer	33	100
Stomach cramps (pains)	31	94
Brain damage	31	94
Diarrhoea	30	91
Skin irritation	29	88
Infertility	28	85
Allergies	28	85
Weakness	27	82
Headache	26	79
Dizziness	24	73
Vomiting	24	73
Birth defects	20	61
Difficult breathing	18	55
Thirst	15	45
Organ failure	13	39
Confusion	12	36
obesity	11	33
Nausea	10	30
Chills	9	27
Autism	7	21
Excessive sweating	4	12
Chest pains	3	9
Diabetes	3	9
Loss of sensation	1	3
Endocrine complications	1	3
Farmers' responses		
Cancer	328	82
Allergies	176	44
Learning problems	160	40
Nervous system problems	144	36
Weakened immune system	112	28

of pesticide-related laws (Grewal et al., 2017). Training farmers is essential if pesticides are to be used in food crops, simple manuals about safe use, better application methods can be developed and distributed to farmers. Consumers can also be updated about methods that can effectively reduce pesticides residues in vegetables.

Conclusion

In Kabale District, Uganda, cabbages, cauliflower, tomatoes and beetroot were commonly grown and sprayed with cypermethrin, mancozeb, profenofos, malathion, metalaxyl dichlorvos and dimethoate, individually or in mixtures.

Poor pesticide use practices were observed and this could be attributed to the lack training on pesticide use, implying that there is need for a comprehensive program to train farmers on pest control. Pesticide use instructions provided on pesticide container labels usually in foreign languages are very difficult for farmers and pesticide sellers to read and understand the active ingredients present in the pesticides. There is a need for provision of this information in local languages to address this gap.

While traders and farmers contacted in the study had limited information about the various ingredients present in pesticides; they expressed concern about adverse effects on human health associated with pesticide exposure. Preventive measures of the effects of pesticide use such as washing vegetables before consumption, growing vegetables for home consumption organically

Table 6. Responses on preventive measures of pesticides' effects on human health.

Preventive measures	Frequency	Perentage
Traders' responses on preventive measures of pesticides' effects on human health		
Wash the vegetables before eating them	46	92
Training farmers on how to apply pesticides	42	84
Respecting actual timelines for harvesting after spraying	33	66
Grow vegetables for home consumption without pesticide spraying	3	6
Buy unsprayed or organic products	2	4
Farmers' responses on preventive measures of pesticides' effects on human health		
Concerned food quality and government agencies should establish pesticide residue monitoring centres at district level	3	10
Farmers should be trained on how to apply pesticides and make them understand their effects on human life	2	7
Farmers should follow actual timelines for harvesting after spraying	3	10
Farmers should use proper pesticide concentrations as instructed by the manufacturers	1	3
Wash sprayed food before consumption	6	21
Grow fruits and vegetables for home consumption	2	7
Buy unsprayed or organic vegetables or fruits	4	14
Dry the vegetables before consumption	5	17
Peel the outer layer	2	7
Identify vegetables with the highest pesticide load and avoid them	1	3

without spraying and buying unsprayed vegetables were well known but little was known about the modern techniques used to pesticide residues in food stuffs.

While majority of the farmers (84 %) stated that pesticide use as the best option to control pests in vegetables, only 18 % of the farmers could correctly interpret instructions on labels provided on pesticide containers. Some farmers (42 %) mix pesticides to use in vegetables, adherence to post spray waiting periods was haphazard and inadequate in many cases. Thus, there is need for broad based farmers' training on pesticide use in Kabale District, regional and countrywide to reduce risk associated with pesticide use malpractices.

CONFLICT OF INTERESTS

There is no conflict of interest.

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Cultivation of edible mushrooms in Namibia: Prospects and challenges of small scale farmers

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The demand for mushroom cultivation rapidly increases over years in Namibia as more people discovered its health and medical benefits, as well as the mushroom economic value. However, high temperatures at some parts of the country had made the cultivation difficult though watering in the mushroom houses was recommended as a measure to decrease temperature and rise up the humidity in the mushroom houses. In order to exploit the Namibian potential for mushroom cultivation it is essential to develop cultivation technologies for small scale farmers, organized communities before introducing it to modern large-scale industrial operations. In Namibia, there are large amounts of agricultural wastes sometimes, previously, considered to be largely unusable. These agricultural by-products readily available in rural and peri-urban communities can be used as substrate for mushroom cultivation which made the cultivation easier and effective to reduce demand for more food security. Hence in this paper challenges and future prospects of the mushroom cultivation are discussed.

Key words: Mushroom, oyster, agricultural waste, challenge cultivation, prospects.

INTRODUCTION

Strong consumer demands and threats of depletion of mushrooms have stimulated increased worldwide production in the past few decades (Chang and Miles, 2004). The increased demand of mushrooms is due to their unique culinary and medicinal properties (Yan et al., 2004) (cited by Onyango et al., 2011). It provides an efficient and economically-viable biotechnology (Bradley, 2013), which can give consistent growth with high biological efficiency (Jonathan et al., 2012) (cited by Rosmiza et al., 2016). It offers lucrative business requires no arable land for production and provides diversification with benefits such as increased income, employment and food and nutritional security (Gateri et al., 2009). Mushrooms are suitable for fresh consumption, pharmaceutical use and cosmetic production (Ministry of Agriculture Malaysia, 2011; Mohd et al., 2013). Edible mushrooms are highly tradable commodities. The consumption of Oyster mushrooms is reported to boost up the body's immune system as it carries tumor-retarding chemicals (Chang et al., 1993).

Worldwide, edible mushrooms have been widely collected from the forests. The greatly increased harvest of forest mushrooms raises many issues and concerns among forest managers and the general public (Pilz and Molina, 2002; Liegel, 1998) especially within special interest groups, such as mushroom clubs, mycological societies, and conservation organizations. These issues and concerns are directly proportional to wild mushroom depletion that could lead to food insecurity among villagers (Waiganjo et al., 2008). Local mushroom

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cultivation is therefore seen as an adequate solution to secure mushroom supply and to control over harvesting from nature (Fang and Zhong, 2002). According to Chang (2006), the challenge in mushroom production is to recognize opportunities such as increasing consumption capabilities with the increase in world population and to take advantage of this by promoting the consumption of mushrooms. In 2014, Asian countries produced more than 74.64% of mushrooms in the world markets, followed by Europe with 19.63%) (FAO, 2015). However, Africa contributes a paltry >1% of the annual worldwide production of mushrooms (Adejumo and Awosanya, 2005).

Mushrooms are highly nutritious and contain 20-40% protein on a dry matter basis, which consists of all the essential amino acids required in the human diet. Their taste and delightful aroma make them a delicious and popular food in restaurants throughout the world (Mshigeni and Chang, 2000). The abundant agricultural waste found in Namibia offers opportunity for mushroom production. Moreover, spent substrate could be used as animal feed after mushroom cultivation (Soto-Cruz et al., 1999) and as compost to enrich soil for plant production (Szmidt and Chong, 2013). Therefore, the cultivation process of oyster mushroom can address the issue of soil waste disposal, economical gain and environmental protection (Deepalakshmi and Mirunalini, 2014). Cultivation of *Pleurotus* species, commonly known as Oyster mushrooms, is the most popular practice among small-scale farmers; mainly because it can fruit over a wide range of temperatures (Rohde and Hoffman, 2012). The Pleurotus species are regarded as easy to grow and have broad adaptability to the environment in which they grow. This is the reason why their production worldwide has increased rapidly (Chang and Miles, 1997). *Pleurotus sajor caju* and *Pleurotus ostreatus* (oyster mushroom) are two of the choice edible mushrooms which can be cultivated in the tropics (Quimio et al., 1990). Oyster mushroom production represents an opportunity for farmers interested in an additional enterprise and is a specialty option for farmers without much land (Rosmiza et al., 2016).

In general, other edible wild mushrooms are well known among Namibian farmers and are widely consumed in the northern regions during the rainy season (Kadhila-Muandingi, 2010). Although formal scientific mushroom cultivation in Namibia has been attempted in the past and with oyster mushroom identified as easy to grow worldwide, Namibian farmers are still struggling to grow oysters using the locally available materials such as grass, wheat and rice straw and maize cobs. It is now well known that mushrooms can be artificially cultivated in Namibia and many projects are well established across the country. However, the general public especially rural communities have little information on prospects and challenges of oyster mushroom cultivation. The present article reflects on the current status of oyster mushroom cultivation in Namibia to provide views for future direction. The paper assessed the mushroom industry prospects and explored issues and challenges facing the mushroom industry for local and communal farmers specifically. The authors report on the identified challenges and opportunities for mushroom farming, as well as expectations and suggest way forwards toward successful mushroom business enterprises.

MATERIALS AND METHODS

Working methodology

Representatives of different mushroom cultivation projects in Namibia attended a workshop which was hosted by the Zero Emission Research Initiative (ZERI) at the University of Namibia main campus. Nine out of fourteen regions of Namibia were represented. Namely: Erongo, Hardap, Kavango West, Khomas, Ohangwena, Omaheke, Omusati, Oshana and Zambezi regions. ZERI, which is the umbrella of mushroom projects in Namibia, sent out invitation letters to all mushroom projects across Namibia, urging/requesting the project managers to nominate two participants for the workshop. Four Mycological researchers from four different campuses of the University of Namibia were invited. The workshop also included two mushroom experts who have been involved in mushroom cultivation. The workshop also had representatives from the Ministry of Agriculture and the Ministry of Youth, Sport and Culture of the Republic of Namibia, as well as the community development sector. Workshop participants were actively engaged on mushroom production activities at their respective projects. Researchers and Ministry representatives selected were those responsible for mushroom community training in their respective area. Due to language diversity, participants were divided into four groups with a group leader. Each group leader was fluent in the dominant language of that specific group.

Data collection process and analysis

Strengths, weaknesses, opportunities, threats (SWOT) analysis was used as a tool to collect data. Open ended interviews were conducted in a group setting, where questions were posed to the groups and they responded accordingly. Group responses were recorded on paper. The analysis based on current performance such as the role and contributions of the entrepreneur; current total of mushroom production in the country; mushroom and mushroom products exports and imports; and the challenges and opportunities facing growers.

RESULTS AND DISCUSSION

Issues and challenges of mushrooms production in Namibia

Various concerns and challenges were identified that can hamper successful mushroom production among small scale farmers in Namibia, requiring attention and approaches of increased mushroom production and access to market. Challenges such as lack of substrate, community commitments as well as the establishment of favorable mushroom houses require human efforts while

Table 1. Challenges and action required in mushrooms industry of Namibia.

Challenge	Action required
Lack of good substrate	Gather straws during harvesting season of rice and straw and store it.
Access to water	Group leaders to approach town councilors for assistance.
Firewood scarcity	Introduce membership fee to buy wood and substrates.
Contamination of spawn	Maintain good hygiene during spawn inoculation.
Lack of standard mushroom houses	Use locally available materials to construct suitable mushroom houses.
Unavailability of Funds	Apply for funds from non-governmental agencies.
Lack of commitment among project members	Introduce attendance list, assign working shifts, sign performance agreement and dismissal of uncommitted members
High temperature	Water the mushroom house floor, roof and wall frequently when the temperature is high,
Mushroom projects are not well marketed.	Create awareness of project in community. Tell the benefits of mushroom consumption in your area, use media, radio, posters and Television shows etc.
Mushrooms fail to meet market standards	Harvest the mushroom timely to catch good price in the market.

Table 2. SWOT Analysis of mushroom industry in Namibia.

Strength	Weakness
Crop residues such as wheat straw (grown commercially in the southern part of Namibia), rice, pearl millet straws (staple food at the northern part of the country), and rice straw, bamboo and field grasses are readily available for mushroom cultivation	Lack of Government funding on mushroom facilities to produce quality compost, spawn and processed products
Mushrooms provide opportunity to make high value-added products	Short shelf life affecting potential products to long distance markets
Eager market for mushroom produce and products	
Spent mushroom substrate can be recycled on cropping system or as animal feed	Lack of commitments amongst project members
Do not require as much land as compared to other agricultural farming activities	Lack of skilled workers to harvest, grade and package mushrooms for retail.
	Lack of firewood due to conservational laws which prevent cutting of trees.
Threats	**Opportunities**
Contamination of spawn due to substandard facilities	Mushroom consumption awareness created globally on health and medicinal values brought better domestic and global market demand
Pests reduce product quality.	Enhanced public awareness in environmentally friendly farming by using crop waste and spent mushroom substrate as a value-added product will improve future sales. This sentence is not clear
Limited supply of organic pest control products.	Mushroom cultivation is labour intensive, creating job opportunities for unemployed youth in rural and peri-urban areas
Market competition from well-established mushroom producers in neighbouring countries.	The industry creates employment to youth and women in rural and peri-urban areas
Mushroom production is labour intensive. This leads to high production costs	The initiative reduces dependence on mushrooms imports in Namibia

others need government involvement (Table 1).

SWOT Analysis of challenges lining mushroom industry in Namibia

A SWOT analysis was conducted based on the study analysis. There are four strengths that need to be highlighted, with consideration of five significant opportunities for successful mushroom farming in Namibia. In contrast, five scores of weaknesses and five scores of threats must also be fully understood and addressed properly (Table 2).

Table 3. Agricultural residues used to cultivate mushrooms in Namibia.

Residue	Mushroom variety
Wheat straws	Oyster and button
Rice straws	Oysters and button
Corn cobs	Oyster, *Ganoderma*spp*, Lentinuna*spp
Maize straws	Oyster, button
Field grasses	Oyster
Saw dust	*Ganoderma*spp,*Lentinuna*spp
Sawdust – straw mixture	Oyster*, Ganoderma*spp,shiitake
Corn cobs – straw mixture	Oyster*, Ganoderma*spp,*Lentinuna*spp

Agriculture residues as a mushroom growing medium

Wood shavings from local woodworkers are used as a substrate for medicinal mushroom cultivation trials in Namibia. Crop residues such as rice, wheat and maize straws are used to grow oyster mushroom in all regions of the country. New agricultural innovations should be studied to analyze the potential use of other agricultural by-products as substrate (Table 3).

Conclusion

Oyster mushrooms (*Pleurotus* species) are a good choice for beginner mushroom cultivators because they are easier to grow. They can be grown on a small scale with a moderate initial investment. Although commonly grown on sterile straw from wheat or rice, they will also grow on a wide variety of high-cellulose waste materials like millet, sorghum and grass straws that are readily available in most areas of Namibia. The present discussion concludes that, there is high potential of Oyster mushroom production in Namibia and hereby encouraging farmers to utilize the opportunity and grow oyster mushroom.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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Biochemical characterization and genetic variability among thirteen black pepper genotypes

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There is limited information on the biochemical variability of black pepper genotypes in Ethiopia. Dried fruit samples from 13 introduced black pepper accessions were used for biochemical analysis. All the determinants were done in triplicates. Biochemical data ranged for essential oil between 1.70-3.60%; oleoresin, 8.30-12.15%; ash, 5.72-7.05%; acid insoluble ash, 1.97-4.06%; crude fiber, 13.61-17.96%; moisture, 7.62-10.14%; bulk density, 520.00-738.00 g/L; and piperine, 5.48-5.56%. Accessions differed significantly (P<0.05) in all characters except in oleoresin and piperine. The phenotypic coefficient of variability (PCV) values were relatively greater than genotypic coefficient of variability (GCV), for all traits; however, the GCV values were near to PCV values indicating high contribution of genotypic effect for phenotypic expression of these characters. Heritability in broad sense (h^2B) ranged between 66.67-95.24, and genetic advance as percent of the mean (GAM) ranged from 0.79 to 71.84. High heritability coupled with high genetic advance for all characters (except for piperine), reflect the presence of additive gene action for the expression of these characters, and improving of these characters could be done through selection.

Key words: Black pepper, genotypes, biochemical characters, variability, heritability.

INTRODUCTION

Black pepper (*Piper nigrum* L.) is cultivated for its fruit, which is usually dried and used as a spice and seasoning. The spicy taste is mainly due to the presence of piperine, a pungent alkaloid (Tripathi et al., 1995). It can be used for medicine, human dietaries, preservatives and bio-control agents (Srinivasan, 2007). The essential oil from black pepper possesses antioxidant and antimicrobial activities (Dorman and Deans, 2000).

Knowledge of genetic variability in crop populations is important for selection of superior genotypes. The success of crop improvement program depends on the amount of genetic variation present in a crop and the magnitude of the variation which is heritable from the parent to the progeny (Prasad et al., 1981). Heritability estimate provides information on the extent to which a particular character can be transmitted from the parent to the progeny (Allard, 1991). Genetic advance shows the degree of the gain obtained in a character from one cycle of selection. High genetic advance coupled with high heritability estimates offers the most suitable condition to decide the criteria of selection (Syukur and Rosidah, 2014).

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Table 1. Description of thirteen black pepper genotypes.

S/N	Genotypes	Source country	Year introduced
1	Bra.32/79	Brazilian	1981/82
2	Sri. 3/80	Srilanka	1984/85
3	Pan. 4/80	India (kerala)	1984/85
4	Kuch. 5/80	India (Kuching)	1984/85
5	T4. 17/79	Costarica	1981/82
6	Pk.-9	India	1985/87
7	Kw.32	Srilanka	1986/87
8	DMKW-7	India	1986/87
9	15/86	Srilanka	1986/87
10	Kw.33	Srilanka	1986/87
11	Kw.11	Srilanka	1986/87
12	14/86	Srilanka	1986/87
13	Gk. 49	India	1986/87

In Ethiopia, black pepper is part of the daily meal, as a spice and as a source of cash from its sell. It is among spice crops grown for export market. Nevertheless, the supply for both local and export market is limited due to low production and productivity. Knowledge on genetic variability in both morphological and biochemical traits of black pepper genotypes in Ethiopia is limited. Where there is insufficient variation within a crop population of a country or a region, one of the options to increase usable variation is introducing from other regions. The present study was done with the objectives of characterizing biochemically and assessing the magnitude of genetic variability, heritability and genetic advance of thirteen introduced black pepper accessions.

MATERIALS AND METHODS

Sample preparation

The biochemical analysis was conducted at Teppi National Spice Research Center (TNSRC) of Ethiopia in July 2015. Samples for the biochemical characterization were taken from 13 accessions of black pepper introduced from different countries (Table 1). The accessions were planted for long term study as the crop is perennial. It was first planted in July 2008. The field design was Randomized Complete Block with three replications. Fruits getting light red were harvested and heaped for about 24 h. For each replication of the treatment 1000 g of fresh berries were collected. The berries were sun dried to 10-12% moisture content on mesh wire bed. The dried samples were prepared for laboratory analysis by grinding as quickly as possible in a grinding mill to pass sieve with 1 mm diameter aperture. The samples were kept in a dry stoppered container until analysis.

Chemical analysis

The extraction of essential oil from 100 grams of ground sample was done by using hydro-distillation according to AOAC (2000). Oleoresins were determined from thirty grams of ground sample by acetone extract method using Soxhlet apparatus according to AOAC (2000). Ash content was determined from 2g sample by heating the dried end product in furnace at 550^{o}C overnight till the difference between two successive weighing not more than 0.1%, according to AOAC (2000). Acid insoluble ash was determined from the ash using dilute HCl as a solvent according AOAC (2000). Crude fiber was determined from 1.5 g sample using preheated Sulphuric acid (H_2SO_4) (1.25% v/v) for acid digestion and natrium hydroxide (NaOH) for alkali digestion according to (AOAC, 2000). Piperine was extracted from 6 g grounded sample using acetone according to AOAC (2000). The concentration was determined by injecting the prepared sample to the High Pressure Liquid Chromatography (HPLC) system. Bulk density and moisture content were determined according to AOAC (2000).

Data analysis

The analysis of variance (ANOVA) was done using Minitab version 19. Significances were declared at the probability level of 0.05. The variance components: genotypic variance (GV), phenotypic variances (PV) and environmental variance (EV) were determined from mean square values of the ANOVA for each trait according to Prasad et al., (1981). The variance components were used to compute the Genotypic Coefficient of Variability (GCV), Phenotypic Coefficient of Variability (PCV), broad sense heritability (h^2B), genetic advance (GA) and genetic advance as percentage of the mean (GAM), according to the methods of Burton (1952), Johnson et al. (1955) and Kumar et al. (1985).

RESULTS AND DISCUSSION

Biochemical characterization

The analysis of variance showed that black pepper accessions differed highly significantly ($P<0.001$) in contents of essential oil and bulk density and significantly ($P<0.05$) in contents of acid insoluble ash, crude fiber, ash and moisture content, but not in contents of oleoresin, and piperine (Table 2 and 3). The biochemical data ranged for essential oil between 1.70-3.60%;

Table 2. Genotypic and error mean squares from ANOVA for biochemical traits of 13 black pepper accessions.

S/N	Characters	Genotype mean square (df=12)	Error mean square (df=24)
1	Essential oil	0.87***	0.18
1	Oleoresin	3.22	1.63
3	Ash	0.77*	0.11
4	Acid insoluble ash	1.19*	0.42
5	Crude fiber	7.12*	3.01
6	Moisture	1.34*	0.61
7	Bulk density	12582.94***	2006.69
8	Piperine	0.001	0.001

* p<0.05, **p<0.01, ***p<0.001.

Table 3. Biochemical composition of 13 black pepper accessions.

Accession	EO %	Ol%	Ash%	AIA%	CF %	M%	BD g/L	Pip (%)
32/79	2.15^{d}e	8.97^{a}	5.93^{cd}ef	3.68^{ab}	13.77^{d}	10.14^{a}	728.67^{a}	5.51^{a}
17/79	2.95^{abc}	9.22^{a}	5.92^{d}ef	1.97^{d}	14.77^{bcd}	9.17^{abc}	732.33^{a}	5.51^{a}
3/80	2.40^{bcd}e	8.87^{a}	6.30^{cd}e	3.75^{ab}	17.28^{ab}	8.01^{cd}	727.33^{a}	5.53^{a}
4/80	2.20^{d}e	9.65^{a}	6.32^{cd}	3.35^{abc}	16.06^{abcd}	8.92^{abcd}	729.67^{a}	5.53^{a}
5/80	2.35^{cd}e	9.70^{a}	5.74ef	3.18^{abc}	14.10^{cd}	7.62^{d}	663.33^{abc}	5.52^{a}
PK/9	3.10^{ab}	8.30^{a}	6.48^{bc}	3.81^{ab}	13.61^{d}	9.63^{ab}	713.33^{ab}	5.48^{a}
14/86	$2.05e^{d}$	10.55^{a}	5.86^{d}ef	3.14^{abc}	17.96^{a}	8.47^{bcd}	650.67^{bc}	5.52^{a}
15/86	2.70^{bcd}	11.10^{a}	7.02^{ab}	3.00^{abcd}	14.36^{bcd}	8.85^{abcd}	722.00^{ab}	5.50^{a}
KW/11	1.70e	10.37^{a}	5.72f	2.72^{bcd}	14.20^{cd}	9.05^{abc}	738.00^{a}	5.50^{a}
KW/32	3.60^{a}	10.22^{a}	6.89^{ab}	4.04^{a}	16.98^{abc}	9.29^{abc}	616.67^{c}	5.56^{a}
KW/33	$2.05e^{d}$	10.00^{a}	5.73f	2.76^{bcd}	16.37^{abcd}	8.34^{bcd}	734.33^{a}	5.56^{a}
DMKW/7	$2.15e^{d}$	10.75^{a}	7.05^{a}	4.06^{a}	13.66^{d}	8.44^{bcd}	520.00^{d}	5.51^{a}
GK/49	2.99^{abc}	12.15^{a}	5.77^{d}ef	2.52^{cd}	14.08^{cd}	8.80^{bcd}	732.67^{a}	5.51^{a}

EO %= Essential oil %, Ol%=Oleoresin%, AIA% = Acid insoluble ash, CF %=Crude fiber %, M%=Moisture%, BD g/L =Bulk density g/L, Pip(%)= Piperine (%); Means in a column that do not share a letter are significantly different.

oleoresin, 8.30-12.15%; ash, 5.72-7.05%; acid insoluble ash, 1.97-4.06%; crude fiber, 13.61-17.96%; moisture, 7.62-10.14%; bulk density, 520.00-738.00 g/L; and piperine, 5.48-5.56% (Table 3). The result shows presence of a considerable variation in biochemical characters among the accessions.

Analysis of variance components

Estimates of the variance components: phenotypic variances (PV), genotypic variances (GV) and environmental variance (EV) are shown in Table 4. The result showed that the phenotypic variances are higher than the genotypic variances. Nevertheless, the PV and GV values are close to each other. The genotypic variances were greater than the error variances for all traits (Table 4). These high genotypic variances indicate that the genotypic component was the major contributor to the total variance for these biochemical traits. Similar results have been reported by other workers (Baye, 2002; Nwofia and Chilekwe, 2015).

Similarly, the PCV values were relatively greater than GCV for all traits; however, the GCV values were near to PCV values (Table 4). The closeness of the values indicates that there was little influence of the environment in the expression of these traits, suggesting the presence of high genotypic contribution for phenotypic expression of these characters (Nwofia and Chilekwe, 2015). It can be concluded that most of the variability observed in the biochemical traits of black pepper are more of a genetic than environmental basis. This indicates that there is substantial opportunity for selection among the accessions for the biochemical traits.

The success of crop improvement program depends on the amount of heritable genetic variation present in a crop (Prasad et al., 1981). Hence heritability is used by breeders in exercising the reliability of phenotypic values. The genetic advance indicates the progress that can be anticipated as a result of exercising selection on the

Table 4. Estimation of components of variance, coefficients of variation, heritability and genetic advance for the biochemical traits of 13 black pepper accessions.

S/N	Character	Mean	EV	GV	PV	GCV	PCV	h^2B	GA	GAM
1	Essential oil	2.49	0.18	0.81	0.87	36.14	37.46	93.10	1.79	71.84
2	Oleoresin	9.98	1.63	2.68	3.22	16.39	17.98	83.13	3.07	30.79
3	Ash	6.21	0.11	0.73	0.77	13.79	14.13	95.24	1.72	27.72
4	Acid Insoluble Ash	3.23	0.42	1.05	1.19	31.72	33.77	88.24	1.98	61.39
5	Crude Fiber	15.17	3.01	6.12	7.12	16.30	17.59	85.91	4.72	31.13
6	Moisture	8.82	0.61	1.14	1.34	12.09	13.12	84.83	2.02	22.93
7	Bulk Density	693	2006.69	11914.04	12582.94	15.75	16.19	94.68	218.79	31.57
8	Piperine	5.52	0.00	0.00	0.00	0.47	0.57	66.67	0.04	0.79

Mean = grand mean for the character, EV= environmental variance, GV = genotypic variance, PV = phenotypic variance, GCV = genotypic coefficient of variation, PCV = phenotypic coefficient of variation, h^2B = broad sense heritability, GA = genetic advance, GAM = genetic advance as percentage of the mean.

population (Sood et al., 2011). Heritability was high for all biochemical traits (Table 4), indicating low influence of the environment on the expression of these traits. Heritability along with genetic advance is more useful than heritability alone in predicting the subsequent effect of selecting better performing individual genotypes as it suggests the presence of additive gene effects (Syukur and Rosidah, 2014).

Heritability in broad sense (h^2B) ranged between 66.67-95.24, and genetic advance as percentage of the mean (GAM) ranged from 0.79-71.84 (Table 4). High heritability coupled with high genetic advance as percentage of the mean for all characters except for piperine, reflecting the presence of additive gene action for the expression of these characters, and improving of these characters could be done through selection.

Conclusion

The results from the analysis of variance showed significant variability between accessions of black pepper for essential oil, ash, acid insoluble ash, crude fiber, moisture, and bulk density. The presence of the variability was further evidenced by the estimates of variance components. The obtained variability was more of genetic than environmental. High heritability and genetic advance observed for all characters indicate that these biochemical characters are controlled by additive genes and selection can be effective for their improvement.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Net income analyses of maize agribusiness in Wukari Taraba State, Nigeria

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The study was carried out to ascertain effects of agribusiness functions and experience on small scale maize agribusiness operators' net income in Wukari, Taraba State, Nigeria. A purposive sampling was used to select four area-markets namely Rafin-Kada, Gindin-Doruwa, Bantaji and Kente markets, where maize agribusiness owners predominantly carry out production and marketing of maize grain. Fifteen small scale maize agribusiness operators were randomly selected from each of the four areas, making a total of 60 operators as representative sample. Interview method and questionnaire was used to illicit response from respondents. Regression results reveal processing, packaging, in addition to sales volume have positive significant influence on operators' net income, while grading, storage, and transportation functions had positive experience had negative insignificant effect. Model summary shows R-square as 0.969, and adjusted R-square is 0.939 yielding an average R-square of 0.954, implying that 95.4% of the variations in the net incomes of the maize entrepreneurs were explained by the exogenous variables. Results of ANOVA reveal a significant model with P = 0.000, and F*Cal 97.78>F*tab 1.77. Null hypothesis (H0: b = 0) is rejected and the alternative hypothesis (HA: b ≠ 0) accepted since not all the exogenous variables have zero effects. Despite regulating grading, storage, transportation, and financing functions to improve production and sales volume; processing, packaging and sales functions are recommended major criteria for incentive provision by stakeholders given their overriding effects on net income cum shelf life improvement. The study concludes that maize agribusiness is profitable in the study area.

Key words: Analyses, maize agribusiness, net income, agribusiness functions, experience.

INTRODUCTION

Maize agribusiness refers to a sector that encompasses farming and farming-related commercial activities. Put differently, the business involves all the steps required to send an agricultural good to market, including production, processing and distribution. Maize is the second most cultivated crop in Nigeria in terms of area harvested, while Nigeria is the second largest maize producer in Africa, after South Africa (Sahel, 2017). It is an important

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component of the economy in a country like Nigeria with arable land, because the produce can be exported to earn foreign exchange (Chen, 2019). In beginning a maize agribusiness, an operator first finds suitable and arable land. As a handy plant, maize can be grown successfully in variety of soils ranging from loamy sand to clay loam. However, soils with good organic matter content having high water holding capacity with neutral pH are considered good for higher productivity. Fertile well-drained alluvial or red loams free from coarse materials and rich in nitrogen are the best soils for its successful growth (Maize production, 2003). The prevalence of these soil requirements in the northern part of Nigeria, especially in the states of Taraba, Kano, Kaduna, Bauchi, Gombe, Adamawa and Jigawa constitute a landmark for higher cultivation of the crop in these areas (Srikanth et al., 2017).

Hitherto, Kohls and Uhl (1990) classified the functions involved in agricultural and food marketing processes under three sets of functions, including exchange functions comprising buying and selling, physical functions, comprising storage, transportation, processing, standardization, financing; and facilitating functions consisting of risk bearing, and market intelligence. Performing each of these functions add value to the product, though require inputs that translates to costs. The ability of the operator to carry out the required functions by adding positive values to the product make an enterprise remain competitive and profitable leading to most firms, entrepreneurs or operators' constant supply of the good/service. Besides, Ghafoor et al. (2017) refer agricultural marketing to all activities which add value to agricultural products as they move from areas of agricultural production to ultimate consumption points. By extension, marketing of agricultural product/produce involves the task of performing the associated agribusiness functions in any given agribusiness venture, leading to the fulfilment of customers' needs and improving net income of stake operators may include, but limited to those performed by a group of industries or entrepreneurs concerned with holders. The functions carried out by agribusiness agricultural produce and services such as assemblage of these goods, storage, transportation, processing, grading, financing among other activities/functions. Agricultural marketing system also relates to economic growth of the agricultural sector by ensuring safe and affordable food to consumers, both of which are directly linked to the food security of any country (https://www.gktoday.in/gk/marketing-of-agricultural-produce-overview/).

Most producers do not sell their goods directly to the final users, but via a set of intermediaries performing a variety of functions. These intermediaries constitute a distributing channel. They are the pathway a product or service follows after production, leading to purchase and consumption by the final users (Ozor and Nwankwo, 2018). Channels of distribution consist of a set of independent organizations involved in making a product or service available to the end users directly and indirectly.

Although goods and services pass through the marketing channels of distribution, but the perishability of farm produce compel farmers to make use of direct distribution channels. Also, since majority of farmers reside in rural areas and are separated from their customers, they also make use of the indirect marketing channels (Imam et al., 2014).

The channels through which sales of agricultural produce are actualized vary from commodity to commodity, and area market to area market. In rural markets, trade is characterized by direct sales of small quantities of produce by producers to village traders and by retailers to rural consumers (Yagana et al., 2014). Greater quantities of produce are channeled into larger rural markets, either by the producers themselves or by traders. These "assembly" markets provide sales and purchase opportunities for traders or collection agents on their own behalf or on behalf of urban wholesalers. Marketing by terminal wholesalers and semi-wholesalers takes place within or near major cities (usually with populations exceeding 0.5 million), but the extent to which this can be done depends primarily on the general state of development of the economy and the demands of consumers (http://www.fao.org/3/x4026e/x4026e03.htm).

In line with the opinion of FAO (http://elearn.luanar.ac.mw/repoz/AECO242/lec03.pdf) presents an adaptable flow chart of the general marketing channel of food grains in India thus:

(i) Farmer → consumers
(ii) Farmer → retailer or village trader → consumer
(iii) Farmer → wholesaler → retailer → consumer
(iv) Farmer → village trader → wholesaler → retailer → consumer
(v) Farmer → Co-operative marketing society → retailer → consumer
(vi) Farmer → Govt. agency → fair price shop → consumer
(vii) Farmer → wholesaler → flour miller → retailer → consumer.

Problems arise because, maize agribusiness seems lucrative, but the risks associated with growing and marketing maize often left operators complaining, not only due to decline in prices, but customers not attracted to their goods, linked to arrival of imported crop type. Again, maize production is sensitive to drought that may lead to the crop failure and famine. Besides, Nigeria has gradually moved to a system where agribusiness operators' produce, process, grade, package, transport, store and sell Maize produce to consumers, and away from a system that involves marketing boards. These changes have given rise to the performing cost-incurring agribusiness activities/functions often of considerable magnitude (http://www.fao.org/3/W3240E/W3240E12.htm), which have great effect on net income of Maize agribusiness.

Despite high production volumes, Nigeria's average maize yield of 11.136 MT between 2015 and 2019 was low among the top producers in various regions of the world. In Africa, it lags behind South Africa with a yield of 12.26 MT within the same period (FAO, 2015). It is hoped that by addressing low yield issues, Nigeria could become the largest maize producer in Africa and one of the largest producers in the world without necessarily increasing the area currently used for its cultivation. Besides, in Nigeria, the 2019 Maize harvest was 12.7 million tonnes, which was 18% above average. However, despite the above-average aggregate production, several localities experienced production shortfalls due to pockets of drought during June-July, flooding in September as well as Fall Armyworm infestations on maize crops (FAO, 2020). More so, low levels of domestic production of maize occasioned by poor quality seeds and fertilization have effects on the quality of the harvested crop, while quality and cob size affect farm gate prices (Kitinoja et al., 2019). And length of market channels increase transport cost among other factors that hinder effective marketing of Maize (Ayoola and Azever, 2010; Onu and Iliyasu, 2008), thereby influencing not only the net income of the agribusiness operators, but other marketing intermediaries of maize grains.

This study provides information on the stress variables influencing maize agribusiness significantly, which would guide the unemployed youths that may venture into the business to earn livelihood. In these regards, commercial maize farming will improve production by overcoming all bottlenecks to enhanced net income. Through checkmating the factors militating against commercial maize production, food security status of Nigeria will equally be improved. Again, private-sector investment and involvement in strengthening all points of the agricultural value chain is crucial to achieving a sustainable boost to productivity (European Union, 2013). More so, Nigeria's maize annual production in 2019 stood at 12.76 million metric tons while the annual maize consumption estimate stands at 11.4 million metric tons, creating a gap of over 400,000 metric tons of Maize which is made up for by importation. The projected demand for 2020 is that the country will need an additional 100,000 metric tons of imported Maize to augment local production amid the disruption of business activities and the restriction of movement across the country in the first quarter of 2020, culminating to reduction in maize cultivation, processing and distribution (FAO, 2020). Again European Union (2013) asserted that there has been increasingly large gap between regional demand and supply, and between regional supply and global demand. These are evidence that maize agribusiness among others is conducive to the development of a nascent African agri-food sector that can deliver significant returns on investment by maize agribusiness/entrepreneurs. Maize is very important and good source of minerals, vitamins, fiber and oil for human and animals alike (Bushra et al, 2019). The starch serves as diluents in pharmaceutical industries and cosmetics. While seeds are used in making alcohol, small scale farmers engage in maize farming, due to its high nutritional values and affordable source of vitamins and minerals for people living in rural areas.

Besides, available research works are on costs and returns, comparative analysis of comprehensive (gross) and net income and maize marketing, which did not take into account effects of agribusiness functions on the operators' net income, as carried out in this study, and wherever available, vary in aspects and scope. Bataineh and Rababah (2016) compared the ability of comprehensive income and net income to predict companies' future performance in emerging markets by studying industrial companies in Jordan. Urassa (2015) worked on factors influencing maize crop production at household levels: A case of Rukwa Region in the southern highlands of Tanzania. The article mainly examined households' socio-economic characteristics affecting maize production in Rukwa in the context of the market reforms carried out in Tanzania in the mid 1980's, rather than commercial maize production and effects of the activities/functions performed by commercial operators on net income of the business

The main objective is to investigate the effects of agribusiness functions and experience on small scale maize agribusiness annual net income in Wukari local government area of Taraba state, while the specific objectives are to:

(i) Identify agribusiness functions performed and experience of small scale maize agribusiness operators in the study area;
(ii) Evaluate the variable and fixed costs, net income, as well as average net income of the studied clienteles;
(iii) Determine the effects of agribusiness functions and experience of small scale maize agribusiness operators' net income.

Hypothesis

1. The null hypothesis tested, H_O: Experience cum cost of carrying out agribusiness functions do not significantly influence net income of small scale maize agribusiness in the study area.
2. The alternative tested, H_A: Experience cum cost of carrying out agribusiness functions significantly influence

net income of small scale maize agribusiness in the study area.

MATERIALS AND METHODS

Net income analysis used in evaluating the profitability of maize agribusiness venture ascertained the net accruals after deducting fixed and variable costs to business. The computation of the annual net income adopted procedures of related schools of thought (James and Patrick, 1988), presented as NFI = GR - Total cost. The net income was calculated by subtracting total expenses from total revenues. All revenues and expenses are properly substituted in the adopted formula stated thus:

$$NI = TR – TC$$

Where: NI = Net income of the agribusiness operator (₦), TR = Total revenue realized from Quantity Sold (₦) and TC =Total cost of performing the Agribusiness functions (₦),

Multiple regression analytical technique used evaluated the relationship between independent variables $X_1, X_2 \ldots X_n$, referred to as operators experience cum agribusiness functions and the dependent variable Y, referred to as the net income of the maize agribusiness operators. The implicit form of the regression model that was used was stated as thus:

$$Y = f(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_{8; \mu i})$$

Where; Y = Maize agribusiness operator's Net income (N), X_1 = Processing Activities; ^{X2} = Cost of Grading Activities; X_3 = Packaging Cost; X_4 = Storage Cost; X_5 = Transportation;X_6 = Quantity Sold; X_7 = Financing; X_8 = Maize Agribusiness Experience; μ = Error Term

The model is expressed explicitly as:

$$Y= b_o+b_1X_1+b_2X_2+b_3X_3+b_4X_4+b_5X_5+b_6X_6+b_7X_7+b_8X_8 + \mu i.$$

Study area

The study was conducted in Wukari Local Government Area of Taraba State (Figure 1). Wukari Local Government has been the headquarters of the historically famous Kwararafa Confederacy which at the zenith of its powers extended to modern Niger, Plateau, Kogi, Nasarawa, Benue States and FCT in the north central geo-political zone, Edo and Cross River in the South- South zone, Kaduna, Kano and Katsina States in the north west zone and Bauchi, Gombe and Adamawa States in the north east zone (Wikipedia, 2020).

Sampling procedure

The study was conducted in Wukari Local government Area, Taraba State, Nigeria. A purposive sampling method was used to select four area-markets where maize grains are predominantly produced and sold by agribusiness operators. These areas include Rafin-Kada, Gindin-Doruwa, Bantaji and Kente. For each of the four areas, fifteen Small Scale Maize Agribusiness Operators were randomly selected for interview, making a total of 60 respondents.

Data collection

The study was conducted using primary data collected through the use of structured questionnaires administered to the respondents. The questionnaire was structured to enable collection of data to achieve the objectives of the study. Also, secondary information gathered was infused accordingly to enrich the study.

Data analysis

Data collected were analysed according to objectives, using descriptive statistics such as percentages to achieve objective (i). While Objective (ii) was achieved using net income analytical procedure, and multiple regression analysis was used to achieve objective (iii).

RESULTS AND DISCUSSION

The result presented in Table 1 x-rays the percentage of variable costs, fixed costs, and net income to total revenue of maize agribusiness ventures studied. Also, the details of the regression analysis showing magnitude of significant and insignificant coefficients among other effects of included variables are presented hereunder as regression output, ANOVA, model summary (Tables 2 to 4, respectively).

Profitability analysis shows how much revenue would be left over after all expenses have been paid by an agribusiness entrepreneur. Many agribusiness operators are required to meet certain profits each year in order to maintain loan covenants with their lenders. These covenants present a problem to agribusiness operatives, as they need to show more profit to meet lender's requirements. Agribusiness operators and firm management focus on the net income calculation because it was a good indicator of the business's financial position and ability to manage investment efficiently. Obviously, higher profits are always preferable to lower profits. Businesses can use higher profits to reinvest in expansion, eliminate debt, and even make payments to their workers (Olayinka and Aminu, 2006). The efficiency in carrying out the required agribusiness functions such as assemblage of these goods, storage, transportation, processing, grading and financing by an experienced agribusiness operator determines volume of net income and business viability/profitability.

Table 1 depicts the percentage of total variable cost to total revenue as 5.64%, which represents that value taken up by variable costs for performing agribusiness functions among which are assemblage of the goods, storage, transportation, processing, grading, and financing. On the other hand, fixed costs such as farm buildings, land, and equipment gulped up 36.55% of the agribusiness total revenue accruals within the period of the study area. The percentage net revenue of 57.81% indicates the total net returns to maize agribusiness ventures in the study area after all expenditures have been deducted. Given an annual net income and average net income of ₦ 26,915,945 and ₦448, 599.083 respectively, it suffices to state that maize agribusiness is

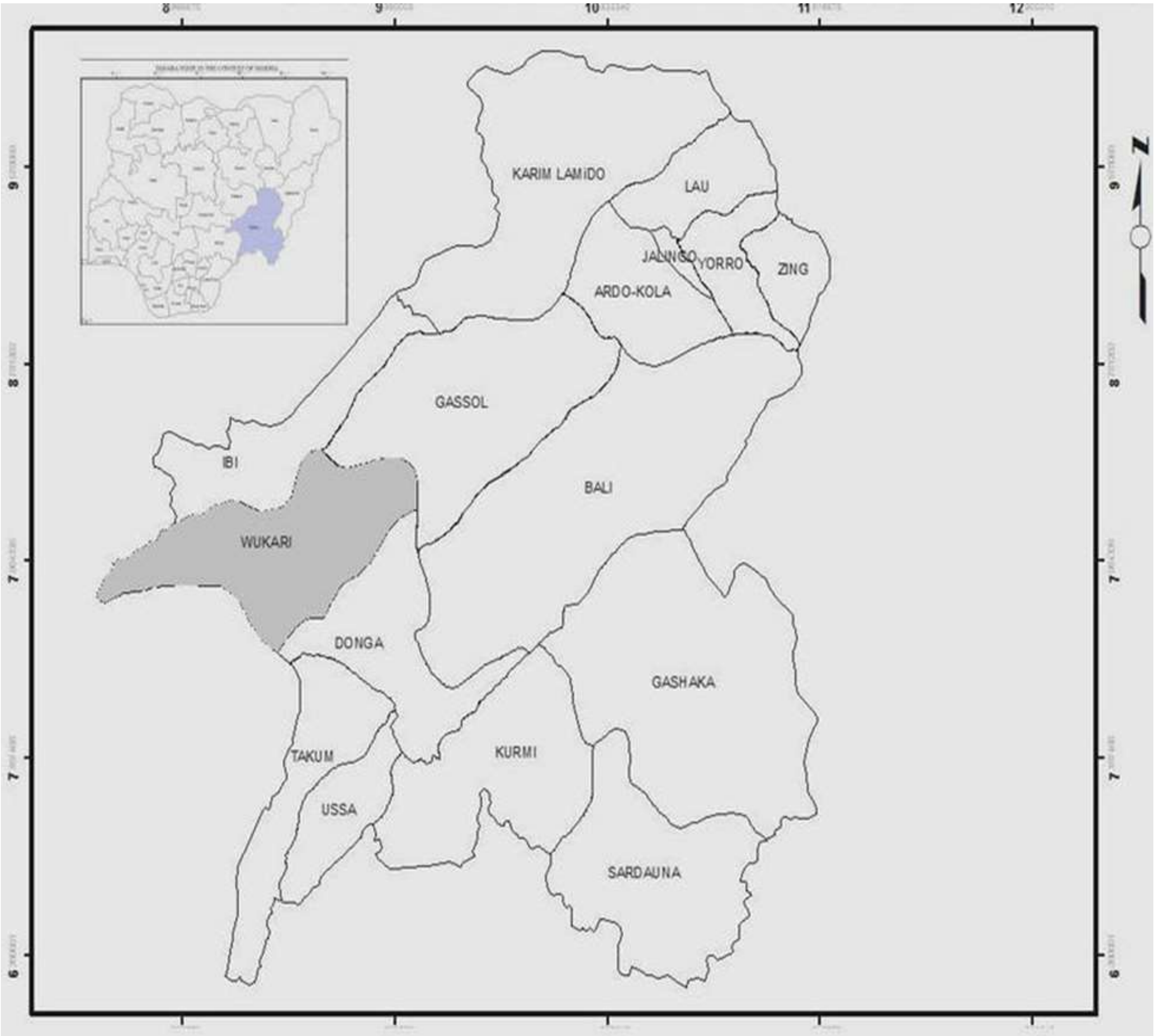

Figure 1. Map of Taraba State showing Wukari L.G.A (Oko et al., 2014).

Table 1. Percent of costs and net income to the total revenue in maize agribusiness.

Items	Item value (₦)	Item value percent (%) of total revenue
Total variable cost	2,625,055	5.64
Total fixed cost	17,016,660	36.55
Total cost	19,641,715	42.19
Net income	26,915,945	57.81
Average net income (per operator)	448,599.083	
Total revenue	46,557,660	
Maize agribusiness experience	12.3 (Years)	

Source: Field Survey, 2018.

Table 2. Regression output: Effects of agribusiness functions on operators' net income.

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Std. error	Beta		
1	(Constant)	9246.216	33799.861		.274	.786
	Processing cost	14.181	4.770	.186	2.973	**.004***
	Grading	4.554	3.373	.109	1.350	.183
	Packaging	7.340	3.507	.174	2.093	**.041****
	Storage	1.086	2.171	.035	.500	.619
	Transportation	1.292	2.838	.017	.455	.651
	Sales	.326	.051	.557	6.410	**.000***
	Financing	.260	.246	.092	1.055	.296
	Maize agribusiness experience	-4808.894	3188.002	-.104	-1.508	.138

a. Dependent Variable: Net Income.
Source: Regression Output, Field Survey, 2018; * = Significant at 1%; ** = significant at 5%.

Table 3. ANOVA.

Model		Sum of squares	Df	Mean square	F	Sig.
1	Regression	11081061359947.912	8	1385132669993.489	97.781	.000[b]
	Residual	722445633126.668	51	14165600649.543		
	Total	11803506993074.580	59			

a. Dependent Variable: Net Income; b. Predictors: (Constant), maize agribusiness experience, transportation, processing activities cost, storage, financing, grading, packaging, sales.
Source: Regression ANOVA, Field Survey, 2018.

Table 4. Model summary.

Model	R	R square	Adjusted R square	Std. error of the estimate
1	.969[a]	.939	.929	119019.329

[a]Predictors: (Constant), maize agribusiness experience, transportation, processing activities cost, storage, financing, grading, packaging, sales.
Source: Regression Model Summary; Field Survey, 2018

profitable in the study area. This finding is consistent with Bataineh and Rababah (2016) results which noted that even though total comprehensive income possesses more informative content and gives further information, the net income is more powerful in predicting future performance of a business venture. Table 2 presents the result of regression analysis, x-raying exogenous variables that influence the clienteles' net income. The variables found to have positive significant influence on the net income of maize agribusiness operators in the study area include, processing, grading, and sales (Table 2). The implications of the regression output are as discussed subsequently.

Processing

The coefficient of effect of processing on the net income of maize agribusiness is 14.181, while the standard error is 4.77. The coefficient is positive and highly significant at 5% level of significance. The implication of this scenario is that net income of business operators increases by 14.18 units for every unit increase in processing, all things being equal, as against specified units for other significant and insignificant variables. This is good, considering the importance of processing in value chain addition of every production venture.

Packaging

The coefficient of effect of packaging of maize produce on net income of the agribusiness operators is 7.34, with a standard error of 3.507. This coefficient is also positive and highly significant at 5% level of significance. This implies that for every one unit increase in packaging quality, net income of maize agribusiness operators would increase by 7.34 units, all things being equal.

Sales

As shown in Table 2, the coefficient of sales quantity is 0.326, while the standard error is equal to 0.051. These are positive and highly significant at 1% level of significance, implying that every one unit increase in sales will lead to 0.326 unit increases in net income of the maize agribusiness in the study area, all things being equal. The agribusiness functions that have negative and insignificant influence on operators' net income are grading, storage, transportation functions, in addition to experience in maize agribusiness. Besides, the result of ANOVA in Table 3 reveals that the model is significant with p = 0.000. Again, the F*Cal = 97.78 is greater than F*tab 1.77, thus, the null hypothesis, experience cum cost of carrying out agribusiness functions do not significantly influence net income of small scale maize agribusiness in the study area **(**H0: b = 0) is rejected and the alternative hypothesis (HA: b ≠ 0) accepted since not all the variables have zero effects (Table 3). More so, processing, packaging and sales quantity have positive and significant influence on net income of maize agribusiness in the area. Therefore, given the results of Table 2, the explicit functional form of the estimated regression equation is given as:

$$Y = 14.181X_1 + 7.340X_3 + 0.326X_6 + \mu_i \, .$$

The choice for the equation is a function of priori expectation of fulfilling economic, statistical and econometric criteria with respect to the signs, magnitude and significance of the regression coefficients.

The model summary in Table 4 show that the R Square is 0.969, while the adjusted R square is 0 .939, yielding an average R square of 0.954. The implication of this is that on the average, 95.4% of the variations in the values of endogenous variable Y (net income of agribusiness operators) were explained by the exogenous or explanatory variables Xi included in the model (Table 4)

Conclusions

In the underlying net income analyses, total variable costs stood at ₦2,625,055; total fixed costs (TC) of ₦ 17,016,660; yielding a total cost (TC) of ₦19,641,715 and a net income of ₦26,915,945 which translates to an annual average net income (NI) of ₦448, 599.08 per respondent. This implies that small scale maize agribusiness in the study is profitable. The result of the regression analysis had an average R^2 value of .954 which means that 95.4% of variations in dependent variable (Y) was explained by the explanatory variables (Xi). Besides, since the F*Cal = 97.78 is greater than F*tab 1.77, and the null hypothesis H_O: Experience cum cost of carrying out agribusiness functions do not significantly influence net income of small scale maize agribusiness in the study area is rejected since three of the explanatory variables, processing, packaging, and sales (Table 2) have positive significant influence on the net income of maize agribusiness in the study area. The study concludes that maize agribusiness functions influence the operators' net income, and are profitable enterprise in the study area. This conclusion is in tandem with the results of the study of Kolawole (2017) that analysed the costs and returns on maize production among small-scale farmers in Osun State Nigeria, where the gross margin was estimated to be ₦ 638,465.22 with a benefit-cost ratio (BCR) of ₦1.74, implying profitable venture. The current decision of the central Bank of Nigeria (CBN) to discontinue the issuance of Form M to importers of Maize/Corn will likely roll back the gains of the intervention in the sector. There is no doubt that current prices of maize will continue to rise to reflect its current scarcity, leading to the depletion of corn grain reserves of last season and shortage in supply. The situation spells doom for poultry farmers across the country, and will likely lead to cut down on production occasioned by high cost of feed and imported medication. A negative spill over effect of the high cost of feed is the scarcity of eggs and broiler meat, cum a consequent rise in the price of eggs across the country. The implications of the current challenges in the maize value chain are that the gains of employing more people in the agricultural sector will be rolled back in the coming months (The Sun, 2020).

Based on the findings, the following recommendations were made:

1. Young and educated unemployed in the area should engaged in maize agribusiness as means of livelihood given the profitability of the venture.
2. Grading, storage, transportation, and financing functions should be regulated to improve production and sales volume given the positive insignificant effects on agribusiness net income in study area.
3. Processing, packaging and sales volume should be major criteria for incentive provision by Government and or NGO stakeholders given the overriding positive significant effects on agribusiness net income in the study area.
4. Experience in maize agribusiness should be considered a pivotal factor though had insignificant, but an overwhelming negative influence on net income.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Involvement of key stakeholders in controlling animal diseases in rural settings: Experiences with African swine fever in Uganda

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Key stakeholders' involvement in the design and enforcement of effective African swine fever (ASF) biosecurity measures is very vital. Unfortunately, many times key stakeholders are less involved in the policy designing process. This study analyzed information from stakeholders in Mukono District, to assess the acceptability of enforcing ASF biosecurity measures among key stakeholders. Mukono District has a high density of pigs and a history of frequent ASF outbreaks. Key informants (n = 23) were identified and interviewed in four sub-counties to generate an ASF control stakeholders' list. Eleven stakeholder groups were identified by the Key Informants. Sixty participants representing different stakeholder groups identified through the Key Informant interviews participated in a workshop to assess stakeholders' characteristics regarding strict enforcement of ASF control measures. Stakeholder grid analysis revealed 60% as drivers, and 40% as supporters. There were no blockers, abstainers, and bystanders. Despite this, majority of the groups (90%) did not have adequate capacity to implement the intervention due to financial constraints and inadequate technical support. These results show that there is great support for enforcement of biosecurity measures if stakeholders are facilitated with financial and technical support thereby limiting outbreaks of ASF in rural areas of Uganda.

Key words: African swine fever, biosecurity, influence, power, roles, interests, stakeholder.

INTRODUCTION

The agricultural sector is very important in the economy of Uganda. It contributes up to 23.8% of the Gross Domestic

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Product (GDP), generating about 48% of export earnings (Sebudde et al., 2018). The livestock sector alone contributes 15% of agricultural GDP (Tatwangire, 2014). This sector registered a 3% increase in the number of livestock and poultry between 2009-2010 with 4.5 million households (70.8%) rearing at least one species of livestock (Uganda Beaural of Stastics, 2016). The pig is one of the important livestock species in Uganda in addition to sheep, goats, cattle and chicken (UIA, 2009). Uganda has the biggest pig population in East Africa (FAOSTAT, 2018). The pig population in Uganda has been steadily increasing over the years; from 0.19 million in 1980; to 1.7 million in 2002, to 3.2 million in 2008 and to 4 million in 2016 (UBOS, 2016). Pig production in Uganda is widespread with about 1.1 million (17.8%) households owning at least one pig (Tatwangire, 2014).

Unfortunately, this rapid growth in the pig sector is affected by many challenges. Some of these include; inadequate quality extension services, high input costs, fluctuating feed sources and prices and pig diseases (Muhanguzi et al., 2012). There are several pig diseases in Uganda but African Swine Fever (ASF) has so far proven to be the single biggest problem hindering the pig industry (Muhanguzi et al., 2012). African swine fever is a highly contagious disease that affects both domestic and wild pigs (Penrith et al., 2004). This pig disease causes enormous economic losses to domestic pig farmers (Mulumba-Mfumu et al., 2019) due to the high mortality rates that accompany outbreaks (Arias and Sanchez-Vizcaino, 2002; Costard et al., 2009). ASF has neither cure nor vaccine (Costard et al., 2013, Penrith et al., 2004). The only way to control the disease at the moment is through quick diagnosis and strict implementation of biosecurity measures (Dione et al., 2017).

In order to control animal diseases, there is need for both international and local animal disease control laws. Uganda has good policies and laws that when well implemented can limit the spread of highly contagious diseases such as ASF. For instance, the Animal Diseases Act (Government of Uganda Animal Diseases Act, 2014), provides for enforcement of quarantines in areas with animal disease outbreaks. The policy prevents the movement of animals and animal products from and into such areas and, animal owners (pigs inclusive) are required to keep them in proper buildings or paddocks constructed in accordance with the specifications. When well implemented, these requirements can potentially limit the spread of ASF. However, despite the presence of these laws, ASF outbreaks are still common (Kalenzi Atuhaire et al., 2013) because the enforcement of these regulations requires the cooperation of several stakeholders.

Stakeholder analysis has been effectively used in multiple disciplines to deduce solutions to various challenges. In the human health sector, stakeholder analysis led to the successful improvement of maternal and newborn health in Uganda (Namazzi et al., 2013). Similarly, in the veterinary sector, effective control of highly contagious animal diseases such as ASF can only be achieved if all key stakeholders are identified, involved in policy designing and implementation of the designed measures.

In Uganda, enhancing the capacity of all pig stakeholders through community sensitizations using drama and radio talk shows has been identified as being important in the control of ASF (Ouma et al., 2017). Stakeholder capacity building ought to be preceded by a stakeholder analysis to develop a proper engagement framework. A proper stakeholder engagement framework determines who should participate, when and how (Luyet et al., 2012). Many times stakeholders are less involved in the policy designing process thus affecting policy implementation. In this study, we assessed the acceptability of enforcing ASF biosecurity measures among key stakeholders in the control of African swine fever in Mukono District, a rural area in central Uganda.

METHODOLOGY

Study area

This study was carried out in Mukono District (0.2835° N, 32.7633° E), located in the central region of Uganda. Mukono District has a total area of 2,986.47 Sq. Km and is bordered by Buikwe District in the East, Kayunga District in the North, Luwero District in the North West, Kampala city and Wakiso District in the South West and a shoreline on Lake Victoria to the South. Mukono District has a high density of pigs and a history of frequent ASF outbreaks. The district is composed of 13 sub-counties (SCs), 72 parishes and 795 villages with a human population of 596,561 (289,804 males and 307,757 females) distributed in 144,160 households (HH) (Uganda Bureau of Statistics (UBOS), 2017). Of these households, 63,079 (43.8%) are involved in livestock rearing. Mukono District is the only district in Uganda, which is piloting a community initiated and monitored ASF control program where ASF stakeholders implement biosecurity measures aimed at ASF control.

Stakeholder analysis

Stakeholder analysis for this study was carried out in 3 phases: the first phase was carried out to generate a list of stakeholder groups who can influence the implementation of ASF control measures in Mukono District. This was followed by categorizing stakeholder groups based on their power and influence towards the successful implementation of ASF control, and their (stakeholder groups) characteristics in terms of their roles and interests towards ASF control.

Generation of ASF pig stakeholder group list for Mukono District

This was carried out in four sub-counties (SCs) of Mukono District, central Uganda. The sub counties were Kasawo, Namuganga, Ntenjeru and Mpunge (Figure 1). In Kasawo SC, key informant interviews were held with one veterinary officer in each of the 6 parishes (Kitovu, Kabimbiri, Kakukuru, Namaliri, Kasana and Kigogola). Additionally, discussions were held with two veterinary officers in Kasawo SC head offices making a total of eight key informant interviews in this SC.

In Namuganga SC, interviews were held with one veterinary

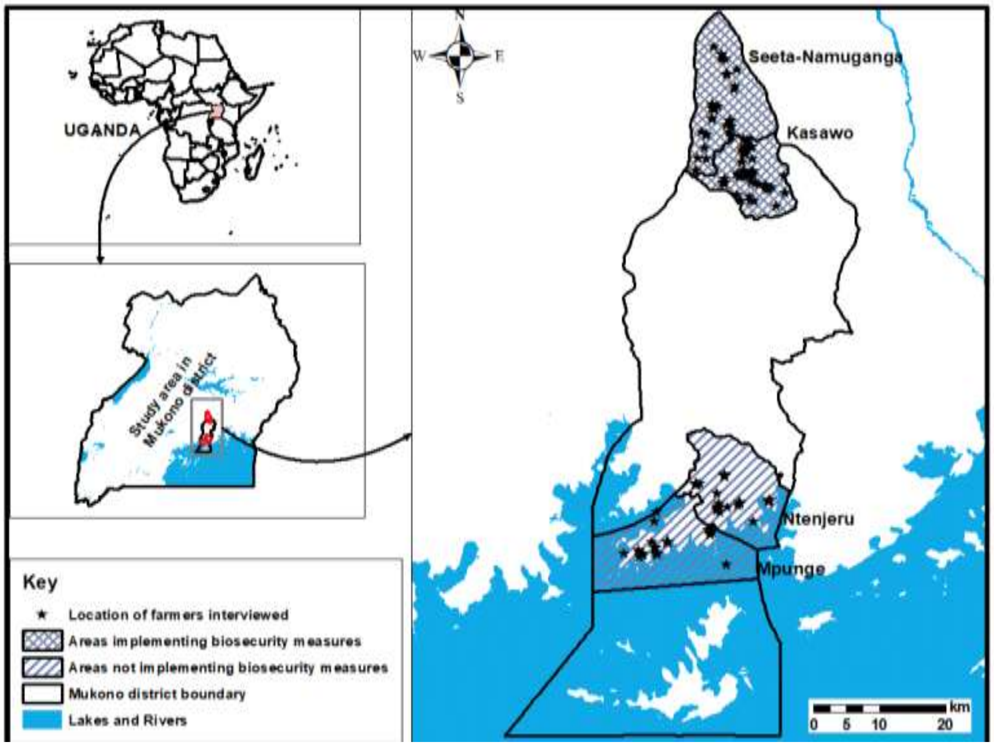

Figure 1. A map of Mukono District showing the study area.

officer in each of the five parishes of Kituula, Kitale, Namuganga, Namanoga and Kayini. In Mpunge SC, one key informant interview was held with one lead pig farmer in each of the four parishes of Ngombere, Mpunge, Lulagwe and Mbazi parishes. In Ntenjeru SC, five key informant interviews were held as follows: two veterinary officers and three parish ASF control mobilizers. We also held one key informant interview with the Mukono District Veterinary Officer (DVO). At this step, respondents were only asked about names of stakeholder groups within and outside Mukono District and their descriptions in relation to ASF control. Consent of each respondent was sought before commencement of the interview to which they responded in approval and their responses were both hand written and audio recorded. The recorded audios were later transcribed and typed in Microsoft® Word. Based on these interviews, a stakeholder group list was developed indicating the name of the stakeholder group and a brief description of their relationship with ASF control in Mukono District.

Categorization of ASF control stakeholder groups

A stakeholder workshop was held at Mukono Zonal Agricultural Research and Development Institute (MUZARDI) on 20/3/2019. The workshop comprised of a total of 60 individual ASF control stakeholders drawn from 13 different stakeholder groups. During the meeting, stakeholders from the same stakeholder group sat closest to each other to allow them to share ideas and report the consensus in case it was required. All necessary visual materials (elements that constitute the ASF biosecurity program, analysis grids, and definitions of key words) were displayed in manila papers on the walls of the workshop room for easy reference by the participants. The stakeholder group list that was earlier developed during the initial steps of the study was displayed as well in manila papers for all participants to view and verify. The workshop facilitator introduced the purpose of the workshop and requested participants who consented to the publication of the workshop results to sign a consent form. Fortunately, all participants consented and signed the consent forms. Using a stakeholder analysis grid, participants classified stakeholders into five categories (of drivers, blockers, supporters, bystanders and abstainers) depending on their power and influence, and level of agreement with the enforcement biosecurity measures in ASF control. The stakeholder categories were defined as follows:

i) Drivers: A stakeholder or group that has high power, influence and high agreement with the enforcement biosecurity measures in the control of ASF and can champion it;
ii) Blockers: A stakeholder or group that has high levels of power and influence in the control of ASF, but highly opposes the enforcement of control measures;
iii) Supporters: Those that support the practices, but whose influence and power may be limited (on their own);
iv) Bystanders: Those that disagree to the control practices but with low influence and support;
v) Abstainers: Those who are neutral to the control practices, but may or may not have influence.

All stakeholder groups were categorized into the five categories by selecting one and asking participants in this group to rate their degree of power and influence in ASF control (using a scale of 1-3) by writing on pieces of paper. Power of a stakeholder was defined as the extent to which a stakeholder was able to persuade other stakeholders to embrace and implement ASF control measures. The influence of a stakeholder on the other hand was defined as the power a stakeholder can exert over the execution of ASF control measures. Each stakeholder group was later asked to assess their own level of agreement with the implementation of ASF control measures using the same scale of 1-3. The level of agreement of a stakeholder was defined as the extent to which a stakeholder approves/ accepts the proposed ASF control measures. The research team analyzed these responses in Microsoft® excel (Microsoft Corp., Washington, DC, USA) and developed the stakeholder categories.

Analysis of stakeholder group categories

After categorization of all stakeholder groups, those categorized as abstainers, bystanders and blockers were separated from the other categories. These participants were asked to brainstorm in focus groups the reasons why they had abstained from or blocked the strict enforcement of ASF biosecurity measures. The stakeholders who were categorized as supporters and drivers were further asked to reveal their roles and interests towards the control of ASF.

Strategies to deal with each stakeholder group

Researchers brainstormed on the strategies to deal with each stakeholder group based on each stakeholder's roles and category. The strategies were in terms of empowerment, continuous engagement, further involvement and further consultation.

Importance and relationships among stakeholder groups

To determine the relationship among the different stakeholder groups, participants were requested to attach circles cut out of manila paper in three sizes as described by Richards and Panfil (2011) were the level of importance is directly proportional to the size of the cut manila paper. The three sizes were large, medium and small representing level of importance of the stakeholder group. Importance of a stakeholder was defined as the roles of such a stakeholder in achieving anticipated results for the implementation of ASF control measures. Since all stakeholder groups were from Mukono district all the circles were purple. For each stakeholder group, the participants described the importance of the stakeholder's involvement in the control of ASF and selected the corresponding size of the circle as summarized below.

Little importance = small circle (1 cm in diameter)
Some or moderate importance = medium sized circle (2 cm in diameter)
Very important = large circle (3 cm in diameter)

The stakeholder group names were then inscribed on these circular cards. The circles were then arranged according to working relations among stakeholder groups. Those with very close working relationships were put closest to each other and vice versa for those with little or no working relationship. Since stakeholder groups located out of Mukono District, failed to attend this workshop, the exercise was done for only stakeholder groups located within the district. The next stage was to attach triangular manila cards of three different sizes, large (3 cm × 3 cm × 3 cm), medium (2 cm × 2 cm × 2 cm) and small (1 cm × 1 cm × 1 cm) representing level of influence of stakeholder to the edge of the stakeholder circle. The outputs were reviewed by all participants, who later discussed the relative importance and influence of each stakeholder. The arrangement was then captured with a digital camera. The overlap of the circles represented the extent of the working relationship between stakeholder groups.

RESULTS

Stakeholder groups in the control of ASF in Mukono

The stakeholder groups that were identified by Key Informants were from both within and outside Mukono District (Table 1). The key stakeholder groups included those involved in animal healthcare such as veterinarians, pig production value chain actors (for example traders), law enforcement, regulatory and administrative agencies at both local and national levels. Table 1 gives a brief description of each of these stakeholder groups.

Grid analysis of stakeholder group categories

The stakeholder grid analysis revealed that 60% of the stakeholders were drivers and 40% were supporters. There were no blockers, abstainers, and bystanders (Table 2). The categorization was in respect to the stakeholder's level of agreement with the use of biosecurity measures in ASF control, power, and influence in implementing ASF control measures in Mukono (Table 2).

The capacity of stakeholder groups to control the spread of ASF

All stakeholders discussed within their stakeholder groups, and each stakeholder group came up with a score between the scales of 1 to 3 to signify their own capacity in the control of ASF, giving reasons for their score as indicated in Table 3. It was observed that 90% of the stakeholders were incapacitated in the implementation of the ASF intervention measures due to financial constraints and inadequate technical support.

The roles of stakeholder groups in ASF control

In general, all stakeholders identified in the study were involved in ASF control in one way or another as shown in Table 4. Farmers were identified to play significant roles in ASF control since they are in direct contact with animals. These roles included reporting suspected ASF cases to veterinarians, restricting animal movements, disinfecting pig sties and restricting visitors from their farms. Interestingly, participants pointed out that Security and judiciary support ASF control strategies through enforcement of measures such as quarantines by restricting unlawful animal movements in the community in addition to apprehending and prosecuting quarantine defaulters.

Interest of stakeholder groups in ASF control

Stakeholders had varying interests in ASF control (Table 5), but all were geared towards increasing pig production to improve both household nutrition and income. The interests of the stakeholders in the implementation of ASF control measures reflected their roles in the community and occupation.

Table 1. ASF control stakeholder group list for Mukono District, Uganda.

S/N	Name of stakeholder	Description
1	Veterinarians	All private and public (local government) veterinary doctors/ officers and animal husbandry officers within Mukono. They treat pigs and provide technical advice to farmers.
2	Agricultural officers	They oversee crop and animal production in the SC.
3	Veterinary/human Drug shops	Sell animal drugs and give extension advice to farmers. Human pharmacies also sell disinfectants (like Jik) to pig farmers for ASF control.
4	Local council (LC) leaders	Include LC 1, 2 and 3 in the lower local government administrative units within Mukono. They help in enforcing ASF quarantines during outbreaks and information dissemination.
5	Pig traders	Butchers, buyers, 'pork joint' operators and transporters, locally termed as '*Babizzi*'. They have a pig traders' association with elected leadership. The traders come from within and outside Mukono.
6	Pig farmers and pig farm workers	Both commercial and small-scale farmers involved in pig rearing with leaders in every village locally called *'Ssabalijja'* who coordinate ASF control activities.
7	Pig consumers	Kasawo and Namuganga SCs pork consumers are organized into a pork consumers' association, that monitors the quality of pork being sold and the hygiene of the butcher.
8	ASF researchers	These include researchers from; COVAB and CONAS at Makerere University, and ILRI. These institutions are involved in ASF research in Mukono and Uganda in general.
9	Security and judicial agencies	Police, crime preventers, the courts of law and prisons within and outside Mukono, all help in enforcing ASF control.
10	Media Houses	Include radios (Sauti Radio), television stations (Bukedde), community radios with raised speakers (that cover 3-4 villages). These media stations, sensitize the community about ASF disease control strategies.
11	District officials	Include the CAO, DVO, OWC /NAADS) officers. UWEP and YLP officials involved in poverty alleviation by distributing animals including pigs to farmers.
12	Pig feed suppliers	Supply animal feeds, give advisory services to farmers regarding control of ASF. They may also help in the spread of ASF in case they sell contaminated pig feeds to farmers.
13	MAAIF	Government Ministry in charge of agriculture, animal industry and fisheries resources in the country. Provides technical guidance for formulation, review and implementation of animal production Acts, policies and legislation.
14	Policy and law makers	District Council makes and approves community by-laws and ordinances while the parliament of Uganda which enacts policy, regulations and acts e.g. the animal disease Act.
15	Dog owners	Stray dogs are believed to aid in ASF spread by moving ASFv contaminated swill from one location to the other.
16	Sub County and Parish chiefs	Government Administrators at the SC and Parish levels. They are involved programme/ activity such as ASF control to be successful in their communities.
17	Church leaders	Church leaders play a pivotal role in the community, for example, the Church of Uganda (COU) in Mukono is involved in pig projects. The Church gives free piglets to Christians.
18	Parish health coordinators	These work with veterinarians for information sharing regarding butcher health and hygiene.
19	Local NGOs	Include Feed the Hungry (involved in buying and distribution of piglets to farmers in Mukono), child fund (works in Jinja and Kampala) but buys piglets from Mukono for distribution in Jinja and Kampala.
20	Pig processors	Include Fresh Cuts that is located in Kampala, buy pigs from Mukono farmers and process pig products. There is also Wambizi, a pig abattoir, located in Nalukolongo, Kampala that receive pigs from all over Uganda.
21	Pig breeders	These produce and sell high quality piglets and pig semen to farmers. Kampala Capital City Authority (KCCA) has a pig-breeding center in Kyanja that has been in this business for five years.
22	Beach management units	These are in areas bordering the lake such as; Katosi and Mpunge landing sites. They handle Silver fish, locally called 'Mukene' used in making pig feeds which when contaminated with ASF can spread the disease.
23	Community Development officers	They sit at the Sub County and heavily engage with all developmental activities, of which pig farming is one of them.

CAO: Chief Administrative Officer, CONAS: College of Natural Sciences, COVAB: College of Veterinary Medicine, Animal resources and Biosecurity, ILRI: International Livestock Research Institute, MAAIF: Ministry of Agriculture, Animal Industry and Fisheries, NAADs: National Agricultural Advisory Services, OWC: Operation Wealth Creation, UWEP: Uganda Women Entrepreneurship Programme, YLP: Youth Livelihood Programme

Relationship, importance and influence of stakeholder groups

According to the proximity of circle attached to the stakeholders, farmers, consumers and traders are all closely related as evidenced by the close grouping of their respective circles. In this cluster, farmers and consumers were seen as more important than traders since their circles were bigger than those of traders. Interestingly, traders and farmers were seen as more influential than consumers because their triangles were bigger than that of consumers.

District officials, security and judicial agencies were all closely related due to their circles being aggregated together but the district officials were seen as more important (bigger circle) than both the security and judicial agencies (smaller circles).

Table 2. Analyzed categories of stakeholder groups in the control of ASF.

Stakeholder	Interest in the issue	Level of agreement	Level of power and influence	Type of power	Category
Pork consumers	Ensure that only clean and pork from healthy pigs is sold	High	Low	Beneficiary	High level supporter
District Officials *(CAO, LC5, OWC, DCDO)*	Supervise the veterinary officers	High	High	Decision maker	High level Driver
Pig Trader	Generate income from pigs and pig products	High	High	Beneficiary	High level Driver
Religious Leaders	Community spiritual overseers	Medium	High	Opinion leader	High level supporter
Community Development Officers (CDO)	Ensure implementation of community development programs	High	High	Development implementer	High level Driver
Agricultural Officer	Provide Agricultural extension service.	Medium	Low	Beneficiary and influence policy	High level supporter
Security and Judicial officials	Enforcement of community law and order	Medium	High	Law and order enforcer	High level supporter
Local Council leaders	Grassroot administrative structure of the community	High	High	Opinion leader	High level Driver
Veterinary officers	In charge and supervisor of animal welfare in the district	Medium	High	Beneficiary and influence policy	High level supporter
Pig farmer	Earn a living from rearing pigs	High	High	Beneficiary	High level Driver
Researchers	Design simple community-based ASF control measures	High	High	Beneficiary and influence policy	High level Driver

DCDO: District Community Development Officer, LC5: Local Council Five.

On the other hand, district officials, security and judicial agencies were regarded as equally influential because their triangles were of equal sizes.

Veterinary officers, CDOs, religious and local council leaders were all closely related as evidenced by their circles being grouped together. Veterinary officers were the most important stakeholders in this group. Comparatively, local council and religious leaders were both deemed moderately important while CDOs were the least important. Collectively, all stakeholders in this group were deemed highly influential owing to the equal sizes of their respective triangles.

Researchers were not related to any other stakeholder group as observed by the standalone circle. They were also not aggregated with any other stakeholder group but researchers were seen as moderately important since their circle had moderate size and are highly influential due to the large size of their triangle. Agricultural officers were not directly mandated in animal production community outreach services although it was noted that in circumstances where no veterinarians existed, they provided minimal animal production services to farmers. In this respect, it was unanimously agreed by the participants that Agricultural officers be excluded from this stage. However, through animal production trainings, Agricultural officers would to some level provide animal production services to pig farmers in the absence of veterinarians (Figure 2).

Strategies for dealing with the stakeholder groups

Following the categorization of stakeholder groups

Table 3. Stakeholder group's capacity to control the spread of ASF.

Stakeholder	Score	Reasons for their capacity	Potential solution
Veterinarians	2(moderate)	Inadequate facilitation and staffing for enforcement.	Increase funding and recruitment for field staff for community outreach.
Agricultural officer	1 (Low)	Inadequate technical knowledge among the staff on ASF the lack of a close working relationship with other stakeholders minimizes their capacity in ASF control.	Recruit more staff for community outreach and provide staff training on animal production.
CDOs	3 (high)	They have a close working relationship with the farmers stakeholders in the community (farmers, traders and butchers) in implementing ASF control measures.	Provide funding for adequate community outreach.
Farmers	2 (moderate)	Inadequate funding and technical knowledge to implement recommended biosecurity measures.	Sensitize farmers on ASF control measures and subsidize prices of effective disinfectants.
Religious leaders	2 (moderate)	There is need for facilitation to enable religious leaders reach out to the community.	Provide funding for community outreach.
Security and Judicial agencies	1 (Low)	Inadequate funding to enforce quarantine.	Provide funding for quarantine enforcement.
District officials	2 (moderate)	Limited human resources and funds humper the effective involvement of the district officials in ASF control.	Recruit more staff and increase supervision funds
Local leaders	2 (moderate)	Limited facilitation to local leaders reduces their effectiveness in sensitizing the community on ASF control measures.	Provide funds for community outreach.
Pork Consumers	2 (moderate)	In ability to accurately identify ASF sick pigs aids the spread of the disease.	Train consumers on simple animal disease diagnostics.
Researchers	3 (high)	They have the funding for research and sensitization of all stakeholder groups in ASF control.	Train all stakeholder groups in disease control measures.

(Table 2), strategies were devised to deal with each of them based on their power, influence and importance. These strategies include empowerment, further consultation, continuous engagement and further involvement (Table 6).

DISCUSSION

This study identified and evaluated stakeholders' interest, capacity, roles and influence/power in relation to the implementation of biosecurity measures in the control of ASF in rural settings. The results of this study revealed that all stakeholders were either drivers or supporters of the intervention. These are vital factors in determining the success of an intervention and could smoothen the implementation and acceptance of the measures among stakeholders. The high level of supporters and drivers may reflect the direct and indirect benefits of the interventions for stakeholders. The direct beneficiaries (farmers, traders, consumers and veterinarians) either earned an income or consumed quality pork while the indirect beneficiaries (district officials, religious and local leaders, judiciary and security) were happy to see an increased level of economic stability in the society. In that respect, community members get employment and reduction in the level of crime in the long run is achieved since most youth would be engaged in pig production. Youth empowerment in agricultural sector would increase food production and household income, create stability in terms of security which leads to socio-economic development of a country. The high level of drivers with high influence in particular at the district and community levels ensures the sustainability of the intervention programs. There is a need to involve stakeholders identified as drivers with high influence at the national level since they are very instrumental in policy formulation and influence (Kanmiki and Bempah, 2017).

All the supporters, such as pork consumers, religious leaders, security and judiciary, and veterinarians are stakeholders who need to be empowered, involved further and continuously engaged (Luyet et al., 2012) so as to become drivers of the intervention (Table 2). The consumers for example should be sensitized on

Table 4. The roles of stakeholder groups in ASF control.

Stakeholder	Roles of stakeholders in ASF control
Consumers	Ensure that the pork butchers and the butcher environment have and maintain good hygiene.
	Promote the consumption of only disease free pork.
Pig Farmers	Ensure proper farm hygiene by; disinfecting the farm and surroundings and restricting visitors entering the farm in addition to constructing improved pig sties.
Religious Leaders	Sensitize people about ASF, and instant reporting of outbreaks to veterinarians.
Agricultural Officers	Sensitization farmers on ASF and report outbreaks to the relevant authorities.
Pig Traders	Instant reporting of outbreaks, slaughtering only on slaughter slabs, not buying of sick pigs and observing proper hygiene in farms and slaughter slabs by disinfecting.
CDO	Sensitize people about ASF, mobilize the community and NGO, link farmers to ASF technical people, coordinate all stakeholders involved in ASF control and assist in enforcing quarantine.
Security /Judiciary	Sensitization of the community and farmers on ASF control measures and enforce quarantine.
Local Leaders	Monitor, mobilize and sensitize farmers on ASF control measures.
Veterinarians	Sensitize, monitor, supervise, and create awareness among all stakeholders on ASF control measures.
	Regulate and enforce veterinary laws, coordinate and provide veterinary services and, initiate the institution of quarantines during ASF outbreaks in their areas of operation.
District Officials	Recommend for declaration of quarantine to MAAIF and enforcement of quarantine in the affected areas of the district. They also enact by-laws intended for ASF control, sensitize farmers on ASF control measures and oversee extension service provision to farmers.
Researchers	Sensitization of all stakeholders in ASF control in the pig production value chain.
	Conduct ASF surveillance and testing.
	Solicit for funding to carry out research on ASF.

the dangers of zoonotic disease such as tuberculosis, anthrax, ebola and helminthiasis that one can contract from consuming uninspected pork although ASF is non-zoonotic. Consumers should also be empowered to form consumer protection associations with a strong voice to ensure the sale of clean and healthy pork. The religious leaders on the other hand are influential people in the community who can change the mindset of the masses and therefore need to be empowered and involved further to continuously remind the masses on the importance of implementing biosecurity. The security and judiciary play crucial roles in the implementation of quarantines during disease outbreaks. Empowering them through formulation of policies with clear guidelines and providing financial support for activities during quarantines could greatly improve on the control of animal diseases in the community (Larry, 2004). The veterinarians believe that recruitment and posting of staff at each parish would tremendously improve on surveillance and service delivery which eventually would lead to success in disease control.

Much as all stakeholders were either drivers or supporters, most of them needed technical support in the implementation of biosecurity measures in the control of ASF. The capacity of almost all stakeholders was either low or moderate and hence needed improvement. As mentioned earlier, there is need for increased human resources to all technical stakeholders and funding for better service delivery (Table 3). Since most stakeholder groups felt that sensitization of farmers, traders and consumers (Table 4) was their responsibility, there should be efforts to standardize and coordinate dissemination messages. The local government department of production is best suited to coordinate this activity since the mandate of improving production is it responsibility. By doing this mixed and confusing messages will be eliminated. This will promote early detection of ASF and rapid implementation of biosecurity measures which to date are still the only effective means of ASF control (Gallardo et al., 2015; Dione et al., 2017). It was generally agreed therefore that involving all stakeholders in developing the guidelines for biosecurity implementation would

Table 5. Interests of stakeholder groups in ASF control in Mukono District.

Stakeholder	Interests of stakeholders in the control of ASF
Security and Judiciary	Are interested in a disease free pigs community, this creates employment, leading to decrease in crime rates in the community
Consumers	They are interested in good hygiene of the butcher and its immediate surrounding environment.
	They are also interested in the consumption of good and disease free pork.
District officials	These want to fulfill their mandate to control ASF epidemic and keep the reputation of their district.
	A good reputation will enable them lobby funds from donors for piggery projects in Mukono district.
	They want to ensure that there is diversity of livestock enterprises for Operation Wealth Creation (OWC) program for people to have improved nutrition and increased household income.
	They want the pig sector to thrive by having increased number of improved pig breeds for people to get employment opportunities
Local leaders	The local leaders are interested in increased household (HH) income among their electorates.
	They want to see their pigs multiply their animals and increase in number to; 1) provide market for pig feeds e.g. maize, 2) get organic manures and access enough pork in their area at affordable/reduced prices.
Agricultural officers	They are interested in community members getting jobs in the piggery sector.
	They want farmers to have supplementary income from pig production.
	They want increased pig manure for crops from pig farmers.
Veterinarians	They want increased protein supply from pig farmers to consumers.
	They are interested in community members getting jobs in the pig sector.
	They want HH to have increased HH income.
Pig farmers	They want communities and HH to comfortably rear pigs for them be food secure.
	Farmers aspire to increase their HH income by getting jobs from increased rearing of ASF free pigs.
	They believe that higher incomes will reduce domestic violence in their homes.
	They to be more food secure and reduce malnutrition among their household members.
CDOs	They prefer having an ASF-free community to motivate pig farmers and increase production and in turn supported government involved in livestock.
Pig traders	They benefit from having an ASF-free community since ASF outbreaks are usually accompanied by several restrictions like quarantines which affect their business negatively.
Religious Leaders	Increased HH and church income from increased piggery production
	Reduced domestic violence among the faithful in their congregation
	Reduced crime rates among the faithful in their congregation
Researchers	They want control the spread of ASF
	They want to increase the level of awareness about ASF among all stakeholder groups involved in pig production.
	They want farmers to produce and sell ASF disease free pigs.

foster ownership of such a policy and subsequent sustainability.

Since financial constraint was mentioned as a challenge, costs of effective disinfectants and other farm inputs needed for disease control need to be subsidized by government to a rate that can be easily afforded by the farmers. The high costs of animal drugs and disinfectants hamper the implementation of biosecurity as a control measure in many developing countries (Kouam and Moussala, 2018). Subsidizing farm inputs relevant to disease control as well as adherence to

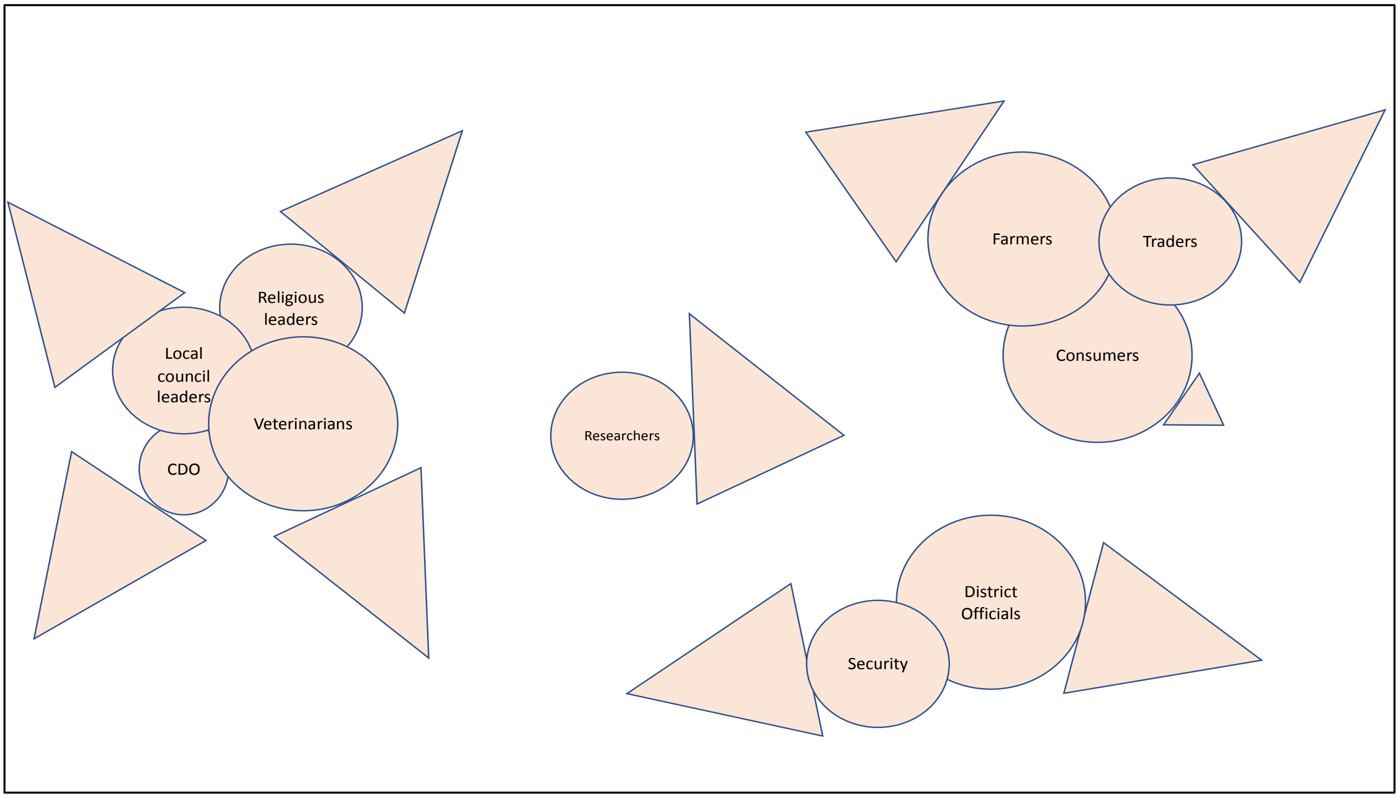

Figure *2.* Relationship, power, influence and importance of stakeholders. Circle = importance of stakeholder; Triangle = power and influence. Stakeholders whose circles are touching or closer indicate similarity in roles in the control of ASF in Mukono District

Table 6. Strategies to deal with each stakeholder groups.

Stakeholder	Justification/criteria		Strategy to deal with stakeholder
	Power and influence	Importance	
Agricultural officer	Low	Moderate	Provide animal production training and continuously engage
Traders	High	Moderate	Consult further and continuously engage
Consumers	Low	High	Empower
Veterinarians	High	High	Involve further and continuously engage
CDOs	High	Low	Consult further and involve further
Security and Judiciary	High	Moderate	Consult further and continuously engage
Local Council leaders	High	Moderate	Consult further and continuously engage
Researchers	High	Moderate	Consult further and continuously engage
District leaders	High	High	Involve further and continuously engage
Farmers	High	High	Involve further and continuously engage
Religious leaders	High	Moderate	Consult further and continuously engage

practices reporting ASF outbreaks, sale of only disease free pork and many other practices that do not require any drugs would play a great role in controlling the spread of ASF.

From this study, it was also revealed that funding of the other stakeholder groups was required to enable them play their roles effectively. Provision of funding to religious leaders, district, and local council, and security and judiciary, veterinarians, agricultural officers and CDO would greatly improve on community outreach services leading to improvement on the implementation of control measures. In the same way, increasing the human resource for the veterinarians, CDOs and agricultural officers would improve on the technical support provision to farmers while to the district, security and judiciary it would improve on supervision and monitoring of service providers to the farmers.

The farmers in the stakeholder analysis meeting felt that it would be proper to involve all stakeholder groups in designing the guidelines of implementing biosecurity measures. This concern arose since farmers in particular thought that their experience in ASF outbreak management at the farm need to be amalgamated with that of the technocrats so as to develop a binding working document for ASF control at farm and butcher levels. Indeed, during the discussions, farmers pointed out some control measures such as each farmer having their own drugs, syringes and needles that the veterinarian can use while treating pigs on a particular farm to avoid transmission of infections from other farms. Secondly, farmers also suggested that the manure from pig sties should be disinfected before use in the crop fields since that could be a potential source of disease spread.

Success in implementing biosecurity measures as a means of ASF control in the rural setting, requires a number of changes in management and animal husbandry practices to be done at the farms, slaughter slabs and butchers. These include: The farmers should be encouraged to desist from free ranging system of management and embrace the use of raised housing or double fencing to reduce contact between their pigs and roaming pigs. Secondly, traders and butchers should be told to stop buying and slaughtering ASF sick pigs. Thirdly, all the slaughter slabs should be fenced to prevent stray dogs, cats, free ranging pigs and birds from accessing swill which can be carried to pig farms and transmit disease. Interestingly, during the meeting participants did come up with some vital and creative ASF control measures. Such measures included:

1) Encouraging individual farmers to have their own injection syringes and needles for treating pigs in their own farms since those of the veterinarians may transmit diseases if not properly disinfected because they (veterinarians) treat pigs in many farms.
2) Farmers were also encouraged to obtain both feeds and water from safe sources (ASF free sources) because many times ASF is spread to unsuspecting farms through African swine fever virus (ASFv) contaminated feeds.
3) Each pig farmer was encouraged to have their own breeding boar where possible or used artificial insemination instead of borrowing a boar from another farmer or using a community boar (where people take their sows to a boar that stationed in one of the farms for servicing). The use of a community boar and boar borrowing aid the spread of ASF among farms.
4) The movement of pig farm wastes especially from pig sties was discouraged since it could spread ASF among farms once one of the farms in infected with ASFv.

The results of this stakeholder analysis show that there is need to sensitize and mobilize the community before the implementation of biosecurity measures for any animal disease control or intervention to succeed. There is also need to consult the stakeholders in the pig value chain during the development of the biosecurity implementation guidelines to promote support and agreement to the intervention. Lastly, it is crucial to promote a good working relationship and understanding among all the stakeholders for the success of the intervention (Auvinen, 2003).

Methodological considerations

We were not able to interview some categories of stakeholder groups who could have had an influence in the intervention, these include: pig feed manufactures, pork processers, law makers and MAAIF officials despite our endeavor to do so. The study was done in only one district and yet the situation in other districts may be varying.

Conclusion

This stakeholder analysis has revealed that all key stakeholders in the pig value chain in a rural area in Uganda were either drivers or supporters of the implementation of biosecurity measures in the ASF control; although, there was need for financial and technical support to key stakeholders for the intervention to be implemented and enforced. These results show that there is great support for enforcement of biosecurity measures if stakeholders are facilitated with financial and technical support thereby limiting outbreaks of ASF in rural areas of Uganda.

Recommendation

There is need for adequate funding for community outreach to facilitate sensitization activities especially to the veterinarians, CDOs and district officials.

ETHICS

Permission to carry out the study was granted by the Ugandan National Council for Science and Technology under the reference number A497. Consent from the District veterinary officer was obtained prior to the start of interviews in Mukono District. All participants were informed that the study was voluntary, confidential, and that they had the choice of ending their participation at any time of the interview. An informed consent was given by all participants prior to the implementation of the study.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Technical efficiency of pineapple production in Republic of Benin

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Assessing the technical efficiency of pineapple producers is essential to avoid waste of resources and above all to target advices for improving the productivity of the pineapple producers. For this, a survey was carried out among 365 randomly selected producers from five major pineapple-producing Communes. Using the meta-border stochastic production model, technical efficiency scores of pineapple producers are estimated. It is found that the average technical efficiency index of pineapple production is 55.92 and 70% of pineapple producers have a technical efficiency index less than 60%. This proves the poor control of pineapple production techniques in Benin and the need to reorganize pineapple production system.

Key words: Efficiency potential, meta-border stochastic production function, pineapple varieties, technical efficiency.

INTRODUCTION

As a coastal country of West Africa located between Nigeria and Togo, Benin is a country whose economy is essentially agricultural. However, despite the agricultural potential offered by its morphology, its exports have always been based on a single crop: the oil palm between 1960 and the late 70s and cotton since the early 80s. To reduce the hardships of the mono-export and get out from the dependence of its cotton economy, Benin opted for the diversification of its agriculture (MAEP, 2011). Pineapple is one of the crops promoted for diversifying sources of foreign exchange. This crop not only contributes to the share of the agriculture in national income, but it possesses a great potential and comparative advantage to compete in the liberalized economy (Tidjani- Serpos, 2004).

Since 1990, pineapple is the most important cash crop for Atlantic Department's farmers who produce more than 98% of the national production (Yabi, 2014; MAEP, 2010). Its production has grown by an average of 12.77% per year (FAOSTAT, 2014) due to the expansion of areas. Tidjani-Serpos (2004) shows that the more the pineapple farm increases, the more the producer has the chance to get out of poverty. Unfortunately, farmers cultivating less than one hectare cannot get out from this situation of poverty. Thus, the increase in the area of pineapples allows producers to ensure their food security and to get out of poverty temporarily.

Coming from South America, pineapple is an

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intertropical and herbaceous crop which belongs to Bromeliaces family with several species that present more or least riser adaptation to drought (N'Guessan, 1985). The pineapple genus includes several species but the more cultivated is *Ananas comosus* which has numerous varieties classified into five groups: Cayenne, Queen, Spanish, Abacaxi and Perolera. Smooth cayenne is the most cultivated over the world but sugar loaf is more cultivated than smooth cayenne in Benin (Arinloyé, 2013).

Pineapple is a crop whose reproduction is ensured by the discharges which are the growths that come out at the base of the fruit (bulbils) or from the plant stem (suckers) or on the fruit (crown). Only bulbils and suckers are used for plantations. When sugar loaf can produce 8 to 15 releases, smooth cayenne does produce 3 or 4. The pineapple cycle length depends on several factors like the release nature and weight, the harvest homogeneity, and the average temperature and altitude (IRFA, 1984; Agence Française de Coopération and CIRAD, 2002). Pineapple must be cultivated on well aerated and with sufficient drainage soils (N'Guessan, 1985; Agence Française de Coopération and CIRAD, 2002) without fin gravel and stone because its roots are frail and superficial. Pineapple is a demanding crop in water which can be limiting factor (Py and Tisseau, 1965) and in some mineral elements (nitrogen and potassium) which must be supplied to its repeated culture. Optimum temperature for its culture is between 22 and 32°C (N'Guessan, 1985; Agee Française de Coopération and CIRAD, 2002; Py and Tisseau, 1965; Adegnandjou, 2014).

All the different parts of the pineapple are used for different purposes. For example, the leaves, which are very rich in cellulose, are used as fuel and in textile industries (FIRCA, 2012). Pineapple fruit can be processed into pineapple powder and pineapple juice into liquor, vinegar and other alcoholic beverages. The leaves used as a source of energy (bio-fuel) in nanoscale research (Zinatloo-Ajabshir et al., 2018, 2019a, b) produced excellent results.

Pineapple is characterized by high price fluctuations. It is the third most important tropical fruit in the world after banana (*Musa* spp.) and Citrus spp. (FAOSTAT, 2015). Nowadays, pineapple crop is cultivated in all tropical regions. Brazil, Thailand, Philippines and Costa Rica productions are respectively 2,491,970 tons; 2,278,570 tons; 2,209,340 tons and 1,678,130 tons in 2008 (FAO, 2011). Although Benin national pineapple production is insignificant at world level, pineapple constitutes a great cash crop for many farmers in Atlantic department of Benin Republic. The need for manpower for its farming and the various possibilities of its process make pineapple a job-creating crop (Gnimadi, 2008) and it offers investment opportunities for SMEs in relation to the supply of inputs, fruit pineapple processing, logistics for distribution in the sub region and inland countries (ABC/SNV, 2016). But despite this dazzling production, the government still does not benefit enough because of international markets conquest and the informal nature of sub-regional trade (Anasside and Aïvodji, 2009) which brews nearly 80% of the pineapple produced in Benin (Biaou, 2018). In order to get more beneficial from pineapple production, and in view of scarcity of resources, globalization of economies marked by competition between nations, the lack of technical support to producers and this new sector introduced in the producer farming system since the end of the 80s; it appears necessary to do the technical Efficiency Analysis of Pineapple Production in Republic of Benin.

Technical efficiency, which refers to certain microeconomic concepts (Farrell, 1957; Rainelli and Piot-Lepetit, 1996), is intended to judge the capacity of a production system to produce at best, through the implementation of all means of production (working capital, land and labor) (Borodak, 2005; Coelli et al., 1998). It measures the gap between the maximum achievable production and the level of production observed taking into account the technology used and inputs consumed (Rainelli and Piot-Lepetit, 1996; Issaka, 2002). The production function that describes the minimum amount of inputs required to produce maximum outputs is called the frontier production function (N'Gbo, 1991; El Arbi Chaffai, 1991; Blancard and Boussemart, 2006). Enterprises whose production level places them on the border are fully efficient in the use of resources (Battese and Coelli, 1992; N'Gbo, 1991).

Commonly, the technical efficiency is often determined using one of those two general approaches: the parametric approach and the non-parametric approach. However, the parametric approach is more used than nonparametric one for various reasons (Amara and Romain 2000; Coelli et al., 1998; Charnes et al., 1978). Parametric methods are based on the specification of a production function whose parameters are estimated by econometric tools. They include the deterministic parametric approach and the stochastic parametric approach (N'Gbo, 1991; Borodak, 2005). The stochastic approach allows the estimation of terms and the hypothesis tests allows the choice of the most suitable functional form (Coelli et al., 1998; Fontan, 2008).

However, as for any production system, not all enterprises are on the border, the analysis of agricultural production efficiency makes it possible to locate the system, to gauge the level of efficiency of the system and to target capacity building to be provided to producers. To satisfy the need to measure the level of efficiency of pineapple producers in Benin, this study is carried out. Because of its strengths and weaknesses the stochastic approach is used. Our target objectives in the present paper are to analyze the level of technical efficiency of pineapple production in Benin. Indeed, to maintain itself

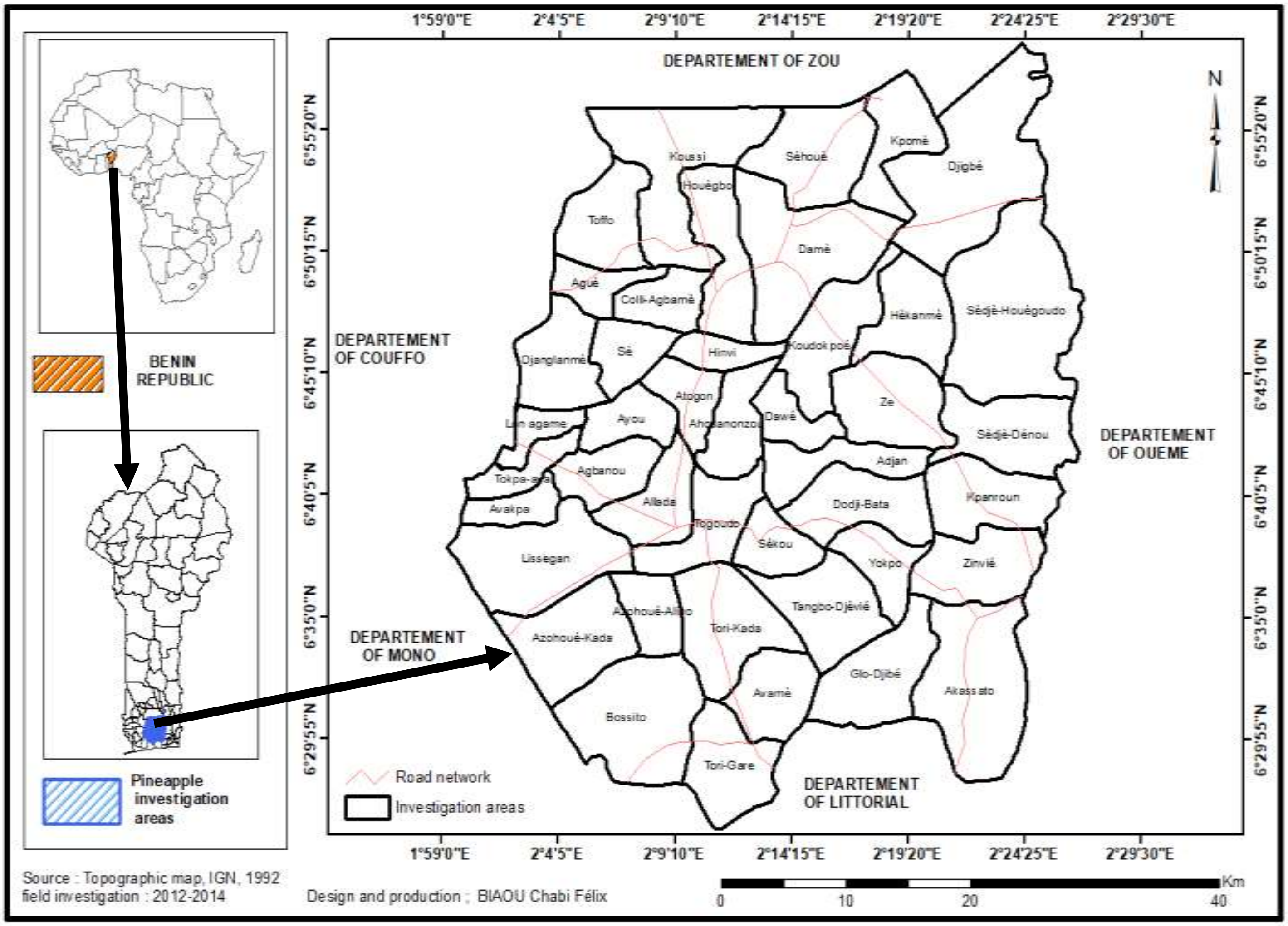

Figure 1. Study area in Benin.

sustainably in this new value chain, Benin must be among the countries with the highest productivity of this crop, despite the boom observed in Latin American and Asian countries (Loeillet, 2015) and climate change that have negative impacts on its production (Houssou et al., 2014).

MATERIALS AND METHODS

Data collection

Study area

This research is conducted in the Atlantic Department, which produces the most 98**%** (MAEP, 2010) of pineapple in Benin. It is densely populated area close to major urban centers of the country, Cotonou, Porto-Novo, Abomey-Calavi, etc. Its estimated population of more than 800 000 inhabitants (INSAE, 2013), is distributed in 8 communities, of which five are the main of pineapple producers (Figure 1).

Sampling methods

Ten producers were randomly selected from the 40 villages selected in the five pineapple producing Communities of the Department. The Community and the village are the two strata we considered. The selected villages were distributed among the Communities in proportion to the number of pineapple producing villages in the Department, and the villages to be surveyed in each Community are determined according to the weight of the area of the pineapple of the village in that of the Community. Of the 400 targeted producers, 365 responded to our interview.

Techniques and data collection tools

The data were collected through individual interview using a

Table 1. Fertilizers supplied and their fractionation to pineapple.

Fertilizer and their fractionation	Modalities
Fertilizer (TYPENGR)	
All the three types of fertilizers	1
Otherwise	0
Fractionation of fertilizers	
All fertilizers supplied two times	0
Each fertilizer supplied more than one time	1 otherwise 0
All fertilizers supplied more than three times	1 otherwise 0

Source: Designed by the author (2015).

questionnaire. They covered the areas and quantities harvested and sold, the quantities of inputs used per hectare (fertilizer, carbide, seeds), the sex of the producer, his age, the labor used per hectare per farming operation, the costs of renting the land and labor, the equipment and materials used, their costs and lifetimes, equipment rental costs, etc.

Analytical methods

Theoretical model

The equation of the stochastic production frontier is defined by:

$$\ln(y_i) = X_i\beta + v_i - u_i \tag{1}$$

with i=1,2,…., N and where X_i denotes the matrix of n columns of the factors of production; B is the parameters to be estimated; Y_i is the dependent variable. v_i is a random component that is distributed on both sides of the production boundary. It measures the error of random factors such as climatic hazards and the combined effects of other variables not specified in the model. It follows a normal distribution of variance σ_v^2 and mean 0 and, u_i A component representing technical inefficiency that is distributed only on one side of the boundary and is a positive random variable of mean μ and variance σ_u^2.

The likelihood function is expressed in terms of the total variance of the composite error $\sigma_s^2 = \sigma_v^2 + \sigma_u^2$ and the share of the variance of u_i in the total variance is $\gamma = \sigma_u^2 / \sigma_s^2$ with $0 \le \gamma \le 1$ represents the relative share of the variance explained by the technical inefficiency. Thus, the closer the value of γ is to 1, the more this gap is mainly attributed to the inefficiency of the actors, and thus the smaller the effects of the random variables are reduced (the model would then be deterministic). This indicator has a key role to justify the statistical coherence of the model.

The improvement of the model resulted in the stochastic functions of inclusive frontier production functions developed by Battese and Coelli (1992). This method not only measures efficiency indices to determine the most efficient production points, but also assesses and compares technological differences between companies and regions (Nyemeck and Nkamleu, 2006; Singbo, 2007). The aggregate production function for all pineapple farms and for each identified production system is identical to Equation 1 but the size of each subgroup is such that:

$$N = \sum_{k=1}^{K} N_k \tag{2}$$

where N_k is the number of operators in each identified production subsystem

The β* coefficients estimated for each subgroup are such that

$$X_i\beta^* \ge X_i\beta \tag{3}$$

Empirical models

The stochastic production function was estimated for all producers and for smooth cayenne and sugarloaf by introducing dumb variables in the stochastic function of frontier production and for both functional shapes Cobb-Douglas and Translog (Mohamed et al., 2008; Coelli et al., 1998). The variables used are:

(i) the quantities per hectare of pineapple production (proanha) in kg,
(ii) the quantity of fertilizer applied (qengha) in kg;
(iii) the quantity of labor required in hj (qmoha),
(iv) the number of seeds or plants (qrejha),
(v) the quantity of floral induction product (qpif) in kg
(vi) depreciation of capital (ameq).

The dummy variables of the model relate to the types of fertilizer input and their fractionation and are defined in Table 1. Thus the two models Cobb-Douglas and Tranlog are written as follows:

Douglas Cobb Model

$$\mathrm{Ln}(Y_{mi}) = \beta_0 + \beta_{m1}\mathrm{Ln}(QAna_i) + \beta_{m2}\mathrm{Ln}(QMOC_i) + \beta_{m3}QMOP_i) + \beta_{4m}\mathrm{Ln}(qBout_i) + \beta_{m5}\mathrm{Ln}(qeau_i) + \beta_{m6}\mathrm{Ln}(CENIE_i) + +\beta_{m7}\mathrm{Ln}(Amort_i) + v_i - u_i$$

Translog model

$$\ln(proanha) = \beta_0 + \beta_1\ln(qengha) + \beta_2\ln(qmoha) + \beta_3\ln(qpif) + \beta_4\ln(ameq) + \beta_5\ln(qrejha) + 0{,}5\begin{bmatrix} \beta_6(qenha)^2 + \beta_7\ln(qmoha)^2 + \beta_8\ln(qpif)^2 + \beta_9\ln(ameq)^2 + \beta_{10}\ln(qrejha)^2 + \\ \beta_{11}\ln(qengha)*\ln(qmoha) + \beta_{12}\ln(qengha)*\ln(qpif) + \beta_{13}\ln(qengha)*\ln(qameq) \\ \beta_{14}\ln(qengha)*\ln(qrejha) + \beta_{15}\ln(qmoha)*\ln(qpif) + \beta_{16}\ln(qmoha)*\ln(ameq) + \\ \beta_{17}\ln(qmoha)*\ln(qrejha) + \beta_{18}\ln(qpif)*\ln(ameq) + \beta_{19}\ln(qpif)*\ln(qrejha) \\ +\beta_{20}\ln(ameq)*\ln(qrejha) \end{bmatrix} \beta_{21}typengr + \beta_{22}(1engp3f) + \beta_{23}(engp3f) + v_i - u_i \tag{4}$$

Table 2. Results of Cobb Douglas model.

Variable	Coefficients	Smooth Cayenne	Sugar loaf	Together
Constance	β_0	13.865*** (0.974)	13.884*** (1.569)	14.080*** (0.99)
Quantity of fertilizer	β_1	0.0761 (0.224)	0.079* (0.057)	0.061 (0.049)
Labor	β_2	-0.008 (0.256)	-0.292***(0.125)	-0.296*** (0.092)
PIF	β_3	-0.067*** (0.016)	-0.0324 (0.0555)	-0.004 (0.429)
Capital	β_4	0.008*** (0.003)	-0.0009 (0.011)	-0.002 (0.007)
Density	β_5	-0.2874 (0.2385)	-0.1335 (0.1267)	-0.155** (0.091)
Fertilizer supplied				
Two types of fertilizers		-	-	-
three types of fertilizers	β_6	0.0236 (0.2222)	0.038 (0.0849)	0.057 (0.055)
Fertilizer fractionation				
Fertilizer supplied two times		-	-	-
One of the fertilizers supplied more than three times	β_7	-0.026 (0.0311)	0.0512 (0.0965)	0.004 (0.057)
Fertilizers supplied more than three times	β_8	0.0481 (0.0517)	-0.0236 (0.0536)	-0.026 (0.037)
Efficiency parameters				
Sigma squared		0.260*** (0.055)	1.73*** (0.1408)	5.970*** (1.269)
Gamma	γ	0.999*** ($0.929.10^{-7}$)	0.9933*** (0.003)	0.9951*** (0.002)
LR		34.8602	203.372	405.764
Mean of technical efficiency (%)		73.509	48.135	59.362

* ;** and *** significant respectively at 10 ; 5 and1%. (   ) standard Error.
Source: Survey data (2013).

Based on the statistical tests of χ² and the likelihood ratio, the model that best meets the different pineapple production systems has been validated (Appendices 1 and 2).

RESULTS AND DISCUSSION

The results of the Cobb-Douglas and Translog functional forms (Table 2 and Appendix Table 1) show that the gamma values are highly significant at the 1% threshold for groups of producers. They are statistically different from zero at the 1% threshold and very close to 1 meaning that the technical inefficiency of pineapple production exists and it depends more on producers than on random effects.

Interpretations of the coefficients of the model

With the Cobb-Douglas model, the coefficients of the estimated parameters directly give the elasticities. As regards to fertilizers, the elasticities are positive and significant everywhere only at the level of sugar loaf producers at the 10% threshold. Therefore, an increase in the fertilizer dose of 1% increases the sugar loaf production by 0.079%. Thus, the input of fertilizers is still beneficial to the cultivation of pineapples, but this contribution by mimicry means that the applied doses vary greatly and the coefficients are insignificant for the most part. In relation to the labour force the elasticities are negative and significant everywhere at the level of sugar loaf producers and for the whole. Consequently, an increase in the labour force of 1% reduces pineapple production by 0.296% and sugar loaf production by 0.292% respectively (Table 2). These results are in line with those of Fontan (2008) for the permanent labour of rice farmers in Guinea. The negative sign of the elasticities of the labour force is explained by several reasons: the agricultural tools used do not allow to time the work actually carried out and the repetitive operations poorly executed (Weeding, spreading of fertilisers) not significantly increase production. The multi-activity of the operators does not determine the actual time spent to carry out each activity. This makes it impossible to accurately determine labour productivity. Only mechanization will help to determine the productivity of agricultural labour.The yield elasticities relative to the PIF (floral induction product) are everywhere negative but significant only for the producers of smooth Cayenne. Thus an increase in the dose of PIF by 1% would reduce the production of smooth Cayenne by 0.067% (Table 2). The PIF participates in the yield thus to the productivity through the number of feet having carried flowers after the treatment of the plants. The more flowering plants there are, the more fruit there is, and the higher the yield

Table 3. Maximum, mean and minimum technical efficiencies according to the cultivated varieties and for the whole (%).

	Smooth Cayenne	Sugar loaf	Together
Mean	73.509	48.135	55.922
Standard deviation	24.392	23.195	24.682
Minimum	15.448	13.023	14.689
Maximum	0.99984	96.134	96.253

Source: Survey data (2013).

will be. The negative sign would mean that the applied dose does not allow for sufficient flowering foot rates for good yield; either the period of application of the PIF does not allow for a sufficient flowering foot rate or the quality of the product used is not the best to allow for a sufficient number of flowering feet. Since the product used is calcium carbide used in other sectors, a study to specify the appropriate quality for the floral induction of pineapple is necessary The elasticities of production with respect to capital are positive and significant for smooth Cayenne producers but not significant everywhere else. These negative elasticities are explained by the unnecessary holding of certain equipment in kind and in number, which are sometimes used only for cultivation operations and are not used for the provision of services to be remunerated.

The yield elasticities in relation to crop density are everywhere negative and significant only at the overall level (Table 2); thus, the higher the density the lesser the production. Pineapple production is at densities ranging from about 10,000 to 90,000 plants per hectare and fertilizer inputs should be based on these densities. The lack of a framework means that producers imitate each other and the applied fertilizer doses not comply with the standard. As the producer seeks to save money, the amount of fertilizer per plant decreases with density; so the higher the density, the less fertilizer, and the lower the yield. Thus the insufficient amount of applied fertilizers explains the productions which are negatively proportional to the densities.

The intake of three types of fertilizer has positive signs everywhere but they are not significant. This indicates that the three types of fertilizer are better than the intake of the two types of fertilizer, but the application periods, the applied doses and even the nature of these fertilisers do not allow a significant increase in production compared to those, which provide only two types of fertilizer. The effect of fertilizer fractionation is variously appreciated. While the intake of one fertilizer more than three times has a positive sign for the production of sugar loaf and for the whole, it is the intake of all fertilizers more than three times that is better for smooth Cayenne. In short, fertilizer doses can be increased, but their fractionation will not benefit plants unless they respect the application periods.

Extension and research implications

These results show that the agricultural amateurism and the lack of supervision of pineapple producers and the implications concern both research and extension. Input doses vary from one producer to another and the standards prescribed for these doses are not respected (Biaou, 2018). Sometimes the quality of some of the inputs used is inappropriate. Pineapple growers need to be made aware and advised that input rates depend on crop densities. Extension and monitoring of farmers can ensure that the standards for the rates of various inputs are met. Extension will need to work in symbiosis with research to address the various problems of this crop. Extension workers will need to specialize in this crop in order to detect the slightest flaws in the fields and propose corrective measures.

Since 1990, the first introduced cultivars have been grown using self-supply of rejects. Not only must these cultivars be renewed for both varieties, but new ones must be developed that can be larger, juicier, and highly productive. These new varieties should be able to force the producer to buy the seedlings after one or two self-supplies. In addition, it must examine the quality of calcium carbide suitable for the floral induction treatment in order to increase the rate of flower-bearing plants after this operation. Indeed, some producers respect the technical itinerary of pineapple cultivation, but the quality of the floral induction product reduces the rate of flower-bearing plants to 60 or 70% instead of 95 to 100%.

Analysis of technical efficiencies

The results show that there are high-performing producers because they are very close to the production frontier as well as technically poor producers. Technical efficiencies vary from one producer to another and from one subgroup of producers to another between 13.023 and 99.984% (Table 3). The average technical efficiency is 55.922% for overall, 73.509% for smooth cayenne producers and

Table 4. Potentialities of Increasing level of technical efficiencies according to producers.

Producer	Smooth Cayenne	Sugar loaf	Together
The least	84.549	86.453	84.739
Average	26.480	49.929	41.901

Source: Survey data (2013).

48.135%for sugarloaf producers. This average technical efficiency index of pineapple producers is below that of cotton producers where Midingoyi (2008) found an average technical efficiency index of 71.16% and those of rice farmers in Benin center for whom Singbo (2007) finds a technical efficiency index of 85.8%. Savi (2009) found that *crincrin* producers have a technical average efficiency index of 66.4% and Houndétondji (2013) found an average technical efficiency index of 81% for maize producers in the municipality of Zogbodomè (Benin). This indicator of the effectiveness of pineapple producers is due to several factors such as the ageing of cultivars, poor management of producers and unavailability of inputs on time.

In fact, with the exception of the first time they produced pineapple, beninese pineapple producers are self-sufficient to produce rejections especially sugarloaf which supply them enough. This practice, which has been going on since the 90's, has finally aged the cultivars of this plant. Furthermore, the non-fully liberalized agricultural input distribution system in Benin penalizes areas where farmers are unorganized and they do not benefit from state subsidies. Thus, these average indices of pineapple producers show the need to change pineapple cultivars, to make available inputs, to supervise and to follow farmers who are mainly illiterate.

According to the average efficiencies, smooth cayenne producers are more effective than those producing sugarloaf. The efficiency of sugarloaf producers varies between 13.023% and 96.134%. Certainly there are successful producers but this proves that the production technique is not mastered, because this variety is more rustic compared to the smooth cayenne. This result indirectly reveals the poor organization of producers and the dysfunction of their management where only 10% of producers are monitored (Biaou, 2018).

Despite the fragility of smooth cayenne, the producers of this variety are more technically efficient than the producers of the sugarloaf variety. Indeed, knowing that they produce a very sensitive variety and for export, they put theirs and respect relatively its requirements. Moreover, producers who deliver to exporters are monitored by their technicians and thus improve their production technique. The few small producers who still cultivate it are meet mainly in the municipality of Toffo where their organization allows correcting the technical shortcomings of their members.

Potentials not yet exploited

These results demonstrate that the technical efficiency scores of pineapple producers could be increased under the same conditions of production. Compared with the whole and overall under the same conditions of use of inputs, the least technically efficient producer could increase its efficiency by 84.739% (1- (14.689 / 96.253)) to reach the efficiency level of the most efficient producer when the average producer will only have to increase it by 41.901% (Table 4). By considering the subgroups, the producer of smooth cayenne the least technically efficient must increase its efficiency by more than 84.549% to reach the level of efficiency of the most efficient producer while the average producer of this variety must increase it by 26.48% (Table 4). Thus, under the current conditions of factor use, it is possible to increase the efficiency of the pineapple producers of 41.90% on average by reinforcing the supervision, the support of the producers on the technical itineraries and the fertilizer inputs and splits.

Distribution of producers according to their efficiency levels

Smooth cayenne producers have right-handed distribution, and more than 30% producers of this variety have an efficiency index greater than 90% (Figure 2). That of sugar loaf producers is bimodal with the first peak reached with more than 22% of producers in the interval [30 40[% and the second peak in the range (80 and 90%) with almost 13% of producers. More than 59% of producers of this variety have a technical efficiency index less than 60%. The distribution of all producers according to the technical efficiency indices has a bimodal appearance. The first peak in the range (30 and 40%) with more than 18% of producers and the second peak in the range (80 and 90%) with more than 13% of producers. Thus, nearly 70% of pineapple producers have a technical efficiency index less than 60%. Overall,

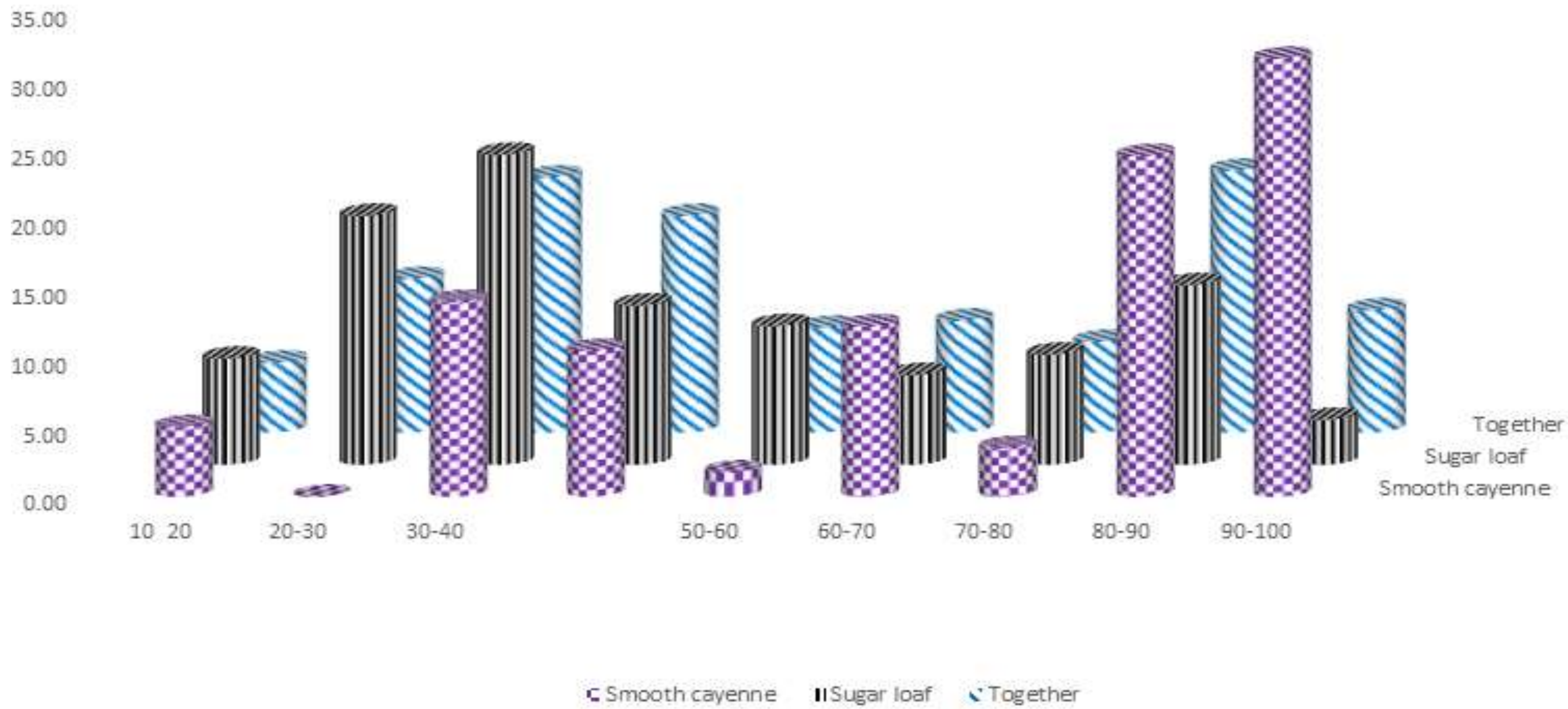

Figure 2. Distribution of pineapple producers according to their technical efficiency index and cultivated varieties.
Source: Survey data (2013).

all Beninese pineapple producers deserve capacity building to boost the production of this fruit.

Conclusion

This study shows the lack of extension workers who might follow advice of pineapple producers to increase their productivities for many factors. The low yields, negative elasticities in relation to fertilizers and their fractioning, to the floral induction treatment are a reflection of this absence. The technical efficiency levels of pineapple producers vary widely with an average of 55.922%.

Producers of smooth cayenne are technically more effective (73.509%) than those of sugarloaf (48.135%), although the latter variety is more rustic. More than 52% have an efficiency score of less than 52.5%, indicating poor mastery of production techniques by most producers and the existence of potential productivity gains with the current level of resource use.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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APPENDICES

Appendix 1. Trans log meta-border production model results.

Variables	Smooth Cayenne	Sugar loaf	Together
Constance	33.241*** (0.995)	12.074 (69.531)	58.682*** (1.00)
Fertilizer quantity	-50.143*** (0.929)	-3.1557 (4.4074)	-4.559*** (0.921)
Labor	-40.733*** (0.954)	1.1888 (10.3837)	-8.13*** (0.973)
Floral induction Product (FIP)	27.381*** (0.982)	1.7779 (3.2527)	-3.124** (1.372)
Capital	16.955***(0.836)	0.2052 (1.7873)	0.3818 (0.7593)
Density	26.551*** (0.838)	0.8905 (7.7473)	-2.516*** (0.813)
[Ln (Fertilizer)]²	-1.731*** (0.653)	-0.1535 (0.2237)	-0.1722 (0.1514)
[Ln (Labor)]²	-8.969*** (0.756)	-1.0005 (0.7864)	-0.7965 (0.6634)
[Ln(FIP)]²	0.3499 (0.388)	0.2523 (0.1566)	-0.182**(0.105)
[LN(Capital)]²	0.110*** (0.028)	0.0012 (0.0085)	0.008* (0.006)
[Ln (density)]²	-8.071*** (0.368)	-4584 (0.4604)	-0.55*** (0.217)
Ln(Fertilizer)Ln(Labor)	1.352** (0.853)	0.3081 (0.4917)	0.4651 (0.3908)
Ln (Fertilizer)Ln(FIP)	0.071 (0.8129)	0.3661 (0.2194)	0.229* (0.169)
Ln (Fertilizer)Ln(Capital)	0.2918 (0.3233)	-0.0525 (0.064)	-0505 (0.0415)
Ln(Fertilizer)Ln(density)	10.469*** (0.773)	0.5689 (0.7853)	0.800*** (0.255)
Ln(labor)Ln(Ln (FIP)	-0.9091 (0.9032)	-0.5765 (0.4482)	-0531** (0.309)
Ln(Labor)Ln (Capital)	-0.2273 (0.5992)	-0.0153 (0.165)	-0.0541 (0.1065)
Ln(labor)Ln(density)	16.466*** (0.796)	0.7331 (1.7316)	2.153*** (0.681)
Ln(FIP)Ln(Capital)	-0.602*** (0.243)	-0.0364 (0.0421)	-0.054* (0.041)
Ln(FIP)LN(density)	-4.242*** (0.556)	-0.0946 (0.541)	-0.296 (0.264)
ln(Capital)Ln(density)	-3.221*** (0.398)	0.0096 (0.2677)	-0.0076 (0.1105)
Fertilizer supplied			
Two types of fertilizers			
Three types of fertilizers	0.0222 (0.1904)	0.075 (0.0907)	0.125** (0.069)
Fertilizer fractionation			
All fertilizer no more than two times			
On fertilizer, more than three times	-0.1143 (0.1481)	0.0981 (0.1019)	0.0304 (0.0759)
All fertilizers more than three times	-0.1338 (0.1746)	0.0101 (0.0644)	-0.0122(0.0574)
Efficiencies parameters			
Sigma squared	0.201*** (0.042)	1.682*** (0.145)	5.970*** (1.269)
Gamma	01*** (256.10^{-9})	0.9934*** (0.004)	**0.9951*** ** (0.002)
Mean of technical efficiencies	74.022	49.016	59.362

Source: Survey data (2013).
( ) Erreur standard Error; *; ** ; *** significant respectively at 10, 5 and 1%.

Appendix 2. Tests of the choice of the appropriate model

To choose the functional form in adequacy with the data thus collected, the LR test proposed by Coelli et al (1998) which follows the Khi 2 law with one degree of freedom was used (Table 1). Thus, the two functional forms Cobb-Douglas and Translog are well suited to the types of producers considered.

Table 1. LR test for both Cobb Douglas and Translog functional forms.

Producers subgroups	Cobb Douglas	Translog
	LR	LR
Together (meta frontier)	404.98	411.066
Smooth Cayenne	40.116	35,092
Sugar loaf	208.738	207,230

Source: Survey data, 2013; $\chi^2(1.5\%) = 2.71$.

To choose the most suitable functional form, the assumption that the second-degree coefficients of the Translog form are zero was tested. The final values of the likelihood function given directly by the model are used for this purpose and the LRG ratio is determined. So the test is as follows:

H0: β_ij = 0 against H1: β_ij ≠ 0

This test is based on the following statistic:

LRG = -2 {ln [L (H0) / L (H1)]} = -2 {ln [L (H0)] - ln [L (H1)]}, where

L (H0) and L (H1) correspond to the likelihood functions for the hypotheses H0 and H1 and therefore represent the values of the respective likelihood ratios of the Cobb-Douglas and Translog functions. This statistic follows a mixed Chi-square law whose number of degrees of freedom is equivalent to the number of restrictions imposed. Thus, H0 is accepted means that the coefficients are zero, so the Cobb-Douglas form function is the most suitable. H0 will then be rejected if LRG> χ² (n; 0.05) and n, being the degree of freedom.

From the results in Table 2, H0 is accepted. Thus the β_{ij} coefficients are statistically zero and the Cobb-Douglas model responds best for determining the technical efficiency of pineapple production for all producer groups (Table 2).

Table 2. Test for the choice of the most suitable model.

Log likelihood function	Varieties		Together
	Smooth Cayenne	Sugar loaf	
Of Cobb Douglas model (LR_C)	-9.371	-357.873	-317.731
Of translog model (LR_T)	-3.465	-352.859	-305.299
Generalized LR LR_G= -2(LR_C-LR_T)	11.8118	10.027	24.864
Degree of freedom	15	15	15
Decision	H_0 accepted	H_0 accepted	H_0 accepted

Source: Survey data, 2013. χ^2 (15.5%) =25.

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Economic efficiency of rubber production and affecting factors: Case of smallholder rubber production in Quang Binh Province, Vietnam

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Rubber is a perennial crop, so to evaluate economic efficiency of smallholder rubber production, the author uses long-term analysis method with values such as actual present value (NPV), Benefit Cost Ratio (BCR), Internal rate of Return (IRR) and annual value. The factors affecting the productivity of smallholder rubber are assessed through the Cobb-Douglas functional production function analysis method with input factors of communication and non-communication. Data were collected through a survey of 200 smallholder rubber business households in 5 key rubber growing provinces in Quang Binh province. The research results show that Quang Binh province has many favorable conditions for rubber development and the smallholder rubber model has developed strongly, the area has increased rapidly but productivity is low, small in scale, unevenly distributed. In localities, most of them are located in remote areas, investment in resources is limited, production households with low average educational level, not much experience in rubber production and investment capital, limited private. Economic efficiency evaluation shows that with a discount rate of 9%, NPV will reach 80,147 VND / ha; IRR = 18% is larger than the current bank loan interest rate of households and B / C = 1.36> 0, so investment in small rubber business in Quang Binh province is effective. Assessment of factors affecting rubber latex production yield shows that, in addition to the variable density of variables included in the model such as fertilizers, labor, pesticides, rubber garden acreage, age orchards, training, rubber growing areas all have significant impacts on latex yield with 95% confidence.

Key words: Economic efficiency, rubber production, smallholder rubber model, Quang Binh rubber, rubber yield.

INTRODUCTION

The smallholder rubber model is being deployed and strongly developed in Quang Binh in particular and in Vietnam in general. This model is playing an important role in local economic development such as creating

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jobs, increasing stable income for rural workers, contributing to poverty reduction; contribute to increase the volume of rubber products for consumption and export; to restructure the rural economy towards industrialization and modernization. However, this model still faces many difficulties and challenges, especially productivity, output and economic efficiency are not commensurate with the local potential. There have been many studies evaluating the economic efficiency of rubber and rubber smallholder production and business, especially in countries with strong rubber plantation and production. However, the researches on each of the different aspects related to economic efficiency of rubber production and business. There are studies with synthetic evaluation of smallholder rubber but there is a sample size gap; some studies only pay attention to the positive aspects of smallholder rubber business and production but do not represent the average of the smallholder rubber in the study area. In particular, rubber trees are perennial crops, productivity and economic efficiency depend on many factors. For each country and territory has its own characteristics, the organization of rubber production and business and assessment of economic efficiency in rubber production and business are also different, so the research method and the category of research is also different. In particular, there are no studies to evaluate the economic efficiency of smallholder rubber production in Quang Binh province. Therefore, the article aims to study and evaluate the economic efficiency of smallholder rubber production in Quang Binh province through the method of long-term investment analysis with indicators such as actual present value (NPV), Benefit Cost Ratio (BCR), Internal rate of Return (IRR), annualized values and assess the factors affecting the productivity of smallholder rubber through the Cobb-Douglas production function analysis method with traditional and non-traditional input factors.

MATERIALS AND METHODS

Select the study site

The study conducted a survey on rubber growing households in Bo Trach and Le Thuy districts. These are two key rubber-growing districts of Quang Binh province with an area of over 88% of the province's rubber area. In 2 districts, select 5 survey sites: TT Nong Truong Viet Trung, Hoa Trach Commune, Tay Trach Commune, Phu Dinh Commune and Le Ninh Farm Center. These are the localities with smallholder rubber area accounting for over 95% of the rubber area of the 2 districts.

Secondary information

Collect and systemize documents that have been published through books, newspapers, summary reports and results of research projects related to rubber tree production and business in general and Quang Binh province's smallholder rubber in particular. These documents are intended to provide general research information, theoretical basis, practical basis, research site characteristics and research methodology.

Primary information

Directly surveying smallholder rubber production and business households through questionnaires. The questionnaire was elaborated with questions related to rubber production and business situation of smallholder rubber households in terms of acreage, investment, total trees, total number of shaved trees and education level, ... To determine the sample size, the author is based on the number of overall samples and according to the 2019 survey data, Quang Binh province has nearly 5000 smallholder households, so the decision on sample size is done according to Equation 1 the sample size is determined by the following equation:

$$n = \frac{\mathrm{N}}{1+\mathrm{N}(e)^2} \tag{1}$$

With the confidence of 95% and P = 0.5, the sample size with permissible error ± 5%, the study identified the sample to be investigated n = 195 and the author determined the number of households surveyed was 200 households.

The survey is conducted according to a stratified statistical method from year 1 to year 20 according to the rubber tree life cycle and for each year 10 households are selected as representatives, these households are selected according to random method course at each survey site. Thus, based on the number of survey sites selected is 5, the sample structure for each site is 40 households and for each year from year 1 to year 20 according to the life cycle of rubber trees, choose 2 households as represent. Data from the 21st year to the 30th year, the author is based on the research results of the Rubber Research Institute, of experts and practical research to estimate. The reason is only investigated until the 20th year according to the rubber tree life cycle is because the smallholder rubber business in Quang Binh province has only been carried out for 20 years, so since the 21st year there is no practical data to evaluate. Therefore, data from 21 onwards following the rubber tree life cycle, the author used the research results of the Rubber Research Institute to ensure more representativeness and accuracy because it was tested in practice.

Methods

Economic efficiency evaluation of rubber production is usually based on annual economic accounting indicators and long-term investment analysis criteria. On that basis, the research uses research methods.

Method of cost accounting, production results and efficiency

Accounting of production costs

Determining the cost of rubber production in 2 periods, the period of basic construction and the period of business. The study identified a basic construction period of 7 years from the year of planting rubber, including reclamation costs, new planting and interest expenses if any; business period is from the 8th year, the cost includes labor cost, fertilizer cost, cost of production tools, depreciation cost of garden (all expenses for basic construction period) allocated to years of economic periods) and financial expenses.

Accounting results and production efficiency

Conducting the calculation of actual yield of latex harvested for 1 ha of rubber of the surveyed household, the productivity usually collected from interviews, household interviews and combined with consideration of number statistical data on the productivity of the adjacent year (year) of the statistical office. Summing up and calculating the results and efficiency criteria as follows:

$GO = Q_i * P_i$

In which:
GO: Revenue collected per hectare of rubber tree area (VND 1,000)
Qi: Latex output of one hectare of rubber (kg)
Pi: Price of 1 kg of latex (VND 1,000)
Intermediate cost (IC): is the total amount of regular expenses in money that you spend to buy and rent inputs and services during the production of that total product.
Value-added (VA): The value of products created during that manufacturing period. It is the difference between the value of production and the intermediate cost.
VA = GO – IC
Mixed income (MI): is the remaining added value after deducting expenses: depreciation of fixed assets, taxes and fees (if any).
MI = VA - depreciation of fixed assets - Tax - Bank interest (if any)
Profit:
Profit = MI - expense of family labor - expense of in kind of a household
Evaluate production efficiency through indicators: GO / IC, MI / IC, LN / IC, VA / IC.

Benefit-cost analysis method

The research uses the benefit-cost analysis method in two ways: (1) Analyzing the annual cost benefit for the business period, the data used to perform the based on collected primary information, annual costs including expenses incurred during the year such as costs of supplies, production tools, labor, allocated depreciation of gardens and allocated financial expenses, basic construction expenses are evenly distributed among the years of the business period; (2) cost benefit analysis for the entire production cycle, using NPV, IRR and BCR indicators, benefits and costs arising in different years are realized at discount rates reasonable. The criteria are calculated by the following Equation 2, 3, 4:

$$NPV = \sum_{t=0}^{n} B_t \frac{1}{(1+r)^t} - \sum_{t-o}^{n} C_t \frac{1}{(1+r)^t} \quad (2)$$

In which:
n: Number of life cycles of a rubber tree
t: Year of investment
Bt: Benefits of rubber trees in year t
Ct: Cost of rubber tree year t
r: Discount interest rate (% / year)
If NPV is > 0, the investment in rubber business is effective and profitable. Conversely, if NPV is <0, financially, this investment is ineffective and should not be implemented.

$$IRR = r_1 + (r_2 - r_1) \frac{NPV_1}{|NPV_1| + |NPV_2|} \quad (3)$$

In which:
r_1: Lower discount rate at which NPV1> 0 is closest to 0
r_2: Higher discount rate at which NPV2 <0 is closest to 0.
NPV: Actual present value
The IRR to find (corresponding to NPV = 0) will lie between r_1 and r_2

IRR is the discount rate that makes NPV = 0, with this discount rate, rubber plantation is completely unprofitable because the income is just enough to offset the costs. Conversely, if IRR is greater than the interest rate, then production is efficient. The larger the IRR is, the higher the economic efficiency is.

$$BCR = \sum_{t=0}^{n} B_t \frac{1}{(1+r)^t} / \sum_{t-o}^{n} C_t \frac{1}{(1+r)^t} = PVB/PVC \quad (4)$$

In which:
PVB: Present value of benefits
PVC: The present value of cost
If BCR> 1 the revenues offset the expenses spent, the greater the investment in economic efficiency and BCR, the higher economic efficiency. If BCR is less than 1, the revenues cannot cover expenses, so the investment is not effective.

Method for analyzing the production function of Cobb - Douglas form

Use this method to assess factors affecting rubber production productivity. From practical analysis, identifying the factors affecting rubber production productivity and including Cobb-Douglas production function model has the form:

$Y = A.\ x_1^{\alpha 1}.\ x_2^{\alpha 2}.\ x_3^{\alpha 3}.\ x_4^{\alpha 4}.\ x_5^{\alpha 5}.\ x_6^{\alpha 6}.\ x_7^{\alpha 7}.\ e^{\alpha_8 K + \sum_{j=1}^{4} \beta_j D_j}$
Or: $LnY = A + \alpha_1 LnX_1 + \alpha_2 LnX_2 + \alpha_3 LnX_3 + \alpha_4 LnX_4 + \alpha_5 LnX_5 + \alpha_6 LnX_6 +$
$+ \alpha_7 LnX_7 + \alpha_8 K + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4$

In which:
Y: latex yield per hectare of rubber (kg / ha)
X1: NPK fertilizer (kg / ha)
X2: Manure (kg / ha)
X3: Labor (person / ha)
X4: Plant protection drugs (Plant protection) (VND / ha)
X5: Area (ha / household)
X6: Tree density (Number of trees / ha)
X7: Age of orchard (years)
K: Training dummy variable is defined as K = 1 if the head of the household has participated in the training and K = 0 if the head of household has not participated in the training.
Dj: Dummy variable for rubber growing area (j = 1 ÷ 4): D1 = 1, Tay Trach commune; D2 = 1, Hoa Trach commune; D3 = 1, Viet Trung Farm Town Center; D4 = 1, Le Ninh Farm Town Center; D1 = D2 = D3 = D4 = 0, Phu Dinh commune.
A: A constant that shows the impact of other factors on latex yield per hectare of rubber in addition to the inputs in the production function.
αi: Elasticity coefficient, reflecting the influence of input factors Xi and training variable K on latex yield per ha of rubber.
βj: Elasticity coefficient, which reflects the influence of the dummy variable in planting region D on latex yield per ha of rubber.

Scenario analysis method

Based on practical experience, put forward the proposed situations for risk variables (input variables affecting production activities) to consider the change of a result variable to consider the change of economic efficiency criteria for smallholder rubber production when there are changes of many risk factors at the same time.

RESULTS

Assessing the economic efficiency of smallholder rubber production in the surveyed households

The survey data of 200 smallholder rubber producing households in Quang Binh province is processed to determine the following indicators.

GO/IC, MI/IC, LN/IC indicators show that, since the start of exploitation, every 1 VND direct cost invested generated 2.89 VND of production value and 1.39 VND mixed income. Since the second year of exploitation, the value of production and mixed income have increased gradually. This means that each households has invested effectively, saved costs and the investment levels are suitable to each household's capacity. The LN/IC indicator shows the effectiveness of the production significantly, the analysis results of this indicator show that there has been an increase over each year of business period, specifically. Since the 2nd year of exploitation, households, of which the rubber plantation are at this age, for every 1 VND spent generated 1.91 VND of profit, this figure has changed significantly since the 3rd year of exploitation accounted for 2.21 VND and keeping the profit for every 1 VND spent until the 12th year of exploitation, starting the 13th year of exploitation, the profit for every 1 VND tends to decrease, accounted for only 1.84 VND; and decrease sharply in the 27th year of exploitation, which accounted for 0.87 VND. In the 30^{th} year of exploitation, the rubber plantation is no longer profitable.

Long-term indicators NPV, IRR, B/C: Local rubber price in the period of 2008 - 2019 declined and always fluctuated, from the actual survey in 2019, the author chose the price of VND 10,000/kg of latex to calculated because most of the surveyed households sell at this price; and choose the discount rate of 9% which is same as the interest rate of the bank for rubber production and business households in 2019. The NPV, B/C, IRR values calculated are shown in Tables 1, 2 and 3.

According to calculated data with a discount rate of 9%, the NPV is 80,147 VND/ha; IRR = 18% which is higher than the current bank loan interest rate and B/C = 1.36> 0. The results show the ratio of income to expenses during the period of rubber plantation at the current price is 1.36 times, which means that the investment smallholder rubber business in Quang Binh province is effective.

Assess the impact of factors on productivity of smallholder rubber production in Quang Binh province

Based on the research method and survey data, the study uses SPSS 16.0 software to process and analyze. The estimation Cobb - Douglas function and the regression equation are summarized in Table 4(*). The value of F - Statistic = 62,176> F0.05 [k-1, n - k] = 1,805 allows to reject the hypothesis that all individual regression coefficients are equals to 0 and accepts the hypothesis that not all individual regressions are simultaneously equal to 0. The multiple determination coefficient (R^2) of the model is 0.864, means that the independent variables in the model are NPK fertilizer, manure, labor, ... explain 86.4% of the change in rubber latex productivity. On the other hand, we assume that variance inflation factor VIF is in the range of 1 to 5 is less than 10, so there is no multi-collinear phenomena there which means the hypotheses poses in accordance with the model. Thus, the given model is reasonable and suitable with reality at the significance level of α = 1%.

Regression equation (*):

$$Y = 1,643.\ X_1^{0,134}.X_2^{0,409}.\ X_3^{0,36}.\ X_4^{0,413}.X_5^{0,071}.X_6^{(-0,253)}..X_7^{0,01}.e^{0,048.K+0,144.D_1+0,142.D_2+0,181.D_3+0,16.D_4}$$

Hay: $LnY = 1,643 + 0,134.LnX_1 + 0,409.LnX_2 + 0,36.LnX_3 + 0,413.LnX_4 + 0,071.LnX_5 + (-0,253)LnX_6 + 0,01.LnX_7 + 0,048K + 0,144.D_1 + 0,142.D_2 + 0,181.D_3 + 0,16.D_4$

Table 4 and the regression equation (*) show that the α_i coefficients of manure, pesticides, area, age of rubber plantation and training were all positive with 99% statistical significance; α_i coefficient of NPK fertilizer and labor were positive with the statistical significance of 95%; except for the α_i coefficient of the negative density variable with a statistical significance level of 95%. Thus, in addition to the variable density, the variables included in the model have a positive impact on the productivity of rubber latex production with the significance of α_i <5%, ie the reliability of the explanatory variables above 95%. In terms of each variable, the α_i coefficient of NPK fertilizer equals 0.1134, means that if NPK fertilizer increase 1% when other factors do not change, the yield will increase by 0.113% with significance level α = 0.031 <0.05 means that the reliability is over 95%, so NPK fertilizer has a positive effect on the productivity of rubber latex; the coefficient α_i of manure has a value of 0.409, means that if manure increasse 1% when other factors do not change, the yield will increase by 0.409% with a reliability of over 99%, indicating that manure has a great positive effect on the productivity of rubber latex; The α_i coefficient of pesticides is 0.413, means that if pesticides increase 1% when other factors remain unchanged, the yield will increase 0.413% with the reliability of over 99%. Thus, the influence of NPK fertilizer, manure and pesticides on rubber latex yield is significant, so that households who know how to use fertilizers and pesticides appropriately will increase productivity. The results of this analysis are consistent with the reality of the production of natural rubber in Quang Binh province, many households do not apply NPK fertilizer appropriately, so these households have lower their productivity. On the other hand, many households do not

Table 1. NPV per hectare.

Year	Discount rate (r=9%)	Productivity of latex (kg/ha)	Revenue (1000đ)	Cost	Profit	PV	Accumulated PV
1	0.9174	0	0	16.670	-16.670	-15.293,6	-15.294
2	0.8417	0	0	8.285	-8.285	-6.973,3	-22.267
3	0.7722	0	0	8.145	-8.145	-6.289,4	-28.556
4	0.7084	0	0	8.460	-8.460	-5.993,3	-34.550
5	0.6499	0	0	8.565	-8.565	-5.566,7	-40.116
6	0.5963	0	0	8.970	-8.970	-5.348,5	-45.465
7	0.5470	0	0	9.415	-9.415	-5.150,3	-50.615
8	0.5019	2.700	27.000	28.952	-1.952	-979,8	-51.595
9	0.4604	4.500	45.000	28.314	16.686	7.682,9	-43.912
10	0.4224	6.000	60.000	32.204	27.796	11.741,5	-32.171
11	0.3875	6.400	64.000	32.709	31.291	12.126,4	-20.044
12	0.3555	6.800	68.000	33.240	34.760	12.358,4	-7.686
13	0.3262	6.700	67.000	33.754	33.246	10.844,0	3.158
14	0.2992	6.700	67.000	35.113	31.887	9.542,1	12.701
15	0.2745	6.600	66.000	34.891	31.109	8.540,6	21.241
16	0.2519	6.600	66.000	34.871	31.129	7.840,5	29.082
17	0.2311	6.600	66.000	35.052	30.948	7.151,3	36.233
18	0.2120	6.500	65.000	35.118	29.882	6.334,9	42.568
19	0.1945	6.500	65.000	35.156	29.844	5.804,4	48.372
20	0.1784	6.500	65.000	35.156	29.844	5.325,2	53.697
21	0.1637	6.300	63.000	34.854	28.146	4.607,4	58.305
22	0.1502	6.000	60.000	34.145	25.855	3.882,9	62.188
23	0.1378	5.800	58.000	33.680	24.320	3.350,9	65.539
24	0.1264	5.000	50.000	31.810	18.190	2.299,4	67.838
25	0.1160	4.500	45.000	30.705	14.295	1.657,8	69.496
26	0.1064	4.200	42.000	30.095	11.905	1.266,6	70.762
27	0.0976	3.700	37.000	28.917	8.083	789,0	71.551
28	0.0895	2.900	29.000	26.241	2.759	247,0	71.798
29	0.0822	2.600	26.000	25.598	402	33,0	71.831
30	0.0754	2.500	25.000	24.669	331	25,0	71.856
30	0.0754		110.000		110.000	8.290,8	80.147

Source: Survey data and author's calculation (2019).

know about rubber production techniques, and how to detect and prevent pests, so the use of pesticides to prevent and control is not up to the technical standards with inadequate doses of pests and diseases that lead to low yields. The labor variable with a α_i coefficient of 0.36 means that if labor increase 1% when other factors remain unchanged, productivity will increase by 0.36% with reliability above 95%. This result is consistent with the practice of smallholder rubber production in Quang Binh province because many households do not have sufficient labor to fertilize and exploit properly so these households have lower productivity than those that ensure the number of labor.

Similarly, area variable has a lower impact on the yield of rubber latex, particularly when an increase of 1% of area when other factors do not change, the yield will increase by 0.071% with reliability above 95%. This is inconsistent with the theory as all are calculated per hectare. However, the fact proves that there is a productivity difference between smallholder producers and larger households because smallholder households are often unable to invest in intensive farming, applying scientific and technological advances in planting and harvestings, therefore, increasing 1% of the area increases the productivity of latex production. Similar to the area variable, the age has a α coefficient of 0.01, means that if the age of rubber plantation increase 1% when other factors remain unchanged, the yield will increase by 0.01% with significance level of $\alpha = 0.027 < 0.05$, that means the reliability is over 95%, so it is concluded that increasing the age of rubber plantation also increases productivity. This result is appropriate

Table 2. Benefit - Cost (B/C).

Year	Discount rate r=9%	Revenue	Cost	GTHT (Revenue)	GTHT (Cost)	Accumulated revenue	Accumulated Cost
1	0.9174	0	16.670	0	15.293,58	0.00	15.293,58
2	0.8417	0	8.285	0	6.973,32	0.00	22.266,90
3	0.7722	0	8.145	0	6.289,43	0.00	28.556,33
4	0.7084	0	8.460	0	5.993,28	0.00	34.549,61
5	0.6499	0	8.565	0	5.566,66	0.00	40.116,27
6	0.5963	0	8.970	0	5.348,52	0.00	45.464,79
7	0.5470	0	9.415	0	5.150,33	0.00	50.615,12
8	0.5019	27.000	28.952	13.550,39	14.530,18	13.550,39	65.145,30
9	0.4604	45.000	28.314	20.719,25	13.036,37	34.269,64	78.181,66
10	0.4224	60.000	32.204	25.344,65	13.603,13	59.614,29	91.784,79
11	0.3875	64.000	32.709	24.802,10	12.675,66	84.416,39	104.460,44
12	0.3555	68.000	33.240	24.176,36	11.817,94	108.592,75	116.278,38
13	0.3262	67.000	33.754	21.853,97	11.009,96	130.446,72	127.288,34
14	0.2992	67.000	35.113	20.049,51	10.507,38	150.496,23	137.795,72
15	0.2745	66.000	34.891	18.119,51	9.578,89	168.615,74	147.374,62
16	0.2519	66.000	34.871	16.623,40	8.782,95	185.239,15	156.157,57
17	0.2311	66.000	35.052	15.250,83	8.099,48	200.489,98	164.257,05
18	0.2120	65.000	35.118	13.779,59	7.444,74	214.269,57	171.701,79
19	0.1945	65.000	35.156	12.641,83	6.837,39	226.911,40	178.539,18
20	0.1784	65.000	35.156	11.598,01	6.272,84	238.509,41	184.812,02
21	0.1637	63.000	34.854	10.312,98	5.705,56	248.822,39	190.517,58
22	0.1502	60.000	34.145	9.010,90	5.127,97	257.833,29	195.645,55
23	0.1378	58.000	33.680	7.991,32	4.640,44	265.824,61	200.285,99
24	0.1264	50.000	31.810	6.320,25	4.020,89	272.144,86	204.306,88
25	0.1160	45.000	30.705	5.218,55	3.560,78	277.363,41	207.867,66
26	0.1064	42.000	30.095	4.468,49	3.201,92	281.831,89	211.069,58
27	0.0976	37.000	28.917	3.611,49	2.822,51	285.443,38	213.892,09
28	0.0895	29.000	26.241	2.596,90	2.349,86	288.040,29	216.241,94
29	0.0822	26.000	25.598	2.136,02	2.103,01	290.176,31	218.344,95
30	0.0754	25.000	24.669	1.884,28	1.859,33	292.060,58	220.204,28
30	0.0754	110.000	0	8.290,82	0,00	300.351,41	220.204,28

Source: Survey data and author's calculation (2019).

because rubber is long-term industrial crop, the life cycle lasts about 30 years. In Quang Binh, since the 8th year, rubber trees have been harvested and started to be exploited. This year, the productivity is still low, in the range of 1800 - 2500 kg of fresh latex per ha; by the 9th year, the latex yield is high and reaches about 3,000 - 4800 kg of fresh latex per hectare, from the 10th to the 20th year, the latex yield increases gradually over years ranging from 5,000 to 7000 kg of latex fresh on hectare, but by the 21th year, the rate of productivity growth is moderate, from the 26th year onwards the tree starts to age, productivity starts to decrease. In this model, the author only studies rubber plantation up to the age of 20, so the latex yield of trees increases gradually over the years. Therefore, the results of analyzing the age of rubber plantation on the impact of increasing rubber yield are reasonable and consistent with reality.

Unlike the above variables, the density variable negatively affects the yield of rubber latex. That means when the density increased by 1%, the latex yield decreased by an average of about 0.253% with a reliabily of over 95%. Through research practice, many smallholder rubber households in Quang Binh tend to grow thicker than the recommended density by soil type to prevent trees from dying due to weather and air. However, in fact, many rubber plantation do not face these risks, resulting in high density and households do not perform pruning to ensure the right density so they do not guarantee space for trees to grow, lack nutrients and susceptibility to pests and diseases leads to a lower yield. Therefore, the research results when increasing the density leads to reduce productivity are consistent with the practice.

The training variable with a α coefficient of 0.048 means that under normal production conditions, rubber

Table 3. NPV according to different discount rates.

Discount rate	NPV (1000đ)
0.08	99.723
0.09	80.147
0.10	63.893
0.11	50.347
0.12	39.021
0.13	29.523
0.14	21.537
0.15	14.806
0.16	9.122
0.17	4.315
0.18	243
0.19	-3.209
IRR = 18%	

Source: Survey data and author's calculation (2019).

Table 4. Estimation of Cobb - Douglas production function.

Variables	Impact lavel	t-Stat	P-value	VIF
(LnA) Constant	1.643	1.338	0.184	
X_1 – NPK fertilizer	0.134	2.188	0.031	1.7
X_2 - Manure	0.409	4.454	0.000	2.1
X_3 - Labor	0.360	2.076	0.040	3.2
X_4 - Pesticides	0.413	4.192	0.000	3.0
X_5 - Area	0.071	3.004	0.003	1.1
X_6 - Density	-0.253	-2.234	0.027	1.1
X_7 – Age of rubber plantation	0.010	3.358	0.001	1.8
K - Training	0.048	2.613	0.010	1.1
D_1 – Tay Trach commune	0.144	2.947	0.004	5.4
D_2 - Hoa Trach commune	0.142	3.080	0.003	4.6
D_3 – Viet Trung farm town	0.181	4.192	0.000	4.1
D_4 – Le Ninh farm town	0.160	4.231	0.000	2.9
R^2	0.864			
F	62.176		0.000	

Source: Survey data and author's calculation (2019).

plantation of trained households is higher than that of untrained households with the reliability above 99%. This result is consistent with theory and practice because rubber is a long-term industrial crop requiring planting, tending and exploitation with proper techniques for high productivity, minimizing risks from pests and natural disasters. Therefore, in practice, the trained households often have more production techniques than those who have not been trained, so the productivity of rubber plantations of these households is higher.

Analyzing whether the yield differences between different planting regions or not, the study conducted an analysis of 5 planting areas in two key districts for planting rubber in Quang Binh province, the results show that productivity of Viet Trung Farm Town is higher than other areas and rubber plantation in Phu Dinh commune has the lowest productivity. Under normal production conditions, investing in the same inputs, if an increase of 1% of the inputs, the rubber productivity in Viet Trung Farm Town is higher than that in Phu Dinh commune, Le Ninh Farm Town, Tay Trach and Hoa Trach by 0.181%, 0.021%, 0.037% and 0.039%, respectively with reliability above 99%. Similarly, investing in the same inputs, if increasing 1% of the inputs, the productivity of rubber in Le Ninh farm town is higher than that of Phu Dinh commune, Tay Trach commune and Phu Dinh commune by 0.16%, 0.016% and 0.018%, respectively, with reliability over 99%. Of the three communes where rubber is planted in Bo Trach district, the rubber plantation in Tay Trach Commune is the most productive. Specifically, investing in the same inputs, if the increase of 1% of the inputs, the rubber productivity in Tay Trach commune is 0.144% higher than in Phu Dinh commune and 0.002% higher than in Hoa Trach commune with reliability over 99%.

In addition to the factors included in the model, latex yield is also influenced by other factors such as weather, varieties, rubber plantation slope and soil type. But these factors are not included in the production function model. Because the households producing and trading rubber trees in Quang Binh province use many different varieties, the accuracy of this variable is not high and the slope of the rubber garden provided by the households is inaccurate and there are regulations on the maximum slope for rubber plantation is not more than 25 degrees.

DISCUSSION

There have been many studies discussing economic efficiency in rubber production, especially in countries with strong rubber plantation and production such as India, Laos, Malaysia, Vietnam, Indonesia, Thailand, and Sri. Lanka. Typically there are a number of research projects such as,A study on the Impact of the Efficiency of Rubber Production on the Welfare of Rubber Farmers in Jambi Province use Cobb-Douglas production function analysis with stochastic fungus production function approach. Results showed that the average rubber farmers in the study area have not been efficient in allocating inputs and not yet prosperous production (Kuswanto et al, 2019). The study examines productivity of rubber in Peninsular Malaysia in a disaggregated form. Data collection 307 observations were used in computing inferential statistics. The results revealed that there is actually a difference in mean TE between the all-age and the matured-age and old-age categories (Aliyu, 2018). The main objective of the study was to figure out, identify and analyse the technical efficiency of rubber smallholders' production in Negeri Sembilan, Malaysia. A parametric Stochastic Frontier Analysis (SFA), with a transcendental logarithmic (Translog) functional form, was used in the study. The inferential statistics showed that, the mean technical efficiency was found to be 0.73 with a standard deviation of 0.089. Thus, this translates that 27% accounted for technical inefficiency (Aliyu et al, 2017). Study evaluates the efficiency level of producing rubber among 95 rubber smallholders in Pahang using the Data Envelopment Analysis (DEA) model, under the assumption of Variable Return to Scale (VRS) and Constant Return to Scale (CRS). The study found the majority of the smallholders were not technically efficient in producing rubber (Ramli and Zulkipli, 2016).

The importance of smallholders in both rubber and oil palm production is the indirect result of the establishment of plantations. Recent historical trends in Malaysia and Indonesia confirm that tied and independent smallholders are perfectly capable to take charge of plantation crop production, even when their yields appear lower than those of estates. This potential could be reinforced through measures such as the provision of training services for the diffusion of best practices along with improved access to finance for intensification and replanting, all of which could have significant impacts on yield improvements (Bissonnette and De Koninck, 2015). Examined the costs and return analysis in rubber latex production in Edo Sate, Nigeria. Multi-stage sampling method was adopted to select 96 smallholder rubber framers for the study. The result of the budgetary analysis indicated that rubber production was profitable in the study area. However, the return on investment of 0.71 indicated a low profit level. The major constraints faced by the farmers were high cost of labour, incidence of pests and diseases, inadequate credit facilities, inadequate extension services among others. It was recommended that extension services should be provide to assist the farmers in tackling the problems associated with pests and diseases as well as training of rubber farmers in the area of management practices in rubber plantation (Ekunwe and Idubor, 2015). Estimated the profitability and the resource use condition of rubber small holders in Nigeria using data collected from 80 randomly selected farmers in Edo, Delta, Ogun and Akwa Ibom state. OLS estimation of the Cobb-Douglas production revealed that farm size, capital and planting material were statistically significant in explaining rubber production. Also, the sum of the elasticities of production (1.079) of the explanatory variables indicates that the rubber farms operate in the inefficient stage. The suggestion are farmers should increase their productivity by integrating their mature rubber plantation with mini-livestocks for increase income and also, agricultural inputs should be made available for agricultural production for increase agricultural output (Mesike and Esekhade, 2015).

Thus, the research on economic efficiency in rubber production and business, the works are mainly discussed in different aspects. Some studies have sample size shortcomings for those who are actually involved in rubber replanting so the results of this study are still inconclusive; Some studies only pay attention to the positive aspects of smallholder rubber business and production but do not represent the average of the smallholder rubber in the study area. There has not been any research on economic efficiency of smallholder rubber business and production model in Quang Binh province. In particular, there are no studies that simultaneously use long-term investment analysis methods with indicators such as NPV, BCR, IRR,

Annualized values and evaluating the factors affecting the productivity of smallholder rubber through the method. Cobb-Douglas production function analysis to evaluate economic efficiency of smallholder rubber production and business in a locality. Therefore, research and assessment of economic efficiency of smallholder rubber production and business in Quang Binh province ensure newness and creativity; Research has based on the general theoretical basis to form the theoretical basis of the smallholder rubber model and evaluate economic efficiency in rubber production, thereby forming research methods, evaluating economic efficiency. rubber production and business activities and research and evaluation of smallholder rubber models in Quang Binh province. Research results have supplemented and enriched theories about economic efficiency assessment in rubber production and business; is an important reference source for organizations and individuals to research and implement issues related to rubber and rubber production and business; at the same time, they are important practical bases to help smallholder rubber households, local authorities at all levels in Quang Binh have strategies and solutions to improve economic efficiency of rubber, rubber production and business. fill in Quang Binh province.

Conclusions

Assessing the economic efficiency of rubber production plays an important role on investing in rubber production, so there have been many study in this field. However, there has not been any work concurrently performing the method of determining the results, production efficiency and assessing economic efficiency through criteria such as revenue, added value, profit or long-term targets such as NPV, IRR, BCR, at the same time, the Cobb - Douglas production function model was used to evaluate the influence of factors on rubber production productivity.

To achive that goal, the study systematize the theory and practice to evaluate economic efficiency of rubber and smallholder rubber production; identify theoretical basis and research methods to conduct research to evaluate the economic efficiency of smallholder rubber production in Quang Binh province and the influencing factors.

The research results show that Quang Binh province has many favorable conditions for rubber development and the smallholder rubber model has developed strongly, the area has increased rapidly but productivity is low, small in scale, unevenly distributed. In localities, most of them are located in remote areas, investment in resources is limited, production households with low average educational level, not much experience in rubber production and investment capital and limited private. Evaluating economic efficiency through long-term investment analysis method with indicators such as NPV, BCR, IRR, and annualized values shows that the typical rubber model in Quang Binh province has economic efficiency. However, the economic efficiency in the period of 2008 - 2019 has many changes due to the great influence from changes in selling prices and interest rates; smallholder rubber plantations have a great growth in acreage and output, but the yield is not as high as about 0.9 - 1.1 tons of dry latex / ha, lower than other localities with similar conditions as Quang Tri province yield of 1.4 tons of dry latex / ha and Nghe An with a yield of 1.2 tons of dry latex / ha.

Evaluation of factors affecting rubber latex production yield shows that, in addition to density variables, variables included in the model such as fertilizers, labor, pesticides, rubber garden acreage, age of orchards and training all have a significant impact on rubber yield with 95% confidence. In addition, research results also identify different growing areas for different productivity and economic efficiency. Besides the factors included in the model, the research results also determine that latex yield is influenced by other factors such as weather, varieties, rubber garden slope and soil type. However, these factors are not included in the model because the accuracy is not high because smallholder rubber business households in Quang Binh province use many other varieties, households provide inaccurate slope and have the maximum slope for rubber plantations is no more than 25°.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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