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Journal of Development and Agricultural Economics

Table of Contents: Volume 7 Number 6 June 2015

ARTICLES

Research Articles

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Full Length Research Paper

Bio-economic modelling of the influence of family planning, land consolidation and soil erosion on farm production and food security in Rwanda

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Rwandan agriculture is not able to meet its population's food needs from its own production, which results in food insecurity. Land degradation is a serious problem which contributes to a low and declining agricultural productivity and consequently to food insecurity. The objective of this paper is to develop a bio-economic model capable of analysing the impacts of soil erosion, family planning and land consolidation policies on food security in Rwanda. The results of the bio-economic model show that a higher availability of good farm land would increase the farm income. Additionally, preserving soils against erosion and reducing risk would allow for releasing more marginal land which would increase food production for home consumption and for the market. Increasing the opportunities for off-farm employment can also increase farm household income. The outcomes of the model support the Rwanda policy on family planning, while the policy on land consolidation is not endorsed.

Key words: Rwanda, land degradation, food security, bioeconomic model, family planning policy, land consolidation policy.

INTRODUCTION

Agricultural statistics indicate that per capita food production in Rwanda is declining (Minecofin, 2003a; RADA, 2005; NISR, 2008). This trend is putting at stake the food security of the rural and urban poor. Rwandan agriculture is not able to meet its population's food needs with the national production.

Land degradation is a serious problem which contributes to the low and declining agricultural productivity and consequently to food insecurity. Land degradation can be defined in terms of loss of actual or potential productivity as a result of natural or human factors (Anecksamphant et al., 1999). Soil erosion and soil mining are believed to

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be the most important causes of land degradation in Rwanda with a soil loss of 50 to 400 tons per hectare per year depending on location (Mugabo, 2005). Some slopes are totally degraded by erosion and no production is possible without restoring fertility. In addition, Rwandan soils have a very low organic matter content and weak soil fertility potential except for the marshy and volcanic soils (Gecad, 2004). Furthermore, land scarcity due to the high population density is limiting the option to extend agricultural land size. In Rwanda, the biophysical causes of land degradation are relatively well known, but less is known about the economic impact of land degradation on farming activities. Very little modelling analysis exists at farm level on the economic consequences of land degradation (Byiringiro and Reardon, 1996; Clay et al., 1998; Musahara, 2006).

Rwanda's population, which is made up mostly of subsistence farmers, has quadrupled during the last 50 years. At present, Rwanda has 9.3 million inhabitants with a density of 380 inhabitants/km^2. The average size of a family farm is 0.76 ha (Minagri, 2004). If the human reproduction rates are not slowing down, the population will double by 2030 (Kinzer, 2007), with dramatic consequences for natural resources and food security. Thus, it is important to balance the increasing population with the limited available land, and ensure food security.

The new land law put in place by the Rwandese government stipulates that, under its article 20, landholdings less than one hectare (ha) are deemed insufficient for effective and efficient agricultural exploitation (Minerena, 2005). Therefore, the Rwanda government prepared to use the land law as one of the drivers of agricultural reform, notably through the provision on land consolidation and minimum land holdings. The farm households whose land is less that 1 ha would have difficulties to register their land (Huggins, 2012). The land law and land policy tend to stimulate farm households whose landholdings are less than one hectare to consolidate their land, but those who are reluctant to comply to the land law and land policy are vulnerable to confiscation of their land (Huggins, 2012; Pottier, 2006). This ruling follows a recommendation made by the Poverty Reduction Strategy paper (Minecofin, 2003b): "households will be encouraged to consolidate plots in order to ensure that each holding is not less than 1 ha. This will be achieved by the family cultivating in common rather than fragmenting the plot through inheritance".

Decisions on land use are basically made by heads of farm households. As in many other developing countries, a farm household system in Rwanda concerns production (of crops and livestock), off-farm activities and consumption (of food, other basic needs and some leisure). A major characteristic is the non-separability of production and consumption decisions. The allocation of productive resources and the choice of activities could affect land degradation and subsequently food security. It is assumed that farm households are rational in pursuing certain meaningful objectives which guide their behaviour (Upton, 1996; Anderson, 2002; Woelcke, 2006; Laborte et al. 2007; Laborte et al., 2009). However, the decision-making process is restricted by the range of possible alternative activities that can be undertaken by farm households and constraints imposed by limited resources availability and other external conditions like agricultural and/or environment policies (Senthilkumar et. al, 2011).

To understand the complex relations at farm level between technical, ecological and economic components, there is a need to combine information from biophysical and social sciences (Kruseman, 2000). Bio-economic modelling is at the interface of biophysical and social sciences, enabling the accommodation of biophysical data in economic analysis (Kanellopoulos et al., 2010; Louhichi et al., 2010).

In developing countries, many studies have made use of bio-economic farm models and there is growing interest for its application (Jansen and Van Ittersum, 2007). However, little modelling analysis at farm household has been conducted in subsistence or semi-subsistence farming. Barbier (1990), Cárcamo et al. (1994), Barbier and Bergeron (1999) and Louhichi et al. (1999) evaluated the economic nature of land degradation and estimated net returns from erosion control. Van Keulen et al. (1998), Kruseman and Bade (1998), Kuyvenhoven et al. (1998), Ruben et al. (1998), Struif Bontkes and Van Keulen (2003) assessed different sustainable technologies to improve farm household income and soil fertility. Dorward (1999) investigated the conditions under which peasant farm household models may need to allow embedded risk. Anderson (2002), Mudhara et al. (2002), Thangata et al. (2002) examined the options for improving household food security for small-scale farms.

Modelling farm households might bring some insights into the ongoing debate on land and family planning reforms and the potential impacts of soil erosion. So far no modelling studies in sub-Saharan countries have incorporated at the same time soil erosion, soil fertility, soil quality and food consumption in terms of energy and proteins, risk, labour, land, cash and credit availability in their economic evaluation of crop production for farms.

The objectives of this paper are:i) to develop a general bio-economic model capable of analysing the impacts of family planning, land consolidation and soil erosion on farm production and food security in Rwanda; ii) to apply the bio-economic model for a typical farm in Rwanda.

The remainder of this paper is structured as follows. The next section describes the study area and the farm household model. Next, data and application of the model for a typical farm are presented. This typical farm household has available resources that are the average of farm types distinguished in (Bidogeza et al., 2009).

This is followed by the presentation of the modelling results regarding food security, technical and economic results for the typical farm. The outcomes of the farm household model are compared with observed farm household data; and the effects of family and land size changes on food security, income and soil loss results are determined and discussed. Thereafter follow the conclusions.

MATERIALS AND METHODS

Area of study and typical farm

The area of study is in Umutara, a former province located in the eastern part of Rwanda, approximately 180 km from Kigali along the main tarmac road between Kigali and Kagitumba (border with Uganda). It has a border with two countries, Uganda in the north, and Tanzania in the southeast. The tarmac road and the geographical position of Umutara imply that the market access is fairly good.

Most inhabitants of Umutara are former refugees who arrived from Tanzania and Uganda after the genocide which ended in 1994. When they returned to Rwanda, Umutara was chosen for their resettlement. The increasing population puts a high pressure on natural resources of the province, and different land uses often compete for the same piece of land.

Umutara province belongs almost entirely to the agro-climatic zone of the Central Bugesera and the Savannahs of the East, which is the driest agro-climatic region of Rwanda. The annual precipitation is quite variable in the region and is on average lower than 1000 mm (Sirven et al., 1974). The irregularity of the precipitation is a frequently stated problem for Umutara. The climate of Umutara is bimodal (Fleskens, 2007), with two growing seasons annually. The agricultural activities for one season referred to as B last from January to June, and agricultural activities for the other season referred to as A take place from July to December.

The pedology of Umutara is quite diverse, notwithstanding that it is only a small area. Two types of soils are dominant in Umutara: Inceptisols and Oxisols (USDA, 1999), mostly located on gentle (2-6%) and moderate (6-13%) slopes, respectively. These land types are covering 60% of the total soil in Umutara province, respectively 40% for Oxisols and 20% for Inceptisols (GhentUniversity, 2002). The chemical fertility of Oxisols is poor; weathered minerals and cations retention by mineral soil fraction is weak, while Inceptisols have a satisfactory chemical fertility and contain at least some weathered minerals in silt and sand fraction (FAO, 2001). Despite of the low fertility of the soils, small-scale farmers maintain soil fertility and reduce soil erosion by using low input systems such as crop rotations, organic fertilisers and few of them also use some chemical fertilisers. However, these land management strategies are not suficient for a sustainable farming.

With respect to the importance of the different crops cultivated in the region: 33% of the cultivated land is occupied by cereals, followed by tubers (29%), leguminous crops (21%) and bananas (15%) (Minagri, 2002).

The farm household analysed in this paper is typical for the province. Important socio-economic variables used to characterise the typical farm household were average farm data at regional or national level derived from the literature and field survey (Kinzer, 2007; Loveridge et al., 2007; Strode et al., 2007; Ansoms and McKay, 2010).

Model specification and data used

General structure

The basic structure of the bioeconomic farm household model is shown in Equation (1). It has the mathematical form of a quadratic programming model (Hazell and Norton, 1986):

$$\text{Maximise } \{Z = c'x - Ø\,\sigma\}$$
$$\text{Subject to } Ax \leq b$$
$$\text{and } x \geq 0 \qquad (1)$$

where: Z = expected utility; c = vector of gross margins, costs or revenues per unit of activity; x = vector of activities; A = matrix of technical coefficients; b = vector of resource availabilities; Ø = risk aversion coefficient (Ø >0); σ = standard deviation of totalgross margin.

The model presented here is a quadratic programming model with a time span of one year (two seasons). The expected utility is the objective function and this is maximized. The farmer is assumed to maximise expected utility which is defined as discretionary income minus the risk premium. Discretionary income is defined as income available for spending after essential expenses have been made (Castano, 2001; Laborte et al., 2009). The most important essentials include clothes, taxes, medication, school fees, kitchen ustensils and food ingredients.

Activities include crop production for home consumption, crop production for sale, off-farm activities, hiring labour, family expenditures, borrowing credit. Major constraints include land, labour in three different periods per season, rotations, available cash, maximum credit, food consumption requirements, soil loss and soil organic matter.

The major activities and constraints are summarized bythe Equations (2) to (14). For the description of the indices, coefficients and variables see Tables 1, 2 and 3, respectively.

$$c'x = \begin{array}{l}\sum_{c,se,lu}(Y_{c,se,lu} * vL^{m}_{c,se,lu}) * Pr_{c,se} - \sum_{c,se,lu}[(Cs_{c,se,lu} * vL^{m}_{c,se,lu}) + (Cs_{c,se,lu} * vL^{c}_{c,se,lu})] - \\ (\sum_{pe,se} vHlab_{pe,se} * Wage) + (\sum_{pe,se} vOfflab_{pe,se} * Wage) - \sum_{pe,se}(Exp_{pe,se})\end{array} \quad - v| \qquad (2)$$

The discretionary income per year is defined as returns from the sale of crops production ($\sum_{c,se,lu}(Y_{c,se,lu} * vL^{m}_{c,se,lu}) * Pr_{c,se}$) plus wages from off-farm activities ($\sum_{pe,se} vOfflab_{pe,se} * Wage$) minus costs of seeds/establishment costs ($\sum_{c,se,lu}[(Cs_{c,se,lu} * vL^{m}_{c,se,lu}) + (Cs_{c,se,lu} * vL^{c}_{c,se,lu})]$) and costs of hired labour ($\sum_{pe,se} vHlab_{pe,se} * Wage$) and expenditures. The standard deviation for total gross margin is calculated from the variance/covariance matrix of gross margins for the crops per

Table 1. Indices used in the farm household model.

Index	Description	Elements
C	Crop	Banana, beans, cassava, groundnut, maize, sorghum, sweet potato
Leg	Leguminous	Beans, groundnut
Len	Non leguminous	Cassava, maize, sorghum, sweet potato
Lu	Land type	Inceptisols, Oxisols
Pe	Period	Periods 1, 2, 3 (in each season)
Se	Season	Season A, season B

Table 2. Coefficients used in the farm household model.

Coefficient	Description	Dimension
AVL	Available land	ha
AVlab	Available labour	man-day
Credilim	Credit limit	fr.rw
Cs	Cost of seed/establishment costs	fr.rw ha^{-1}
En	Energy content per crop	Kcal kg^{-1}
Enreq	Energy requirement	Kcal $season^{-1}$
Exp	Expenditure	fr.rw
Labreq	Labour requirement	man-day ha^{-1}
MaxOfflab	Maximum off farm labour	man-day
Pr	Price products	fr.rw kg^{-1}
Prot	Protein content per crop	g kg^{-1}
Protreq	Protein requirement	g $season^{-1}$
Ri	Rate of interest	%
Soc	Soil organic matter	t ha^{-1} $season^{-1}$
Socav	Soil organic matter available	t ha^{-1} $year^{-1}$
Soill	Soil loss	t ha^{-1} $season^{-1}$
Soilltol	Soil loss tolerance	t ha^{-1} $year^{-1}$
Totcostse	Total cost of seeds/establishment costs	fr.rw ha^{-1}
Totrev	Total returns from crop sales	fr.rw ha^{-1}
$Varcovar^c$	Variance /covariance matrix of Gross Margins of crops for home consumption (using constant product prices)	-
$Varcovar^m$	Variance /covariance matrix of Gross Margins of marketed crops.	-
Wage	Wage	fr.rw day^{-1}
Y	Yield	Kg ha^{-1}

($\sum_{pe,se}(Exp_{pe,se})$) and total interest (*vI*).

$$\sigma = \sqrt{\sum_{c,se,lu}[varcovar^{m}_{c,se} * (vL^{m}_{c,se,lu})^2 + varcovar^{c}_{c,se} * (vL^{c}_{c,se,lu})^2]} \quad (3)$$

season and the area of crops per season for consumption and for marketing, respectively.

Land constraint (for each season and land type)

$$\sum_c (vL^{m}_{c,se,lu} + vL^{c}_{c,se,lu}) \le AVL_{se,lu} \quad (4)$$

Labour constraint (for each season and each period)

Table 3. Variables used in the farm household model.

Variable	Description	Dimension
vCach	Cash	fr.rw
*v*Cred	Credit required	fr.rw
*v*Hlab	Hired labour	man-day
*v*I	Total interest	fr.rw year^{-1}
*v*L^{c}	Land allocated to crop for consumption	ha
*v*L^{m}	Land allocated to crop for market	ha
vNewcred	Credit added each period	fr.rw
vOfflab	Days allocated to off farm activities	man-day
*v*Repay	Repayment	fr.rw
σ	Standard deviation of income	

C'X $\sum_{c,lu}[(Labreq_{c,pe,se,lu} * vL^{m}_{c,se,lu}) + (Labreq_{c,pe,se,lu} * vL^{c}_{c,se,lu}) + vOfflab_{pe,se}] \leq vHlab_{pe,se} + AVlab_{pe,se}$ (5)

$$vOfflab_{pe,se} \leq MaxOfflab_{pe,se} \quad (6)$$

Rotations constraint (for each season and each land type)

$$vL^{m}_{leg,se,lu} + vL^{c}_{leg,se,lu} = vL^{m}_{len,se,lu} + vL^{c}_{len,se,lu} \quad (7)$$

Minimum food consumption constraints (for each season)

$$\sum_{c,lu}[(Y_{c,se,lu} * vL^{c}_{c,se,lu}) * En_{c}] \geq Enreq_{se} \quad (8)$$

$$\sum_{c,lu}[(Y_{c,se,lu} * vL^{c}_{c,se,lu}) * Prot_{c}] \geq Protreq_{se} \quad (9)$$

Cash constraints (for each season and each period)

$$vCash_{pe,se} = vCred_{pe,se} + vOfflab_{pe,se} * Wage + \sum_{c}(Totrev_{c,se}) - vHlab_{pe,se} * Wage - Exp_{pe,se} - \sum_{c}(Totcostse_{c,se}) \quad (10)$$

Required credit (for each season and each period)

$$vCred_{pe,se} = vCred_{pe-1,se} * (1 + ri) - vRepay_{pe-1,se} + vNewcred_{pe,se} \quad (11)$$

Credit constraint (for each season and period)

$$\sum_{pe} vCred_{pe,se} \leq Credlim_{se} \quad (12)$$

Soil loss constraint (per year for each land type)

$$\sum_{c,se}[(Soill_{c,se,lu} * vL^{c}_{c,se,lu}) + (Soill_{c,se,lu} * vL^{m}_{c,se,lu})] \leq Soilltol_{lu} \quad (13)$$

Soil fertility constraint (per year for each land type)

$$\sum_{c,se}[(Soc_{c,se,lu} * vL^{c}_{c,se,lu}) + (Soc_{c,se,lu} * vL^{m}_{c,se,lu})] \leq Socav_{lu} \quad (14)$$

The software used for optimization of the quadratic programming farm household model is General Algebraic Modelling System, version 22.6 (GAMS) with the solver CONOPT.

Sources of data used

In 2004 and 2005 data were collected in Umutara province by the National Institute of Statistics of Rwanda, in the framework of a national agricultural farm survey held twice annually. This farm survey database can be obtained from the authors upon request. In addition, a small survey was conducted in October, November and December 2007 through interviews in order to collect information supplementary to the national farm survey. For the latter survey, farm households were asked questions about family expenditure and income, crops and rotations, production costs and output prices, labour use and costs, market availability. Supplementary information related to coefficients of the current farming were estimated from literature (MCDF, 1984; Birasa et al., 1990; Minagri, 1991; Ghent university, 2002; CPR, 2002; Minagri, 2002; Zaongo et al., 2002; Van Ranst, 2003; CIRAD, 2004 and Minagri, 2006). These coefficients are estimated under low input systems. Low inputs are defined as no significant use of purchased inputs such as artificial fertilizers, improved seeds, pesticides or equipment. Input and output prices in the region were derived from the database on the market prices list provided by the Minagri (2007). Data to generate many of the coefficients for soil characteristics of the region were obtained from the natural resource database hosted by the “Carte Pedologique” Unit at the Ministry of Agriculture (Birasa et al., 1990).

Activities

Farm household activities consist mainly of crop production, off-farm activities and hiring in labour or working as farm labour on other farms. Livestock is not a major activity for the farm type

Table 4. Input-output information on crops for Oxisols.

Season		A	A	A	A	A	A&B	A&B
Crop activities	**Unit**	**Beans**	**Groundnuts**	**Maize**	**Sorghum**	**Sweet potatoes**	**Cassava**	**Banana**
Inputs-output								
Yield[1]	kg ha^{-1}	670	500	990	1,050	6,300	6,000	15,000
Price[2]	fr.rw kg^{-1}	141	419	100	106	90	177	83 (98)[a]
Revenues	fr.rw ha^{-1}	94,470	209,500	99,000	111,300	567,000	1,062,000	1,357,500
Cost of seed/establishment cost	fr.rw ha^{-1}	8,500	23,000	2,000	800	23,000	50,000	93,200*
Gross margin	fr.rw ha^{-1}	85,970	186,000	97,000	110,500	544,000	1,012,000	1,264,300
Labour[3]	man-days ha^{-1}	104	98	116	108	94	129	264
Total energy[4]	10^3kcal ha^{-1}	2,231	2,835	3,237	3,664	5,720	6,378	5,190[b]
Total Protein[4]	g ha^{-1}	158,120	129,000	75,240	112,350	86,310	48,000	56,250[b]
Soil loss[5]	t ha^{-1}	11.8	19.9	21.8	24.9	14.3	16.2[b]	2.5[b]
Soil Organic carbon[6]	t ha^{-1}	3020	1887	3020	1887	3775	1887[b]	3020[b]

[1]Minagri (1991) and Minagari and INSR (2006); [2]Minagri (2007a); [3] MCDF (1984); CIRAD (2004) and White et al. (2005); [4] WHO (1985); FAO/WHO (2000) and own calculations; [5] Roose (1994), Wischmeier (1995), Roose and Ndayizigiye (1997) , CPR (2002), Lufafa et al. (2003), Fleskens (2007), USDA (2009), and own calculations; [6] Sys et al. (1993) and own calculations.; [a] price per Kg of banana, respectively in season A and B. [b] These values are concerning season A. *The costs and revenues of Banana (multiyear crop) are based on annuities.

considered. Major food crops in Umutara include beans, groundnut, maize, sorghum, cassava, sweet potatoes, and banana. Crop activities in the model are production for sale and production for home consumption, since farm households consume a large part of their own products and sell what remains. Thus, we have assumed in the farm household model that any production above subsistence requirements will be sold.

All crop activities are defined at the level of annual cropping systems except banana and cassava, which are perennial crops. Subsequently, each of the perennial crops is assumed to have equal land area in the two growing seasons.

Table 4 presents a summary of input-output information for the different crop activities for season A and for Oxisols. Input-output information for the other season and the other soil type is provided in Appendix A.

Off-farm activities are important for the household systems in Rwanda. Off-farm activities represent an alternative source of income which must be taken into account when maximizing the farm income. Available off-farm activities concern informal sector work and include activities such as running small businesses, hiring out labour or working as vendor in the market etc. The family labour that can be devoted to off-farm activities depends on the available labour of the head of the household since he is the one who is mostly involved in these activities. However, off-farm opportunities are scarce in these rural areas. In our farm household model, we have assumed that a head of household can devote at most 50% of the available time for labour to off-farm activities. The daily wage received by the head of household for participating in off-farm activities is 400 fr.rw. This is the average daily wage for agricultural and informal non agricultural labour in eastern region (Strode et al., 2007).

Hired labour can be used in addition to farm household labour when cash is available. Hence, hired labour and farm household labour may be regarded as perfect substitutes. The wage of hired labour amounts to 400 fr.rw per man-day (Strode et al., 2007).

Borrowing can be seen as an option to supplement insufficient cash in order to finance seeds, hired labour, school fees, etc. Financial institutions could be important sources of credit facilities. However, in practice farmers find it quite difficult to acquire credit from these institutions due to the lack of collateral. Instead, credit can be obtained from informal sources like “credit club”, the primary source of credit in Umutara. Loans plus interest must be repaid at the end of the cropping season. Interest is paid at the rate of 10% per month depending on the “credit club” to which a farm household has subscribed. Although that credit can be available, it is constrained by a credit limit .

Constraints

Land available for the representatative farm household is based on the average farm size in the eastern region, which is 0.7 ha (Loveridge et al., 2007). Crops may be grown on two soil types Oxisols and Inceptisols.

Labour requirements for crop activities (Table 4) vary depending on crop development stage. Most of the field operations on crops (land preparation, planting/sowing, crop maintenance, hand weeding and harvesting) have to be performed during a particular period of the season. Thus, each season is divided into three periods of two

Table 5. Energy and proteins recommended by World Health Organization (1985).

Age	Energy/day (kcal)		Proteins/day (gr)	
	Male	Female	Male	Female
0-11 months	679.8	628.3	11.9	11
1 to 3 years	1123	1057.3	12.8	12.2
4 to 6	1454.4	1408.5	16.7	16.9
7 to 9	1758	1570	22.7	22.8
10 to 12	1984.4	1805.1	28.6	30
13 to 14	2177.3	1942.6	37.8	38
15 to 16	2435.7	2055.1	46.8	44.1
17 to 18	2657.2	2113.0	51.9	42.2
19 to 29	3324.8	2315.3	44.3	39.6
30 to 60	3285.6	2344.8	44.3	39.6
60+	2287	1886.7	44.3	39.6

months. Small-scale farm households typically use family labour. Composition of the household determines labour capacity. The labour capacity of an adult farm household member is 100%, while children (10-18 years) and adults over 65 years of age are assumed to have 50% working availability. The available farm family labour may be subject to fluctuations over the year.

In fact, for school-going adolescents, labour contributions vary, depending on whether they live at home during school year. Additionally, children also contribute to the farm labour force during their vacations in April, July, November and December. We assume that available labour that can be allocated to activities is equivalent to 5 days per week per adult. However, 1 day per week per adult is substracted since farm households allocate labour to other necessary activities such social and household activities (e.g. firewood and water collection). The total labour requirements for crop production should be met by farm household labour and hired labour.

Rotation restrictions are set for individual crops for agronomic reasons. Crop rotations can be very important for pest and disease control, for maintaining soil fertility and reducing soil erosion. Seasonal crop rotation practices are widely adopted by farmers throughout the country. Crop rotations are incorporated in the model as strict equality constraints and imply that areas of the crops in the rotation are equal. The most frequently adopted rotations for the region are cereals-leguminous (that is, maize and sorghum with beans and groundnut) and tubers-leguminous (that is, sweet potatoes with beans and groundnut).

Cash is required to finance expenses of crop production during each cropping season and is a major constraint for small-scale farm households. These expenses include family expenditures, purchase of seeds and hiring labour. Cash is also needed for family expenditures. Cash is available from farm household's own savings made in the previous harvesting season. Moreover, cash may come from off-farm activities and credit. Credit limits set a limit to the amount of credit to be lent to a farmer. The limit varies from 5,000 Fr. Rw to 50,000 Fr. Rw depending on the wealth of the farmer. In the model, we assumed a credit limit of 10,000 fr.rw (Bidogeza et al., 2009).

Food consumption constraints in the model reflect the need of the household to first secure the household food requirements since the primary objective of small-scale farmers in Rwanda is to provide their families with adequate food . Food purchases have not been considered in model since the food consumption is mainly from the farm's food production. Small-scale farmers can hardly buy food. Consumption constraints are specified to guarantee minimum energy (in kilocalories) and proteins (in grams) per season. The minimum food requirements are obtained from the World Health Organization (WHO) recommendation level of energy and proteins per person (Table 5).

Soil organic carbon (SOC) is one of the key factors that affect agricultural production, nutrient availability and soil stability (Tang et al., 2006), particularly in highly weathered Rwanda soils where organic matter is the major source of nutrients. SOC is a dynamic property of soil, not a static one (Cooperband, 2002). The crop requirements for SOC are derived from Sys et al. (1993). The right hand side of the SOC constraint specifies its tolerance value below which yields begin to decrease (Barbier, 1998). Arshad and Martin (2002) suggested that for SOC a decrease of 15% over the average or the baseline value seems reasonable to use as critical value.The baseline SOC values considered are the organic carbon content of the two soil types for a soil depth of 1m (Ghent University, 2002).

Soil loss above certain limits will lead to the degeneration of soil reserve and soil fertility resulting in the destruction of the usable agricultural land. The farm household model takes soil loss into consideration as a constraint. Soil loss values are required for each crop activity. These values are incorporated into a soil loss constraint for each of two land types, respectively Inceptisols and Oxisols. The Wischmeier's model (Universal Soil Loss Equation) is used to calculate the soil loss coefficients (Wischmeier, 1995). The model predicts gross soil loss per unit of land as:

$$A = R*K*L*S*C*P \tag{15}$$

where A is the estimated soil loss in tons per hectare. R is the rainfall erosivity calculated based on the total kinetic energy of the rainfall and the maximum rainfall intensity over a continuous 30 min period. It represents the potential erosive risks for a particular region. R values have been derived from Equation (16) and are obtained from measurements in a region of Uganda which has close similarities with Umutara (Lufafa et al., 2003).

$$R = 47.5+0.38*Pr \tag{16}$$

In formula (16) Pr is the seasonal precipitation (mm). K is soil erodibility and represents soil resistance. K is a function of texture,

Table 6. Variance/Covariance Matrix of GM with variable prices (VP) and constants prices (CP) for Season A.

Parameter	Sorghum		Maize		Beans		Peanuts		Banana		Sweet potatoes		Cassava	
	VP	CP	VP	CP	VP	CP	VP	CP	VP	CP	VP	CP	VP	CP
Sorghum	$9.6.10^8$	5.10^8	$4.5.10^7$	$2.2.10^8$	$9.8.10^8$	$3.4.10^8$	$2.6.10^8$	$1.01.10^9$	$5.1.10^9$	$1.2.10^9$	$2.9.10^9$	$1.06.10^9$	$2.5.10^9$	$1.9.10^8$
Maize	$4.5.10^7$	$2.2.10^8$	$4.7.10^8$	$3.9.10^8$	$4.1.10^7$	$-1.6.10^7$	$5.6.10^8$	$1.1.10^9$	$6.8.10^8$	$2.5.10^8$	$9.5.10^8$	$1.4.10^9$	$2.1.10^9$	$6.3.10^8$
Beans	$9.8.10^8$	$3.4.10^8$	$4.1.10^7$	$-1.6.10^7$	$1.4.10^9$	$5.6.10^8$	$8.7.10^7$	$2.5.10^8$	$7.4.10^9$	$1.3.10^9$	$3.8.10^9$	$-5.9.10^6$	$1.5.10^9$	$-2.3.10^8$
Peanuts	$2.6.10^8$	$1.01.10^9$	$5.6.10^8$	$1.1.10^9$	$8.7.10^7$	$2.5.10^8$	$4.5.10^9$	$6.4.10^9$	$-4.1.10^9$	$1.8.10^9$	$1.2.10^9$	$5.9.10^9$	$1.6.10^8$	$1.7.10^9$
Banana	$5.1.10^9$	$1.2.10^9$	$6.8.10^8$	$2.5.10^8$	$7.4.10^9$	$1.3.10^9$	$-4.1.10^8$	$1.8.10^9$	4.10^{10}	$5.4.10^9$	2.7.1010	$1.6.10^9$	$2.3.10^{10}$	$2.3.10^8$
Sweet potatoes	$2.9.10^9$	$1.06.10^9$	$9.5.10^8$	$1.4.10^9$	$8.4.10^9$	$-5.9.10^7$	$1.2.10^9$	$5.9.10^9$	$2.7.10^{10}$	$1.6.10^9$	$1.4.10^{10}$	$8.9.10^9$	$2.5.10^{10}$	$2.92.10^9$
Cassava	$2.5.10^9$	$1.9.10^8$	$2.1.10^8$	$6.3.10^8$	$1.5.10^9$	$-2.3.10^8$	$1.6.10^8$	$1.7.10^9$	$2.3.10^{10}$	$2.3.10^8$	$2.5.10^{10}$	$2.9.10^9$	$4.9.10^{10}$	$2.95.10^9$

organic matter, permeability and soil structure. K values for Inceptisols and Oxisols are respectively 0.20 and 0.25 (Roose and Ndayizigiye, 1997; Henao and Baanante, 2006; Fleskens, 2007). L*S represent hillslope length and steepness, and reflects the effect of topography on soil loss rates at a particular site. Values used for Inceptisols with slope of 4% and Oxisols with slope of 9% are respectively 0.42 and 1.3 (Roose, 1994). C is the land use and land cover factor and expresses effects of surface cover and roughness, soil biomass, soil-disturbing activities on rates of soil loss at particular sites. Values used are obtained from Lewis (1988; cited by Fleskens, 2007). Banana has the lowest C-value of 0.04, while sorghum has the highest C-value of 0.45. P is management practice and expresses the effects of supporting conservation practices, such as contouring, buffer strips, terracing, etc. on soil loss at a particular site. When no erosion control practice is used, P equals 1. Planting crops with dispersed trees could be attributed a P value of 0.6, use of grass strips lowers this to 0.4 and grass strips with hedgerows P to 0.1. Thick mulching also has a P of 0.1 (Fleskens, 2007 and Roose, 1994).

The right hand side of the soil loss constraint specifies the soil loss tolerance. The concept of soil loss tolerance is defined as the maximum acceptable soil loss from an area which will allow a high productivity to be maintained for a long period of time. In the model, soil tolerance values used for Oxisols and Inceptisols were derived from Pretorius and Cook (2002), 12 t ha^{-1} yr^{-1} and 16 t ha^{-1} yr^{-1}, respectively. Pretorius and Cook (2002) have assigned soil tolerance values to soils depending on their root penetration depth. The Oxisols have generally steeper slopes and lower soil depth, while Inceptisols are on gentle solpes and deeper soils.

Inclusion of risk in the farm household model

It is important to account for risk in any agricultural productive activity (Hardaker et al., 2004; Anderson and Dillon, 1992). Risk is defined as a measure of the effect of uncertainty on the decision-maker (Upton, 1996). Farm households in Rwanda are facing an unstable income from season to season due to unpredictable rainfall and fluctuations of market prices. Most small farmers typically behave in risk-averse ways, they are willing to forgo some expected income for a reduction in risk (Acs et al., 2009). Ignoring risk-averse behaviour in farm household models may lead to results that are unacceptable to the farmer, or that have little relation to the decisions he actually makes.

From Equation (1) risk is explicitly incorporated in the farm household model. The risk is calculated following a quadratic programming approach (Hazell and Norton, 1986). This method computes the standard deviation from the variance-covariance matrix and the level of the stochastic activities. Since seasonal fluctuations in farm prices and rainfall have a large effect on farmers' income, risk has been calculated for two types of production activities: home consumption and market. To compute risk for home consumption, we use gross margin with constant prices, while gross margin with variable prices is used to compute market risk. Data from six years are used to determine the variance and covariance matrix. This is refered to in Table 6 for Season A. The variance and covariance matrix table for Season B is shown in Appendix B.

Given the difficulty to objectively assign a risk aversion parameter for typical farm, we have assumed that small-scale farm households are somewhat risk averse (Ø = 1.0). This value is derived from Anderson and Dillon (1992) as they grouped relative risk aversion as follow: Ø = 0, risk neutral; Ø = 0.5, hardly risk averse at all; Ø = 1.0, somewhat risk averse (normal); Ø = 2.0, rather risk averse; Ø = 3.0, very risk averse; Ø = 4.0, extremely risk averse.

The risk aversion coefficient of 1 is within the range of values reported by Senkondo (2000), that is, -0.98 and 2.64 with an average value of 0.774 for the situation when the farmer has inadequate food stocks, which is a situation quite similar for the typical farm household in Rwanda.

Set up of the calculations

Calculations are made for a typical farm household on Oxisoils and Inceptisoils for the two growing seasons of a year. Table 7 shows some specific farm characteristics for the representatative farm household considered in the model. The farm household is composed of one adult male, one adult female, two kids under 10 years old and four children are of age 10-18. This family size follows from

Table 7. Characteristics of the typical farm household used as input in the model.

Parameter	Unit	Farm household
Total farm size	ha	0.7
Inceptisols (slope of 4%)	ha	0.28
Oxisols (slope of 9%)	Ha	0.42
Family size	Person	8
Available Labour	man-day	
Season A		
Period 1		104
Period 2		64
Period 3		144
Season B		
Period 1		64
Period 2		104
Period 3		64
Wage off-farm income	fr.rw/day	400
Available cash at the start of the year	fr.rw	5,000
Credit limit per season	fr.rw	10,000
Rate of interest per month	%	10
Family expenditure	fr.rw.	128,000
Energy requirement (Kcal/Household)		
Season A	10^3 kcal	3,067
Season B	10^3 kcal	3,067
Proteins requirement (Grams/Household)		
Season A	10^3 gr	49
Season B	10^3 gr	49

Note: Average exchange rate in 2007: US$1 = 550 Fr.Rw.

the average national rate of birth with six child per woman (Kinzer, 2007). The household is supposed to benefit of the labour from the children while they have vacation. Consequently, the available labour within the household fluctuates within the year as it can be seen from the Table 7. Average yearly expenditures of the typical farm household are estimated on the basis of national value representing the consumption poverty line per adult equivalent per year. That value is estimated at 64,000 Rwandese francs per adult equivalent per year (Ansoms and McKay, 2010). The farm household is assumed to have two adults (the head of household and his wife). The children are added to this adult equivalent. For the cash availability, we assume that the farm houshold has a cash of 5,000 Fw.Fr at the beginning of the year (Bidogeza et al., 2009).

Subsequently, the results from the typical farm household model are compared with actually observed values. Lastly, additional calculations are made with the model to examine the effects of the land area and family size on food security , income and soil loss results. Therefore, the farm household model is optimized with nine different combinations of land area and family size. Three households with a family size of five, eight, and ten persons are combined each, with a land area of 0.5, 0.7 and 1 ha, respectively. The household size of five, eight and ten reflect respectively: the Government's policy on family planning which encourages families to have at most 4 children per woman (Solo, 2008); the current average family size (about 8) and a rather high household size, also often encountered in Rwanda. The land areas embody, respectively the possible future, the actual, and the minimum recommended land size.

RESULTS AND DISCUSSION

Calculations have been made first to determine the optimal farm plan for the typical farm.

Technical results

The optimal cropping plan for the typical farm is presented in Table 8. A large proportion of land is allocated to banana, beans, sweet potatoes and sorghum which reflects the food habits in Umutara province. Banana and sweet potato have higher calories per hectare while beans have the highest level of proteins per hectare. Banana covers a much larger proportion (47%) of the land in the optimal farm plan than other crops because of its high calories per hectare. In addition, banana protects well the soil since it causes less soil loss. Sweet potato also has high yield of calories per hectare but, because of the high soil loss rate compared

Table 8. Optimal cropping plan for season A and B.

	Area (ha)			
	Season A		Season B	
Land type	**Inceptisols**	**Oxisols**	**Inceptisols**	**Oxisols**
Crops for home consumption				
Banana	0.067	0.209	0.067	0.209
Beans	0.035	0.161	0.056	0
Cassava	0	0	0	0
Groundnut	0.015	0	0.006	0
Maize	0	0	0	0
Sorghum	0.134	0	0.004	0
Sweet potatoes	0.019	0.032	0.125	0.082
Crops for sale				
Banana	0.010	0.018	0.010	0.018
Sweet potatoes	0.0006	0	0	0
Unused land	0	0	0	0.112
Total	0.28	0.42	0.28	0.42

to banana, a smaller land area is allocated to sweet potato than banana. Beans are produced to a relatively large extent (20%) because of its highest level of proteins. A small proportion of the available land is allocated to sorghum and groundnut to supply additional calories and proteins and secure the nutritional requirements of the farm household.

From the model results, both nutritional requirements and soil loss are binding constraints. However, soil loss is restricting only on marginal land (Oxisols). Banana and beans cause less erosion compared to other crops. This explains why they are grown mostly on marginal land (70%).

Cassava is not considered in the optimal farm production although it has the highest yield of calories per hectare. The model considers that an optimal plan including cassava is too risky since it has a higher variability of production and prices compared to other crops.

Technical results for fixed resources, specifically land, on-farm labour and off-farm labour are shown in Table 9. The area under Inceptisols is fully used in both seasons, whereas the model leaves 0.112 ha of the area under Oxisols unexploited in season B. This is because of constraining soil loss and SOC. A total of 172 man-days and 106 of man-days remain available, for in seasons A and B, respectively. In both seasons, labour allocated to the off-farm activity is at its maximum level.

In our farm household model we have differentiated the crop production for home consumption from crop production for sale. The model results reveal that 88% of the land is allocated to crop production for home consumption, while 8% remains unused and 4% of land is used for crop production for sale. A large proportion of land for home consumption is needed to secure the World Health Organisation’s (WHO) nutritional requirements, that is, to maintain the food security status. The model results identify soil loss and risk as the major explanations why some land remains idle while a small portion of land is allocated to crop production for sale. At relatively low extent, SOC has some influence on the optimal farm production.

From the model results, crops which contribute mostly to secure calories for the representatative farm household throughout the year are banana and sweet potatoes providing respectively 48% and 26% of total energy, respectively. Beans is the major supplier of proteins with 48% of total proteins required.

Economic results

The farm income can come from off-farm activities and crop production for sale. Although there is sale of crops, revenues from crop production for sale are small since the model has allocated major portion of land to crop production for home consumption. Therefore, the major contributor of farm income is from off-farm activities with 55%, while sale of crops production contributes 45%. Net farm income equals to 18,680 fr.rw, yearly. Net farm income is the cash income after substrating the cash expenditures. Banana is almost the only cash crop, because of its high gross margin per hectare. The model has shown that risk and soil loss are playing a role to maintain this subsistence trait. The restricting food requirements explain why the typical farm in our model is

Table 9. Optimal seasonal resource use and constraint and their shadow prices or slack values activities.

Parameter	Unit	Season A			Season B		
		Level of activity	Shadow price (fr.rw/ha)	Slack value	Level of activity	Shadow price (fr.rw/ha.)	Slack value
Land type	**Ha**						
Inceptisols (slope: 4%)		0.28	63,845	0	0.28	42,515	0
Oxisols (9%)		0.42	16,354	0	0.308	0	0.112
Soil loss*	t ha^{-1}						
Inceptisols (slope: 4%)		4.48	0	2.2			
Oxisols (9%)		5.04	1,785				
SOC*	kg ha^{-1}						
Inceptisols (slope: 4%)		1,960	0	726			
Oxisols (9%)		2,286	163	0			
On-farm labour Use in:	man-day						
Period 1		26	0	58	26	0	18
Period 2		25	0	19	17	0	66
Period 3		29	0	95	22	0	22
Off-farm labour use for the head of household	man-day						
Period 1		20	400	0	20	400	0
Period 2		20	400	0	20	400	0
Period 3		20	400	0	20	400	0
Credit	fr.rw	10,000	0	10,000	10, 000	0	10,000
Nutrition requirements							
Calories	10^3 kcal	3067	-12.81	0	3067	-12.80	0
Proteins	10^3g	81	0	32	55	0	6

*Values of soil loss and SOC are for a year. Note: Average exchange rate in 2007: US$1 = 550 Fr.Rw.

willing to forego some land or prefers to grow subsistence crops in order to avoid risk.

The farm household model reports the shadow prices for the fixed resources and constraints that are fully used. A shadow price indicates the maximum amount by which the model's objective function could be increased if an additional unit of the resource were to become available (Hazell and Norton, 1986). For example, in case of the land constraint expressed in ha, a shadow price of 1.5 indicates that the value for the objective function would increase by 1.5 if the availability of land would increase by one 1 ha. Table 9 presents shadow prices of some of the fixed resources and constraints. Off-farm activities are extremely important for the typical farm. One man day labour allocated to off-farm activities would increase farm income with 400 fr.rw. Scarcity of employment opportunities refrain farm households from hiring out labour. In the case of land: the maximum rent a farmer should be willing to pay for one additional hectare of land type Inceptisols would be 63,845 fr.rw and 42,515 fr.rw, respectively in season A and B. Land with Oxisols is only fully used in season A with a shadow price of 16,354 fr.rw.

The farm household model calculates the shadow prices for levels of soil loss for the two types of soil. In the case of soil loss, shadow prices represent the amount by which the objective function would change if the constraint on soil loss were increased by one unit. They represent the maximum allowable cost of erosion reductions (Carcamo et al, 1994). Thus, allowing 1 t ha^{-1} more soil loss can increase farm income with 1,785 fr.rw for Oxisols. The shadow price of soil loss for Inceptisols is zero. Likewise for SOC the shadow price for the Inceptisols is zero, while for Oxisols, it is restricting. This implies that soil loss on Inceptisols and SOC do not entail negative economic consequences. However, in the long run, an acceptable solution from both economic and environmental perspective should be found, i.e. less erosive solution which generates at the same time an acceptable level of profitability.

Comparison of the household model results with observed household data

The model results are compared with information from literature and farm surveys. With regards to crop allocation the farm model results indicate that banana occupy a large proportion of the land (43%), followed by beans (20%), sweet potatoes (20%) and sorghum (10%). These results are relatively consistent with the information from the farm survey done in the region , which affirms that the most cultivated crops are beans (95% of the farmers), banana (85%), maize (75%), sweet potatoes (72%), sorghum (70%) and cassava (60%) (Minagri and INSR, 2006).

Banana and sweet potatoes are known to have less calories and proteins per kg compared to other crops, but are favoured in the model and in the real farming since they have high calories per hectare. Additionally, the two crops tend to produce even when other crops fail completely; they also produce during the nutritionally critical pre harvest period such April-May and November-December (Kangasniemi, 1999). Moreover, banana is causing less soil loss.

Despite its high energy yield per hectare, the model hasn't selected cassava due to its high production and price variance. The cassava production is varying over years because of the recurrent virus of African mosaic which quite often damages the crop (Mukakamanzi, 2004).

The model indicates that a major proportion of crop production is self-consumed to secure nutritional requirements of the typical farm household, a small proportion is sold. The food security status is maintained at the expense of getting cash from the crops. This fact is widely observed in Rwanda where farming is mostly subsistence oriented.

However, the model has attributed a small portion of banana production for sale. This is consistent with the findings from Kangasniemi (1999) and Okech et al. (2001), expressing that in regions where traditional cash crops are missing (coffee and tea), bananas are by far the most remunerative cash crop for Rwandan farmers.

The farm model reveals that the shadow prices of the good land (Inceptisols) are very high compared to the cost of renting one hectare of land per year in southern and eastern regions of Rwanda, which is 22,600 fr.rw. as reported by Takeuchi and Marara (2007). However, these shadow prices are more close to the cost of renting one hectare of land per year in the northern region of Rwanda, which is 50,000 fr.rw as reported by Fané et al. (2004). The shadow prices of marginal land are small or zero. Therefore, the model has left out a portion of marginal land where we would expect the farm to fully exploit his farm due to its small size. The cultivation of marginal land causes much more soil loss than cultivation on the good soils, which may explain why the model abandons some of the marginal land because of much soil loss, which may prevent their profitability. Barbier and Bergeron in Honduras (1999) also found that farmers were likely to crop less on erodible fields. Furthermore, we have observed from the farm survey (Minagri and INSR, 2006) that despite of the small size of the farms, 25% of the farmers prefer to put some land on fallow to enrich the soil or because they don't see any profitability to farm the whole farm once not all land is needed for their subsistence.

With regard to labour, the model shows that there is much on-farm labour available since the shadow price is zero, while off-farm activities are used to the maximum. This corresponds with the current situation in Rwanda where off-farm employment is already an important source of income for rural households (Loveridge et al., 2007). However, this option is limited by low availability of off-farm activities. Therefore, availability of off-farm employment would improve the income of farm households.

The results from the bio-economic model of the typical farm provide a valid and acceptable approximation of the reality. Hence, we use the model to test for different policy simulations for the typical farm and also for other farm types.

Effects of household size and land area changes on food security, income and soil loss results

Table 10 indicates the effects of household and land size on food security, income and soil loss results. According to the model, for the majority of farm households, it is possible to meet the WHO nutritional requirements. However, households with 8 members and a farm size of 0.5 ha and household of 10 members with farm size of 0.5 ha and 0.7 ha are not able to secure the WHO energy requirements. Therefore, calorie requirements were lowered (Table 10) until a feasible solution was reached. However, from Table 10 it can be seen that a household with 5 members and a farm size of either 0.5, 0.7 or 1 ha can obtain a high income and that soil loss has relatively little economic impact. This is in accordance with the family planning policy of Rwanda Government which promotes a fertility rate less than 4 children per woman. Indeed, for a household of 5 members even with the lowest farm size (0.5 ha) considered, it is possible to secure the WHO' s recommended level of calories and proteins, and additionnally get a relatively high income. Table 10 highlights the fact that with more people having less land food security cannot be achieved and soil loss has a high economic impact at least for the marginal land with Oxisols. This finding seems to contradict the conclusion made by Tiffen et al. (1994). In their study conducted, in Machakos region in Kenya, they asserted that population growth has a positive impact on the

Table 10. Effects of household size and land area changes on food security, income and soil loss results.

Parameter	Land area (Ha)	Food requirements met		Income in Rwandese francs	Soil loss Shadow prices in Rwandese francs	
Household size (members)		Energy (%)	Proteins (%)		Inceptisols	Oxisols
	0.5	100	100	33,891	0	1,964
5	0.7	100	100	40,295	0	603
	1	100	100	41,545	0	0
	0.5	78	81	17,118	0	3,703
8	0.7	100	100	18,680	0	1,785
	1	100	100	32,095	0	1,052
	0.5	62	63	17,118	0	3,703
10	0.7	87	92	4,728	0	3,988
	1	100	100	17,855	0	2,062

economic development. Contrary to the findings of Tiffen et al. (1994): rather than saying "More people, less erosion", our findings indicate that fewer people leads to little economic impact of soil erosion and enough food for each household. However, these differences have to be distinguished by keeping in mind that the farm household model is a yearly based model and under low farming inputs while Tiffen et al. (1994) examined interactions of people and environment over a period of sixty years in association with intensive farming systems.

GENERAL DISCUSSION

In this article, a bio-economic farm model has been presented that can be applied for a typical farm household and be used to simulate the impact of family size, farm size, and soil erosion on farm production and food security. The bio-economic farm household model was developed by using a mathematical modelling approach. Here, some of the important underlying assumptions are discussed.

Capturing subsistence farming in the model

In this paper, the authors did not consider the option of purchasing food. Considering the option of purchasing food for the current typical farm with very low inputs and a farming fully focussed on subsistence would not represent the reality of livelihoods of farmers in the east region of Rwanda. However, this option may be appropriate for the livestock farms (they are large farms of more than 3 ha) who are also found in the region, but are less important in terms of total population in the province. Castaño (2001) and Laborte et al. (2009) have considered the option of purchasing food in their respective farm household models in the contexts of semi-subsistence and subsistence farming. Livestock activities, however, have been considered in their models. These activities are missing for the typical farm household considered in our model. It is known that livestock activities may constitute another source of income and a form of savings, which may then allow farmers to purchase food when necessary.

Subsistence farmers used the food produced from their own farms to feed their families. However, during the period of starvation, subsistence farmers may consider the option of purchasing food. In this article, the year considered in the model is assumed to be 'normal' where farmers do not have to face starvation due to droughts or inundation. Moreover, although that we did not program the option of purchasing food in our model, which would give more flexibility to household, we have dealt this in a flexible way in the sense that we relaxed the food constraints at the moment when the model was not able to produce enough food (Table 10).

Risks consideration in the model

In this article, the authors have used the method of standard deviation of the gross margin to compute risk instead of a safety-first approach, including Target-MOTAD. The model somehow makes already use of the safety-first approach principle in the sense that food requirements are explicitly formulated as constraints.3.5.

Maximizing the objective function in the model

In this paper, we have assumed that the farmer is pursuing one objective that is to maximize the expected utility. Thus, the expected utility is the objective function and this is maximized. Subsistence farming characterizes most of the agricultural production of rural developing countries. Mishev et al. (2002) have stated that subsistence farmers are prone to maximize utility functions. Castaño (2001) and Laborte et al. (2009) have conducted empirical studies wherein the objective function was to maximize utility defined as discretionary income, in Andean hillside farms of Columbia and northern Philippines, respectively. Discretionary income is defined as income available for spending after essential expenses have been made. The farmer is assumed to maximise one objective function, which is the expected utility defined as discretionary income minus the risk premium. However, subsistence farmers may, also pursuit several objectives as Berkhout et al. (2010) have shown that there is heterogeneity in the farmer goals and preferences, in relation to the role of farm enterprise. Therefore, not considering all objectives of the farmer in the modelling approach, may lead to the results that differ from the reality. Given that the different approaches to capture the objective (s) of the farmer have their own limitations, the results should be analysed with respect to the particular farming system (Van Calker, 2004).

Conclusions

In this paper, a bio-economic model was developed to analyse the impacts of family planning, land consolidation and soil erosion on farm production and food security on a typical farm in Rwanda and on other farm types.

The results of the model show that a higher availability of good land increases farm income, whereas a higher availability of marginal land has slight impact on income. Considering that soil erosion is a restricting factor on marginal land, preserving soils against erosion would release more marginal land and increase food production. Farm household income would also benefit from better off-farm employment opportunities.

Household size and land area changes have a large impact on food security, income and soil loss. Our model results suggest that most farm households can satisfy the WHO minimum nutritional requirements. However, with more people and less land, it is difficult to fulfill the WHO's energy and proteins requirements. Households with a large family size and small land area cannot ensure their food security. The model results show that a household with 8 members and a farm size of 0.5 ha and a household of 10 members with farm size of 0.5 ha and 0.7 ha are not able to secure the WHO energy requirements. Also, results show that soil loss has in those situations a relatively high economic impact. However, households with the lowest person: land ratio easily secure their food security and soil loss has relatively little economic impact for those households.

The outcome of the model supports the Rwanda policy on family planning which intends to encourage every woman to have a human reproduction rate below 4. However, the land policy to encourage farmers with a total land area below 1 ha either to consolidate their land or to quit farming is not supported by the results. Our results show that a household of 5 members with a farm size of at least 0.5 ha is able to comply with the minimum food security requirements and to get a relatively high income; additionnally, the soil loss has little economic impact. In the context of Rwanda with a rapidly growing population, a minimum area of 0.5 ha instead of 1 ha should be considered (for the time being).

Moreover, policy makers should target adoption of technologies that reduce land degradation and risks to further improve food security.

Conflict of Interest

The authors have not declared any conflict of interest.

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Appendix A

Table A1. Input-output information on crops for Oxisols in Season B.

Season		B	B	B	B	B	B&A	A&B
Crop activities	**Unit**	**Beans**	**Groundnuts**	**Maize**	**Sorghum**	**Sweet potatoes**	**Cassava**	**Banana**
Inputs-output								
Yield	kg ha^{-1}	690	450	940	1,050	6,300	6,000	15,000
Price	fr.rw kg^{-1}	167	538	127	118	93	177	83 (98)[a]
Revenues	fr.rw ha^{-1}	115,230	242,100	119,380	123,900	585,900	1,062,000	1,357,500*
Cost of seed/establishment cost	fr.rw ha^{-1}	10,000	30,000	2500	900	30,000	50,000	93,200*
Gross margin	fr.rw ha^{-1}	105,230	212,100	116,880	123,000	555,900	1,012,000	1,264,300
Labour	man-day ha^{-1}	104	98	116	108	94	129	264
Total energy	10^3kcal ha^{-1}	2,297	2,551	3,073	3,664	5,720	6,378	5,190[b]
Total protein	g ha^{-1}	162,840	116,100	71,440	112,350	86,310	48,000	56,250[b]
Soil loss	t ha^{-1}	14.4	30.4	26.6	30.4	17.5	19.7[b]	3[b]
Soil organic carbon	t ha^{-1}	3020	1887	3020	1887	3775	1887[b]	3020[b]

[a] Price per Kg of banana, respectively in season A and B. [b]These values are concerning Season B. *The costs and revenues during establishment of Banana (multiyear crop) are based on annuities.

Table A2. Input-output information on crops for Inceptisols in Season A.

Season		A	A	A	A	A	A&B	A&B
Crop activities	**Unit**	**Beans**	**Groundnuts**	**Maize**	**Sorghum**	**Sweet potatoes**	**Cassava**	**Banana**
Inputs-output								
Yield	kg ha^{-1}	1,000	760	1,490	1,580	7,300	7,000	17,000
Price	fr.rw kg^{-1}	141	419	100	106	90	177	83 (98)[a]
Revenues	fr.rw ha^{-1}	141,000	318,440	149,000	167,480	657,000	1,239,000	1,538,000
Cost of seed/ establishment cost	fr.rw ha^{-1}	8,500	18,000	2,000	800	30,000	50,000	93,200*
Gross margin	fr.rw ha^{-1}	132,500	300,440	147,000	166,680	627,000	1,189,000	1,445,300
Labour	man-day ha^{-1}	95	91	110	106	85	91	264
Total energy	10^3kcal ha^{-1}	3,330	4,309	4,872	5,514	6,628	7,440	5,882[b]
Total protein	g ha^{-1}	236,000	196,080	113,240	169,060	100,010	56,000	63,750[b]
Soil loss	t ha^{-1}	3.1	1450	5.6	6.4	3.7	4.2[b]	0.7[b]
Soil organic carbon	t ha^{-1}	2320	1450	2320	1450	2900	1450[b]	2320[b]

[a] Price per Kg of banana, respectively in Season A and B. [b] These values are concerning Season A. *The costs and revenues of Banana (multiyear crop) are based on annuities.

Table A3. Input-output information on crops for Inceptisols in Season B.

Season		B	B	B	B	B	B&A	B&A
Crop activities	**Unit**	**Beans**	**Groundnuts**	**Maize**	**Sorghum**	**Sweet potatoes**	**Cassava**	**Banana**
Inputs-output								
Yield	kg ha^{-1}	1,050	700	1,410	1,580	7,300	7,000	17,000
Price	fr.rw kg^{-1}	167	538	127	118	93	177	83 (98)[a]
Revenues	fr.rw ha^{-1}	175,350	376,600	179,070	186,440	678,900	1,239,000	1,538,000
Cost of seed/ establishment cost	fr.rw ha^{-1}	10,000	30,000	2500	900	30,000	50,000	93,200*
Gross margin	fr.rw ha^{-1}	165,350	346,600	176,570	185,540	648,900	1,189,000	1,445,300
Labour	man-day ha^{-1}	95	91	110	106	85	91	264
Total energy	10^3kcal ha^{-1}	3,496	3,969	4,610	5,514	6,628	7,440	5,882
Total protein	g ha^{-1}	247,800	180,600	107,160	169,060	100,010	56,000	63,750[b]
Soil loss	t ha^{-1}	3.7	7.8	6.8	7.8	4.5	5.11[b]	0.8[b]
Soil organic carbon	t ha^{-1}	2320	1450	2320	1450	2900	1450[b]	2320[b]

[a] Price per Kg of banana, respectively in season A and B. [b] These values are concerning season B. *The costs and revenues of Banana (multiyear crop) are based on annuities

Appendix B

Table B1. Variance/Covariance Matrix of GM with variable prices (VP) and constants prices (CP) for Season B.

Parameter	Sorghum		Maize		Beans		Peanuts		Banana		Sweet potatoes		Cassava	
	VP	CP	VP	CP	VP	CP	VP	CP	VP	CP	VP	CP	VP	CP
Sorghum	$1.7.10^9$	$2.2.10^8$	$9.6.10^8$	-3.2.107	$1.6.10^9$	-3.9.106	$2.1.10^9$	$6.6.10^8$	$1.1.10^{10}$	$3.2.10^8$	$4.5.10^9$	-2.10^8	$1.7.10^{10}$	$5.3.10^8$
Maize	$9.6.10^8$	$-3.2.10^7$	$2.5.10^9$	$6.6.10^8$	$4.3.10^8$	$-1.8.10^8$	$1.5.10^9$	$-3.4.10^8$	$4.5.10^9$	$-3.4.10^8$	$2.2.10^9$	$-5.7.10^8$	$1.1.10^{10}$	7.3.107
Beans	$1.6.10^9$	$-3.9.10^6$	$4.3.10^8$	$-1.8.10^8$	3.10^9	$4.7.10^8$	$2.3.10^9$	$1.8.10^7$	$1.5.10^{10}$	2.6.108	$6.8.10^9$	-1.10^8	$2.5.10^{10}$	$2.2.10^9$
Peanuts	$2.1.10^9$	$6.6.10^8$	$1.5.10^9$	$-3.4.10^8$	$2.3.10^9$	$1.8.10^7$	$4.7.10^9$	$3.1.10^9$	$1.4.10^{10}$	$1.2.10^9$	$7.4.10^9$	-6.10^7	$2.6.10^{10}$	$1.9.10^9$
Banana	$1.1.10^{10}$	$3.2.10^8$	$4.5.10^9$	$-3.4.10^8$	$1.5.10^{10}$	$2.6.10^8$	$1.4.10^{10}$	$1.2.10^9$	$1.4.10^{11}$	$1.4.10^9$	$5.1.10^{10}$	$-4.9.10^8$	$1.4.10^{11}$	$1.6.10^9$
Sweet P.	$4.5.10^9$	-2.10^8	$2.2.10^9$	$-5.7.10^8$	$6.8.10^9$	-1.10^8	$7.4.10^9$	-6.10^7	$5.1.10^{10}$	$-4.9.10^8$	3.10^{10}	$2.9.10^9$	$6.9.10^{10}$	$-1.3.10^9$
Cassava	$1.7.10^{10}$	$5.3.10^8$	$1.1.10^{10}$	$7.3.10^7$	$2.5.10^{10}$	$2.2.10^9$	$2.6.10^{10}$	$1.9.10^9$	$1.4.10^{11}$	1.6.109	$6.9.10^{10}$	$-1.3.10^9$	$3.5.10^{11}$	$2.3.10^{10}$

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Metal silo grain storage technology and household food security in Kenya

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A treatment effect and ordered logit models were used to evaluate the impact of metal silo storage technology on household food security and factors influencing adoption of metal silo. Farmers' perception of the effectiveness of metal silo against larger grain borer and maize weevil was also analyzed. The most important factor households considered when choosing a storage facility was effectiveness against storage pests followed by security of the stored grain and durability of the storage facility. Metal silo adopters had 1.8 months more of adequate food provisioning than non-adopters. Compared to non-adopting households, metal silo adopters only sold a little portion of their maize initially to meet immediate cash needs and kept the bulk of it until the fifth month after harvest. Consumption was stable throughout the year for the metal silo adopters. Non-adopters sold most of their maize immediately after harvest and consumption was higher than sales. Household size, literacy of the household head and land size increased the likelihood of adopting the metal silo technology. Households with access to financial services (bank account and/or mobile money) were more likely to adopt metal silo. Distance to the nearest passable road reduced odds of adopting metal silo technology. The use of metal silos prevented damage by larger grain borer (LGB) and maize weevil for 98% and 94% of adopters, respectively. This study finds evidence that metal silo technology is effective against main maize storage pests and its adoption can significantly improve food security in rural households.

Key words: Food security, grain storage, metal silo, storage pest.

INTRODUCTION

Two-thirds of the people in eastern and southern Africa (ESA) live in rural areas where they make a living from agriculture, often from degraded and marginal lands, with little opportunity to diversify incomes through additional employment in non-farming activities. Addressing rural poverty and food insecurity is therefore central to any efforts to improve human well-being and livelihoods in the region (http://www.undp.org/mdg/, accessed 30 April, 2011). Cereal grains form a major part of crop production in Africa. One of the key constraints to improving food and nutritional security in Africa, however, is the poor post-harvest management that leads to 20-30% loss of

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Figure 1. Metal silos.

grains, with an estimated monetary value of more than US$ 2 billion annually and can reach US$ 4billion (Zorya et al., 2011). Post-harvest losses remove part of the supply from the market contributing to food price spikes as was experienced between 2008 and 2011 by (Rosegrant et al., 2015). Postharvest losses also cause resource wastage because natural resources, human and physical capital are committed to produce, process, handle and transport food that no one consumes.

Apart from causing grain weight losses, incidence of pest attack of the stored grains is also linked to mycotoxin contamination and poisoning. In 2004, for example, one of the largest aflatoxicosis outbreaks occurred in rural Kenya, resulting in 317 cases and 125 deaths (Lewis et al., 2005). The main economically important storage insect pests are maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae), the larger grain borer (LGB) *Prostephanus truncatus* Horn (Coleoptera: Bostrichidae), angoumois grain moth *Sitotroga cereallela*, Oliv. (Lepidoptera: Gelechiidae) and the lesser grain weevil *Sitophilus oryzae* Linne (Coleoptera: Curculionidae) (Markham et al., 1994).

Traditional storage practices in Africa countries cannot guarantee protection against major storage pests of staple food crops like maize (FAO, 2008; Gitonga et al., 2013). The lack of suitable storage structures for grain storage and absence of storage management technologies often force the smallholders to sell their produce immediately after harvest. Consequently, farmers receive low market prices for any surplus grain they may produce to avoid post-harvest losses from storage pests and pathogens (Kimenju et al., 2009; Tefera et al., 2011). Farmers also cannot use their harvest as collateral to access credit, (Semple et al., 1988; Tefera et al., 2011). It is therefore, crucial that appropriate, affordable storage technologies are readily available to farmers for them to safely store and maintain quality of their produce (Thamaga-Chitja et al., 2004). Safe storage of maize at the farm level is crucial, as it directly impacts on poverty alleviation, food and income security of the smallholder farmers.

Application of chemical insecticides has been recommended in order to protect against insect-pest and pathogen attack during storage (Dales and Golob, 1997). However, insecticides are frequently unavailable or too expensive for subsistence farmers in developing countries. As an alternative strategy to reduce postharvest maize grain losses in Africa, the International Maize and Wheat Improvement Center (CIMMYT) implemented an SDC funded project titled "Effective Grain Storage for Sustainable Livelihood of African Farmers,". The project successfully introduced the development and fabrication of metal silo technology in Kenya and Malawi (CIMMYT, 2011). A metal silo is a cylindrical structure, constructed from a galvanized iron sheet and hermetically sealed (Figure 1). The metal silo technology has proven to be effective in protecting the harvested grains from attack not only from the storage insects but also from rodent pests (Tefera et al., 2011). The objectives of this paper were to assess the effectiveness of the metal silo storage technology against the main maize storage pests, impact of the metal silo on the length of storage of surplus, consumption and sale of maize.

METHODS

Econometric analysis

The study used the proportional-odds (Ordered logit) model to estimate the likelihood of a household going without food for a whole day or sleeping hungry. The dependent variables were two food security indicators assessing whether any member of the household went to sleep hungry or went a whole day without food. The responses were recorded and coded as follows:

0 = never; 1 = rarely (1-2 times); 2 = sometimes; 3 = often (>10times).

The odds ratio of being food insecure is assumed to be constant for all categories.

$$\text{logit } (p_1) \equiv \log \frac{p_1}{1 - p_1} = \alpha_1 + \beta' X$$

$$\text{logit } (p_1 + p_2) \equiv \log \frac{p_1 + p_2}{1 - p_1 - p_2} = \alpha_2 + \beta' X$$

$$\text{logit } (p_1 + p_2 + ... + p_k) \equiv \log \frac{p_1 + p_2 + ... + p_k}{1 - p_1 - p_2 - ... - p_k} = \alpha_k + \beta' X$$

Where $P_1 + P_2 + … + P_k = 1$; β is a vector of coefficients and X is a vector of explanatory variables.

Ordered logit model simultaneously estimates multiple equations depending on the number of categories. The number of equations is equal to the number of categories minus one, which are three equations in this current study. The key assumption in ordered logit is the parallel regression, meaning that there is only one set of coefficients for each independent variable. This implies that the coefficients for the variables in the equations estimated simultaneously would not vary significantly if they were estimated separately except that the intercepts would vary. The error term is assumed to be normal with zero mean and unit variance (Greene, 2002).

Sampling and data collection

Sampling was conducted in two phases with the first phase targeting households that did not own metal silo (control group) and the second phase households that adopted metal silo for grain storage. Same questionnaire was used to interview the two groups. A baseline survey preceded the metal silo adopters' survey to allow for the comparison of the two groups. A list of sub-locations (Census, 2009) was obtained from Kenya National Bureau of Statistics (KNBS) and grouped into six maize production agro-ecological zones (AEZ). These are dry transitional (DT), dry mid altitude (DMA), moist mid altitude (MM), high tropics (HT) moist transitional (MT) and low tropics (LT). Proportionate to size random sampling was then used to select 120 sub-locations across the six (AEZ) based on the number of households in each zone. Chiefs and assistant chiefs provided a list of all households in each sub-location from which 12 households were randomly selected and interviewed per sub-location, resulting in a sample size of 1344. The household survey of the metal silo storage technology was conducted in 18 districts, distributed in three agro-ecological zones namely moist transitional, moist mid transitional and dry mid altitude.

The survey targeted all the farmers who had acquired metal silos either through the project implementation partners or through the artisans in Nyanza and Eastern provinces. A sampling list of 94 households distributed in 12 districts was obtained for the Nyanza region from which 73 households were interviewed. A list containing 51 metal silo owners distributed in 6 districts was obtained from Embu and all were interviewed. This resulted in treatment group of 124 households which was compared with the randomly selected control group.

Data collection was preceded by recruiting and training 18 enumerators and three supervisors from diverse cultural backgrounds. After the training the questionnaire was pretested and revised for primary data collection. Three teams were formed, each comprising of a supervisor, six enumerators and a driver. Enumerators were provided with laminated slides clearly showing various storage facilities and main grain storage insect pests as visual aids during the interview. Data was collected between October 2010 and March 2011.

Data cleaning was done in SPSS and analysis using stata software. The mean difference on key demographic and social economic variables between the two groups was tested using a student t-test. The dependent variables were two proxies of severe food insecurity (Going the whole day without food or sleeping hungry) were regressed against demographic and social economics factors. A two stage regression was fitted to compare the effect of metal silo use on months of adequate household food provisioning (MAHFP) between the two groups while checking for possible self-selection bias. The likelihood ratio test for the independence of the primary and selection equations indicated no evidence of self selection in adoption of metal silo technology by the adopters. MAHFP is measured by asking the respondents the number of months they did not have enough food to feed their families and using that information in computing the months of adequate food provisioning.

RESULTS

Household characteristics for adopters and non-adopters of metal silo

Both adopters and non-adopters of metal silo technology were dominated by male headed households (Table 1). The average age of the household head was about 53 years for both groups. Males aged between 15-64 years constituted 52 and 54% of the primary decision maker in maize farming for the non-adopters and adopters, respectively. The proportion of aged male decision makers is significantly higher for the adopters (15%) than for non-adopters (7%). The average household size was seven and six persons for adopters and non-adopters, respectively. Meta silo adopters had 25 years of farming experience compared to 28 years for non-adopters. Adopters also on average had 10 years of formal schooling and 95% were literate compared to 7 years and 83% literacy for non-adopters. More metal silo adopter households (78%) had savings account in a commercial bank than non-adopters (47%). Mobile banking was more popular with 97% of adopter households owning a virtue M-PESA account compared to 74% for non-adopters. Metal silo adopters were more food secure than non-adopters. Households that adopted metal silo were significantly closer to the passable road (1.5 km) than non-adopters who on average were 3.1 km away from the road. Adopters were more endowed in land and cultivate an average of 8 acres annually compared to 5 acres cultivated by non-adopters. Metal silo adopters on average lost 3 kg of grain per season to storage pest while non-adopters lost 75 kg. The amount of grain lost to pest by metal silo adopters was from grain kept aside in bags for consumption to avoid frequently opening the silo.

Maize storage technologies used by households

Most non-adopters (60%) used a space in the house and improved granaries (17%) to store their maize (Table 2). Some households stored their maize in the kitchen over smoke. Most metal silo adopters (78%) used metal silo for maize storage. However, they also kept aside some maize in the bag inside the house for regular consumption to avoid opening the silo more frequently. Traditional granaries were less popular probably because they are not secure and prone to attack by storage pests. Security was one of the most important factors farmers considered when choosing a storage facility.

Factors farmers consider before choosing maize storage technology

When choosing grain storage technologies, farmers

Table 1. Household social economic characteristics.

Variable	Mean		t-test for Equality of Means		
	Non-adopters	Adopters	Difference	t	p>t
Demographic characteristics					
Gender of the household head (%)	81.00	86.00	5.00	-1.426	0.156
Age of the household head (years)	53.41	53.30	1.16E-01	0.102	0.919
Household size	6.02	6.95	-9.21E-01	-3.392	0.001
15-64 yrs male primary decision maker	0.52	0.54	-2.38E-02	-0.514	0.608
15-64 yrs female primary decision maker	0.35	0.29	6.14E-02	1.453	0.148
>64 yrs male primary decision maker	0.07	0.15	-7.46E-02	-2.307	0.023
>64 yrs female primary decision maker	0.06	0.02	3.62E-02	2.430	0.016
Literacy level of the household head	0.83	0.95	-1.23E-01	-5.742	0.000
years of schooling of the household head	7.07	10.27	-3.20E+00	-7.988	0.000
Household's years of farming experience	27.72	24.56	3.15E+00	2.400	0.018
Social economic characteristics					
Total annual income? (000'KES)	186.42	386.11	-2.00E+05	-3.811	0.000
Acres of land owned by the household	4.42	9.11	-4.69E+00	-2.712	0.008
Total land cultivated in the year	4.65	8.23	-3.57E+00	-4.868	0.000
Bags of shelled maize	9.11	12.09	-2.99E+00	-1.779	0.077
Months of food insecurity in one year	2.27	0.93	1.34E+00	7.600	0.000
Savings/bank account	0.47	0.78	-3.15E-01	-8.054	0.000
M-Pesa account (virtual banking account)	0.74	0.97	-2.33E-01	-11.886	0.000
Distance to the nearest passable road (KM)	3.12	1.52	1.59E+00	4.048	0.000
Social event	0.24	0.30	-5.52E-02	-1.183	0.239
Loss due to storage pests (kg)	74.92	3.42	7.15E+01	10.224	0.000

Table 2. Storage facilities used by rural households.

Storage structure	Non-adopters (N=1344)	Adopters (n=124)
	Percent	Percent
Metal Silo	0.3	78.2
Basket (Adita)	4.5	2.4
Large pot	1.1	0.0
Separate structure used for maize storage	9.4	15.3
space in house used for maize storage	59.7	48.4
Traditional crib (round bottom)	5.5	7.3
Traditional granary (cylindrical shape)	7.4	3.2
Traditional storage over fire in kitchen	6.3	2.4
Improved granary (wicker wall)	3.2	8.1
Improved granary (wooden wall)	13.5	4.0
Other structure	0.7	10.5
plastic containers	0.1	0.0

considered effectiveness against insect pest as very important criteria, followed effectiveness against rodent, security of the stored grain and the lifespan or durability of the technology (Figure 2). Many farmers did not consider cost of acquiring and maintaining the technology important. This is because if the technology met the conditions farmers considered important to them, they would likely recoup their investments in the technology over time through better prices emanating from delayed sale.

Maize stored in metal silos was effectively protected from LGB in 98% and from maize weevil in 92% of the

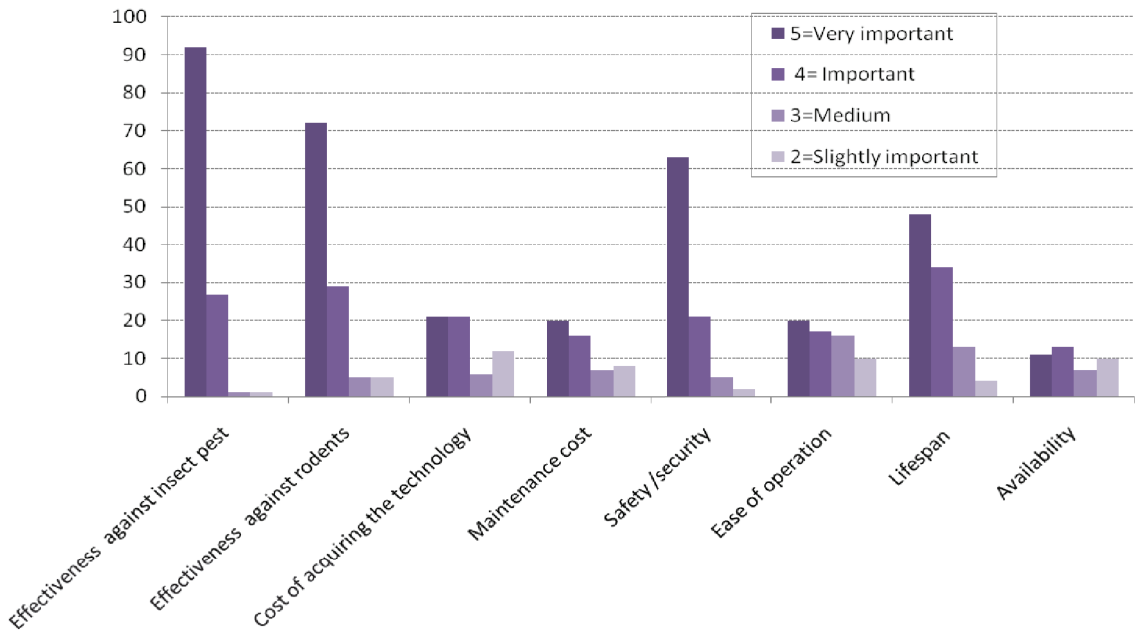

Figure 2. Determinants of storage technology choice by rural households.

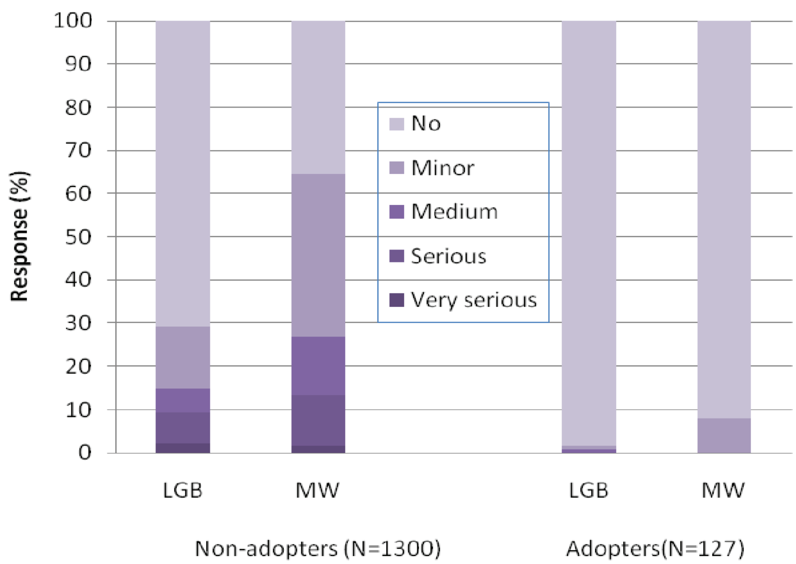

Figure 3. Households' perception of LGB and maize weevil damage.

households that owned silos (Figure 3). Households that did not have metal silo suffered more storage losses of between two and15% from LGB and maize weevil compared to metal silo adopters.

Comparison of maize sale and consumption pattern for metal silo adopters and non-adopters

Both metal silo adopters and non-adopters sold some of their maize soon after harvest to meet immediate household cash needs. Metal silo users delayed selling their maize only disposing a little in the first month (Figure 4). They sold much of their maize five months after harvest to benefit from better prices. Amount of maize sold declined sharply until the seventh month when the remaining maize was sold off to give room to next harvest. Maize takes between 3 and 4 months to mature in dry regions and 5-6 months in mid and high altitude areas. Consumption was stable and smooth throughout

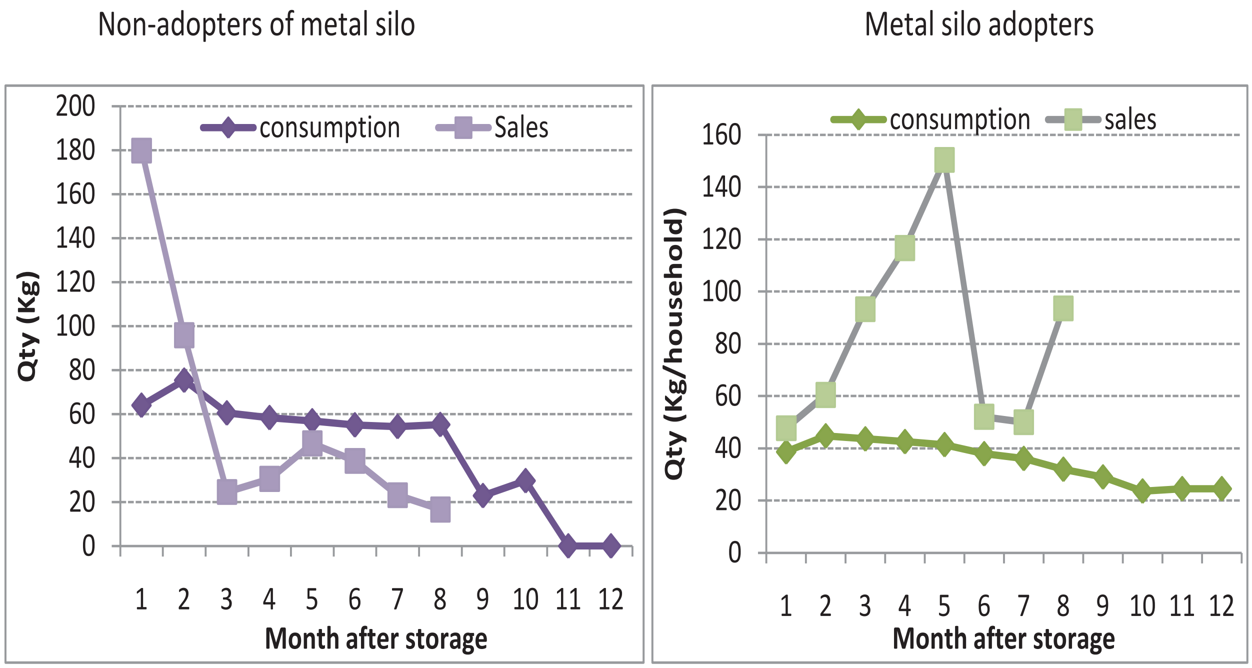

Figure 4. Comparison of sales and consumption by metal silo adopters and non-adopters.

the year for the metal silo adopters (Figure 4). The consumption curve was below the sales curve implying that much of the grain was sold than consumed. Households that adopted metal silo for maize storage were food secure for a whole year.

Unlike metal silo adopters, non-adopters sold much of their grains within the first month after harvest. Consumption curve was above the sales curve except for the first two months after harvest. This meant that by the mid of second month, much of the grain had already been sold and whatever little that remained was kept for food. The grain reserves got exhausted by the eleventh month and households had to buy from the market.

Ordered logit model

Households in potential agro-ecological zones like moist mid altitude (MMA), moist transitional (MT) and high tropics were less likely to sleep hungry or go a whole day without food than households in dry mid altitude.

An increase in household size by one member increased the chance of sleeping hungry by 5% and going without food the whole day by 17%. Distance from the main road was also associated with likelihood of a household being food insecure. Factors associated with reduced household food insecurity include adoption of metal silo technology, owning a mobile phone virtual account or a bank savings account. Male headed households were more likely to go without food the whole day compared to those headed by females (Table 3).

Two-stage treatment effect model

The dependent variable in this model was the number of months a household went without food for a period of one year. The model shows that female headed households were less food insecure than for male headed households. Households with literate heads and larger land parcels were also less food insecure. Interestingly, households that hosted large social events like wedding and burial were less food insecure compared to households that did not host such events. Generally households are food insecure by 3.5 months but this period is reduced by 1.8 months when households adopt metal silo storage technology (Table 4).

The household size, literacy of the household head, land size and possession of a savings account in a bank or virtue mobile phone-based account increases the odds of adopting metal silo technology. However, distance to the nearest passable road reduced the odds of metal silo technology adoption. The likelihood ratio test for the independence of the primary and selection equations yield a *p*-value of 0.5949. We fail to reject the null hypothesis that rho=0 and conclude that there is no evidence of self-selection in adoption of metal silo technology by the adopters.

DISCUSSION

This study demonstrated that 96% reduction in maize grain losses was achieved after acquisition of the metal

Table 3. Ordinal logit regression food security indicators.

Category	Variables	Sleep hungry				Go whole day with no food			
		Odds ratio	Std. Err.	z	P>z	Odds ratio	Std. Err.	z	P>z
AEZ	Low tropics	1.4	0.4	1.21	0.227	0.46	0.19	-1.84	0.066
	Moist mid altitude	1.0	0.2	-0.39	0.951	0.52	0.14	-2.42	0.016
	Dry transitional	1.1	0.3	0.02	0.834	0.92	0.25	-0.29	0.768
	Moist transitional	0.7	0.2	-1.70	0.129	0.31	0.09	-4.09	0.000
	High tropics	0.4	0.1	-3.26	0.001	0.07	0.04	-4.79	0.000
Demographic	Household size	1.1	0.0	1.97	0.067	1.17	0.04	4.49	0.000
	Household head Gender	0.9	0.2	-0.31	0.641	1.62	0.36	2.15	0.031
	Household head literacy	1.3	0.3	1.38	0.311	1.00	0.01	-0.37	0.710
	Experience in farming (years)	1.0	0.0	3.94	0.000	0.94	0.03	-1.70	0.089
Social economics	Savings account	0.4	0.1	-5.48	0.000	0.96	0.03	-1.4	0.162
	M_Pesa account	0.8	0.1	-1.56	0.108	0.24	0.06	-5.45	0.000
	Distant to the nearest passable road (km)	1.0	0.0	1.97	0.049	0.74	0.15	-1.42	0.154
	Land owned (acres)	1.0	0.0	-1.01	0.321	0.99	0.02	-0.64	0.521
	Total annual cultivated land (acres)	1.0	0.0	-1.08	0.397	0.99	0.02	-0.31	0.756
	Nl income	0.9	0.1	-1.49	0.146	1.01	0.01	0.97	0.330
	Metal silo ownership (1=Yes,0 otherwise)	0.2	0.1	-2.74	0.003	0.27	0.20	-1.74	0.082
	Number of observations		1408				1416		
	LR chi2(16)		144.21				184.2		
	Prob > chi2		0.00				0.00		
	Pseudo R2		0.0804				0.1494		
	Log likelihood =		-824.66				-524.25		

silo by the farmers. The metal silo is easy to handle and can be produced in different sizes, from 100 to 3000 kg grain holding capacity, based on requirements. The metal silo, which is a tried-and-tested technology in Latin America offers the following major advantages to African farmers: (i) maintains the quality of the stored product; (ii) air tightness creates effective non-residual fumigation; (iii) avoids the use of insecticides; (iv) requires little space and can be placed inside house; (v) reduces post-harvest losses to virtually nil if properly used; (vi) enables smallholder farmers to take advantage of fluctuating grain prices; (vii) prevents rodents and other pests/pathogens that could potentially harm consumer health; and (viii) can be built in-situ with local labour and easily available materials (FAO, 2008; Tefera et al., 2011).

After adopting the metal silo, farmers delayed selling the bulk of their grains until later in the season to benefit from improved prices. Metal silo adopters were also food secure for 1.8 months longer than non-adopters. Poverty reduction and food security will not be realized if farmers are unable to store grains and sell surplus production at attractive prices. Food security exists when all people, at all times, have access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (Pinstrup-Andersen, 2009).

Several people in Africa, however, are food insecure. Despite significant advances in modern food storage methods, many smallholder farmers in developing countries still rely on traditional storage methods for storing grain. Although relatively simple and inexpensive to construct and maintain, traditional storage systems lead to substantial post-harvest losses (Mughogho, 1989). Inadequate post-harvest storage contributes significantly to food insecurity. The metal silo can play an integral part in ensuring domestic food supply, and in stabilizing food supply at the household level by smoothing seasonal food production, as demonstrated by the households that have already adopted the technology. The metal silo is air-tight. As a result, respiration of the biotic components of the grain mass (fungi, insects and grain) increases CO_2 and reduces O_2 concentrations that limit insect development

Table 4. Two stage least squares: Impact of metal silo on food security.

Number of observation	**1428**		
Design df	1425		
F (11, 1415)	5.43		
Prob > F	0.0000		
	Coefficient.	Std. Err.	P>t
Months of food insecurity			
Household size	0.03	0.024	0.222
Household head Gender	-0.45	0.163	0.006***
Household head Age (yrs)	-0.01	0.005	0.121
Household head literacy	-0.38	0.213	0.071*
Hosting big social events	-0.47	0.139	0.001***
Savings account	-0.10	0.145	0.481
M_Pesa account	0.24	0.171	0.160
Distant to the nearest passable road (km)	-0.01	0.009	0.148
Land owned (acres)	-0.01	0.006	0.043**
Total annual cultivated land (acres)	0.00	0.010	0.963
Metal silo adoption	-1.83	0.625	0.004***
_cons	3.45	0.474	0.000***
Metal silo adoption			
Household size	0.04	0.019	0.051**
Household head Gender	0.18	0.163	0.274
Household head Age (yrs)	0.00	0.004	0.929
Household head literacy	0.54	0.223	0.016**
Savings account	0.43	0.117	0.000***
M_Pesa account	0.59	0.203	0.004***
Distant to the nearest passable road (km)	-0.04	0.023	0.080*
Land owned (acres)	0.01	0.005	0.034**
Total annual cultivated land (acres)	0.02	0.008	0.015**
Primary decision maker (15-64 yrs female)	-0.18	0.126	0.163
Primary decision maker (>64yrs male)	0.34	0.203	0.090*
Primary decision maker (>64yrs female)	-0.35	0.316	0.266
_cons	-3.11	0.451	0.000***
/athrho	0.14	0.128	0.286
/lnsigma	0.84	0.026	0.000***
Rho	0.14	0.125	
Sigma	2.32	0.059	
Lambda	0.31	0.292	
LR test of indep. eqns. (rho=0): chi2(1)=0.28 Prob>chi2=0.5949			

Note *** significant at 1%; ** significant at 5% and * significant at 10%.

(Navarro and Donahaye, 2005). Farmers choose storage technology based on its effectiveness against storage insects. The metal silo is a useful food security element in the grain storage and distribution chain. Smallholder farmers with a metal silo could feed their family year round and free to decide when to bring surplus harvest to market. Grains, particularly maize and beans can be stored in the metal silo for up to three years without any problem (SDC, 2008). This helps schools, urban dwellers and smallholder farmers to set aside the reserves needed when changing climate conditions or natural disasters lead to crop failure (FAO, 2008).

The metal silo empowers smallholder farmers. The metal silo not only offer the opportunity to smooth hunger between staple crop harvests but farmers also are able to improve farm incomes by storing crops and selling it at premium prices when demand outstrips supply later in the post-harvest period. Quality is an important determination of crop retail prices (Kohl and Uhl, 1998) and effective storage is crucial to improving agricultural incomes and food security for smallholder farmers. Following the introduction of metal silos, adopting farmers have learnt to monitor the market and time their produce sales to coincide with right market conditions for better returns. Farmers use the additional income to improve their living standards. A follow-up visits to adopting farm families showed that and some had ventured in enterprises with higher returns like commercial poultry farming and goat fattening. Even though most household heads were males, metal silos were mainly managed by women. Managing the metal silo amd its content can improve women's status and self-esteem (SDC, 2008).

Apart from its effectiveness in mitigating storage losses, engaging in metal silo fabrication and marketing can create jobs for the youth and rural enterprise development (Tefera et al., 2011). For instance, in Latin America, the POSTCOSECHA Programme (Postharvest Program) relied on a large number of local tinsmiths for the production of metal silo (SDC, 2008). In 2007, there were 892 metal silo manufacturers working in El Salvador, Guatemala, Honduras and Nicaragua. The metal silo manufacturing activity provided an additional source of income for tinsmiths. When they were not working in the fields, they spent their time producing metal silos. From the production of metal silos alone, tinsmiths annually earned a net annual income of about US $ 470 (SDC, 2008). This study has demonstrated that the same can be replicated in Africa with wider promotion and adoption of metal silo technology among millions of smallholder grain producers. This study finds evidence that metal silo technology is effective against main maize storage pests and its adoption can significantly improve food security in rural households.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Effect of *Aspillia africana* leave on reproduction of rabbit

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This study investigated the effect of *Aspillia africana* leaves on reproduction of rabbit and was conducted at the rabbit section of the University Teaching and Research Farm of Joseph Ayo Babalola University Ikeji-Arakeji Osun State, Nigeria. The experiment has a complete randomized design with four treatments and one control. Each treatment has two replicates as well as the control. Twenty-four (24) cross-breed (New Zealand White and Flemish) rabbits were used. (Twenty primiparous Does, and four bucks). The *A. africana* leave was harvested and sun dried and then grinded into powder form in the laboratory. The grinded leave of *A. africana* was mixed with concentrate from a reputable feed mill in Nigeria in ratio of Concentrate: *Aspillia* leaves treatments and control allocated. Treatment A (80:20), Treatment B (60:40) Treatment C (40:60), Treatment D (20:80) and control (100:0). The average weekly weight gain, gestation period, birth weight, weight at parturition, litter size and survival of the does were taken and computed for statistical analysis. Among the treatments, Treatment C showed a higher birth weight, implying a better conversion and utilization of the feed (Concentrate (40%): *A. africana* dried leave (60%) combination) by the fetus with average birth weight of 42.50 g. Analysis of the feed composition also showed 24.25% protein, and the energy 2942.69ME/kcal. The use of *A. africana* dried leave can be safely used, and recommended as observed at the level of inclusion in Group C treatment in this study, especially in the dry season to the farmers to upgrade the reproductive potential of their rabbits.

Key words: Rabbit, *Aspillia africana* leave, effect, reproduction.

INTRODUCTION

Rabbit production is one of the livestock enterprises with the greatest potential and opportunity for expansion in Nigeria. A domestic rabbit (*Oryctolagus cuniculus*) can be a great source of meat, if its production is encouraged amongst livestock producers.

The world production of rabbit meat is estimated (Anon,

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1994) to be 1.5 million tons per annum. This would mean per caput annual consumption of 280 g per person per year (Moreki, 2007). The five major world's rabbit producing countries are Italy, Commonwealth of Independent States (Russia and the Ukraine), France, China and Spain. In Africa, the leading rabbit producing countries are Morocco and Nigeria and these are reported to produce 20000 to 99000 tons meat per year.

It has been estimated that the daily minimum crude protein requirement of an adult in Nigeria varies between 65 and 85 g per person. However, it is recommended that 35 g of this minimum requirement should be obtained from animal products (Oloyede, 2005).

Rabbits are ideal small livestock project for peri-urban or rural areas, especially in developing countries such as Nigeria, Botswana etc. with a significant proportion of citizenry living below poverty datum line. They are quite clean and relatively odourless. The raising of rabbits can be anything from a profitable hobby to a fulltime living and can readily serve to complement other livestock, such as Poultry, Fish, and Piggery etc as source of animal protein. Rabbits fit well into a balanced farming system and its initial investment is minimal when compared with other types of livestock. Their conversion rate of local feeds e.g. grains, greens and left-over food to quality meat is high even as these feed are within the reach of farmers. They complement well with vegetable growing. Excess and waste from vegetable gardens and kitchen goes to feed the rabbits, whereas their manure is used to fertilize gardens, thus forming a profitable cycle and aiding the balance of nature.

In Nigeria, it is of interest that rabbit farming is still on small scale or backyard production. Even at this level, productivity, survival rate and availability of forages during dry season are still a big challenge to farmers, especially forages that can satisfy their fiber requirement, but they are widely distributed and available during the raining season.

The nutritional and the medicinal importance of *Aspillia africana* leave has been established, it is called hemorrhage plant which serves as an antimalaria (Waako et al., 2005) and anti viral (Okoli et al., 2007) widespread in Africa. It is used in traditional medicine to stop bleeding from wound, clean the surfaces of sores, treatment of rheumatic pains, bees and scorpion stings and for removal of opacities and foreign bodies from the eyes (Okoli et al., 2007). The effect of *A. africana* leave on reproduction is not well documented, however unauthenticated information in some communities in Nigeria said it prevent conception when boiled, alleviate menstrual cramps and dysmenorrheal.

The global interest in search for anti-microbial substances from natural sources has led to increase investigation of more plants than before (Fasola and Iyamah, 2014). Andrade-Neto et al. (2003) investigated some plant parts commonly used in the treatment of Malaria and observed that, the medicinal values of plants and their component phytochemicals such as alkaloids, tannins, flavonoids, phenolics and other compounds have been found to produce a definite physiological action on human body. A systematic search for useful bioactivities from medicinal plants is now considered to be a rational approach in nutraceutical and drug research. The presence of antioxidants and phytochemicals in Blueberries (Zegarac, 2014) is associated with cardiovascular and cognitive health, cancer and diabetes prevention, others include *Adansonia digitata, Alstonia congeensis*, *Khaya senegalensis* (Coker et al., 2000), *Tithonia diversifolia* (Oyewole et al., 2008; Fasola and Iyamah, 2014).

A. africana is one of the many indigenous plant used by trado-medical practitioners in Nigeria to cure certain illness and posses the ability to stop bleeding, block infection and quick wound healing. The plant is popularly known as "hemorrhage plant" (Okwute, 1998). It is known as organgilia in Ibo, Tanzanian in Hausa, Yungun in Yoruba and Edemedong in Efik (Single, 1965). It is a common weed of field crops in west Africa found in fallow land almost everywhere especially in the forest zone. It is a scrambling perennial herb varying in height from 60 cm to about 1.5 m depending on the amount of rainfall (Akobundu and Agyakwa, 2011). The flowers are bright yellowish florets and the fruits are bristly and minutely hairy with four (4) angled schemes about 5 mm long.

A. africana has also been reported by Okoli et al. (2007) that the leaves has many other additional uses such as palliative properties because its chemical constituents are capable of arresting wound bleeding, inhibiting the growth of microbial wound contaminants and accelerating wound healing. In Kenya, they are used to kill intestinal worms, in Uganda it is used to treat gonorrhea (Okoli et al., 2007). The methanol extract of the leaves are reported to cure malaria and respiratory problems (Fasola and Iyamah, 2014). A concussion of the leave are used to cure eye problem and as a lotion for the face to relieve febrile headache.

Despite the acclaimed importance of the leaves of *A. africana* based on its medicinal advantage reported by many scholars and researchers, the information about its nutritional constituents as well as its effect on the reproductive performance of rabbit is scarce in spite of its wide distribution and availability in Africa.

In Africa, most rabbit keepers or rabbit farms are not large or economically viable enough to justify the use of several or different rations in feeding rabbit. It is a common practice to use just one compounded diet or domestic remnants for the entire herds. To obtain effective performance and feed efficiency, diet should be formulated to meet the needs of animal particularly age or stage of production. It is of great importance that feed given to rabbit must ensure good maintenance, and high productivity, taking into consideration the effective utilization of the feed, sound reproductive performance, in term of fertility, gestation period, parity, birth weight and survival rate of the litters as well as profitability. This is the main focus of this research.

Objective of the Study

The major objectives are:

i. To establish the effect of *A. africana* leaves on reproductive performance of rabbit, taking into consideration the gestation length, parity, birth weight, litter size and survival rate of the kids.
ii. To establish the need for the inclusion of *A. africana* leaves in rabbit feed.
iii. To ascertain the most economic level of inclusion for high productivity.

Problem statements

There is low reproductive performance of rabbit in the tropics which has reduced interest of farmers going into its production. The information on the reproductive potential of rabbit fed *A. africana* leaves is scanty.

MATERIALS AND METHODS

Research site

The study was carried out on the Rabbit Unit of The Teaching and Research farm Joseph Ayo Babalola University, Ikeji-Arakeji Osun State, Nigeria. Joseph Ayo Babalola University is situated in Oriade Local Government Area (LGA) of Osun State in South Western Nigeria. The Local Government has an area of 465 km² with population of 148,617 (Andrade-Neto et al., 2003). It is predominantly occupied by the Ijesa people. Its capital is Ijebu-Jesa (or Ijebu Ijesha) in the north of the area at 7°41′00″N 4°49′00″E / 7.68333°N 4.81667°E. It is situated in the tropical rain forest zone, with scattered swamps, rivers, waterfall and living springs in Erin-Ijesha, a town in the local Government that serves as a tourist center. The soil is fertile and encourages the cultivation of various types of food and industrial crops (Zegarac, 2014).

Statistical analysis

All data collected were subjected to analysis of variance (ANOVA) using the procedure of SAS Institute Inc. SAS/STAT Users Guide (1999). Significant difference mean values were compared using the Duncan Multiple Range Test.

Experimental animals and management

Twenty-four rabbits (twenty primiparous Does and four Bucks) were used for the experiment. They were sourced locally from domestic backyard Rabbit farmers, in towns around Joseph Ayo Babalola University Ikeji-Arakeji Osun State, Nigeria, where the research was carried out. The Does were selected randomly and not specie based. They were allocated into hutches at four does per treatment in two replicate. The experiment has four treatments and one control. Each treatment has two replicate and contain two Does per replicate in one treatment making four Does in one treatment. The initial weights of the rabbits were taken to measure the body weight gain on weekly basis. They were fed with the prepared ration for two weeks to acclimatize and treated for five days with antibiotics and ivermectin based injectable.

Table 1. Ratio of test and control feed mixture.

Treatment	Ratio of feed mixture
A	80:20
B	60:40
C	40:60
D	20:80
Control	100:0

Test materials and diet

Two feeds were use for this experiment, the plant forage leaves of *A. africana*. The leave was sun-dried and grinded into powdered form in the laboratory, and a standard poultry grower's mash as concentrates (from a renowned commercial feed mill company in Nigeria). The grinded dried leave of *A. africana* and the concentrates were mixed in the ratio of Concentrate: *A. africana* leave for the four treatments and control as shown in Table 1. Table 2 shows the proximate analysis of the feed samples in ratio as mixed per treatments as well as the analysis of the grinded leave of *A. africana*.

The daily ration fed to the rabbit was measured by using the weight of the biggest doe. The biggest doe used for the experiment was the giant Flemish which weighs 2.51 kg. 5% of the weight was taken as daily ration feed measurement fed to the rabbits. 5/100 × 2.51 = 0.13 kg Approx. 0.13 kg. This form the daily ration fed to each doe and later increase by 10% during pregnancy.

The rabbits were stabilized on the prepared feeds for two weeks with an accurate weight gain taken on weekly basis. After two weeks of acclimatization with the experimental feed, the Does were introduced to the Buck for mating, and observed for two weeks for pregnancy through gentle abdominal palpation, increment in body weight and refusal to accept Buck.

The gestation period was observed and recorded per Doe in each treatments as well as the control. The birth weight of each kit was taken and recorded within twenty-four hours of kindling as well as the weight of the mother Doe after parturition.

RESULTS AND DISCUSSION

The performance test of *A. africana* leaves on reproduction of rabbit using different treatments and parameters are presented in Tables 3, 4, Figures 1 and 2. The parameters used as basis of data and record are weight before mating (WTBM), weight after mating (WTAM), birth weight (BIRTHWT) litter size, weight at parturition (WTPPAT) gestational period and survival rate (SURV RATE). There are four treatments and one control, with two replicates in each treatment. The test leave of *A. africana* and concentrate used were given in five different ratios of (Concentrate: *A. africana* leave). Treatment A (80:20), Treatment B (60:40), Treatment C

Table 2. Proximate analysis of feed sample.

Sample	% Ash	% Crude protein	% Crude fibre	% Ether extract	% Dry matter	Gross (kcal/g)	ME (kcal/kg)
TRT1	8.50	23.80	12.00	8.00	91.56	4.316	3005.13
TRT2	11.00	24.15	15.00	7.00	91.98	4.318	3044.43
TRT3	6.50	24.25	15.00	7.00	92.13	4.321	2942.69
TRT4	8.00	22.71	20.00	7.00	92.18	4.310	2764.66
TRT100	7.30	21.00	10.00	8.00	92.01	4.300	3192.86
Grinded Aspillia leave	15.00	20.65	14.00	8.00	91.25	3.716	2861.63

Source: University of Ibadan, Nigeria. Laboratory Department Faculty of Animal science. Keys: TRT1-4 = Test treatment; TRT100 = Control treatment.

Table 3. The weekly weight gain by rabbit does.

Variable	Mean	Standard deviation	Standard error	Coefficient of variation	Range	Minimum	Maximum
WTBM	1.8	0.33	0.09	18.07	1.1	1.3	2.4
WTAMWK_1	1.7	0.59	0.16	34.52	2.45	0	2.45
WTAMWK_2	1.77	0.61	0.17	34.56	2.4	0	2.4
WTAMWK_3	1.81	0.63	0.18	34.95	2.5	0	2.5
WTAMWK_4	1.86	0.64	0.18	34.52	2.6	0	2.6
WTPPAT	1.34	0.82	0.24	61.4	2.15	0	2.15
GESTATION	21.92	13.35	3.85	60.92	32	0	7
LITTER SIZE	2.58	2.43	0.7	94.04	7	0	7
BIRTHWT	23.54	18.11	5.23	76.91	42.5	0	42.5
SURV RATE	1.54	2.3	0.64	149.21	6	0	6

Keys: WTBM = Weight before mating; WTAMWK1-4 = Weight after mating week one to four; WAPPT = Weight at parturition; BIRTHWT = Birth weight; SURV RATE = Survival rate.

(40:60), Treatment D (20:80) and Control (100:0). The weight of the Does in all the treatments is not significantly different ($p>0.05$) WTBM and WTAM but increases progressively from WTAMWK1-WTAMWK4 (Table 3 and Figure 1).

The gestation period in all the treatment is similar with Treatments C and D having a higher number of days (Table 4 and Figure 2). The litter size also differ with Treatments A, C and control having a higher size (Table 3). The average birth weight of the kits is highest in Treatment B and C, but with lowest survival rate (Table 3).

In this research, it was discovered that the rabbit Does placed on four treatments (in different ratio of the leave and concentrate) were mated, became pregnant and carried the pregnancy to term (28 to 32 days) with an average gestation period of 30 days, this is in agreement with 31 days observed by (Moreki, 2007).

The result also showed a negative relationship between the birth weight and the litter size in Treatments A, B, C and D, in agreement with Zerrrouki et al. (2004) and Prayaga and Eady (2012) reports, that the larger the litter size, the smaller the birth weight. However, the survival rate was significant ($P<0.05$).

The Gestation period (29.5, 32 and 30 days) and litter size (4.5, 3.0, and 3.33) for Treatments A, C, and control respectively (Table 4 and Figure 2) showed a similar reproductive response,

Table 4. The reproductive performance of rabbit does.

Treatment	WtPPat	Gestation	Litter size	Birthwt	Surv rate
A	1.95	29.S0	4.50	23.33	2.67
B	1.65	28.00	1.33	32.50	0.33
C	1.85	32.00	3.00	42.50	0.00
D	0.62	28.00	1.67	13.33	0.33
CONTROL	1.18	30.00	3.33	21.67	3.33
MEAN	1.45	23.77	2.77	26.67	1.33
CV%	38.0	38.9	46.6	41.9	115.9
SE	0.28	4.62	0.64	5.58	0.77

Keys: WtPPat = Weight at parturition; Gestation = Gestation period; Littersize = Litter size; Birthwt = Birth weight and SurvRate = Survival rate.

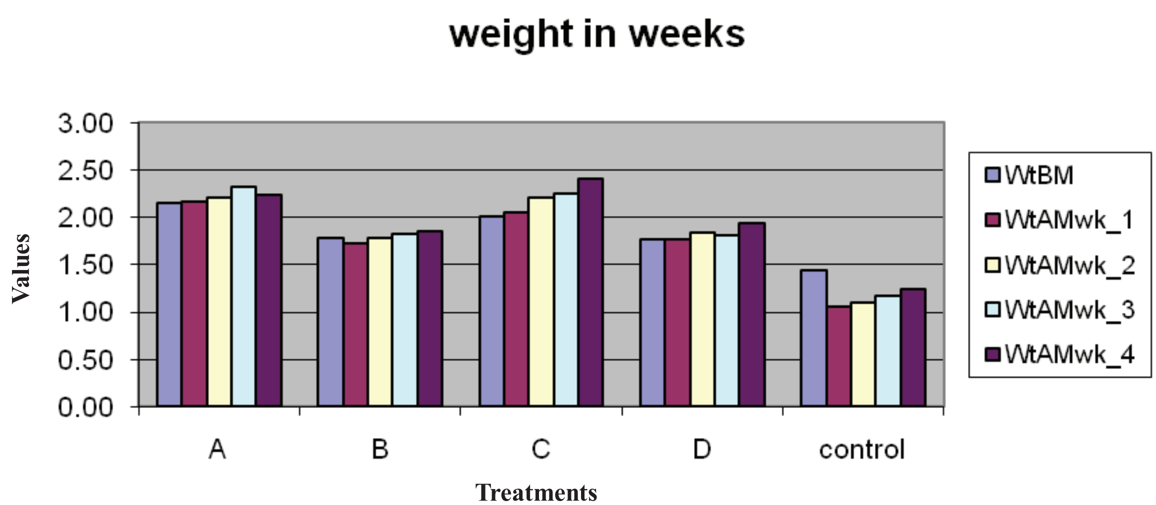

Figure 1. Graph showing the weight gain in weeks of does. Keys: WTBM = Weight before mating; WTAMWK1-4 = Weight after mating week one to four.

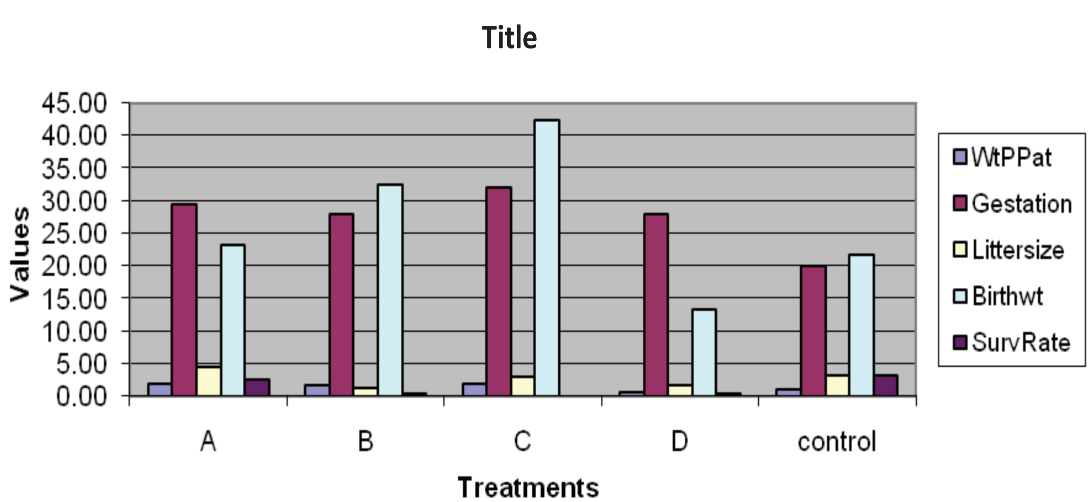

Figure 2. Graph Showing the Reproductive Performance of Rabbit Does. Keys: WtPPat = Weight at parturition; Gestation = Gestation period; Littersize = Litter size; Birthwt = Birth weight and SurvRate = Survival rate.

indicating that rabbit will perform well on any of the three treatments. Among the three treatments, Treatment C showed a higher birth weight, implying a better conversion and utilization of the feed (Concentrate (40%): *A. africana* dried leave (60%) combination) by the fetus.

The 42.50 g average birth weight observed (Treatment C) is in agreement with the Zerrrouki et al. (2004) report, that the average weight of young rabbits at birth was 51 g. and that for survivability of the kitten, it should have at least 40 g body weight at the time of birth, and broiler rabbits kitten between 40 to 50 g or more.

The lower survival rate experienced with Treatment C can be ascribed to the inability of the mother Doe to shed its fur for the kitten to prevent unfavorable environmental condition, as observed in this treatment, this is common with primiparous Doe (Moreki, 2007), hence the inability of the kitten to survive.

CONCLUSION AND RECOMMENDATION

The composition of the feed in Treatment C among other values showed 24.25% protein and the energy 2942.69 ME/kcal as shown in Table 2 indicate that the feed is nutritious, hence the higher average litter size and birth weight observed compared to other groups.

The use of *A. africana* dried leave can be safely used, and recommended as observed at the level of inclusion in this Group, especially in the dry season to upgrade the reproductive performance of rabbits. The plant is a weed, palatable to rabbits, readily available and cost little or nothing to get in this part of the world, especially during the raining season; it can be harvested, dried, and stored for use even at commercial level.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

A stochastic frontier analysis on farm level technical efficiency in Zimbabwe: A case of Marirangwe smallholder dairy farmers

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This study empirically investigates farm level technical efficiency of production and its associated determinants for Marirangwe smallholder dairy farmers, in Manyame district, Mashonaland east province in Zimbabwe. Using a stochastic production frontier model and a two step estimation approach, results for a sample of 27 smallholder farmers indicates that for the agricultural season 2013/2014, the average efficiency level was 54.9% particularly suggesting that dairy farmers are operating far below their production potentials. In particular, age, veterinary and extension, gender, farming experience and market performance were found to be significant factors affecting technical efficiency of the dairy farmers. The results of the study reveal that market performance, farming experience and gender positively affect the efficiency of dairy farmers. The results on gender implies that male farmers are more inefficient in dairy farming when compare to their female counterparts. On the other hand, age and veterinary and extension services was found to be positively associated technical inefficiency.

Key words: Technical efficiency, dairy farmers, stochastic frontier analysis, marirangwe, smallholder, two step approach.

INTRODUCTION

The agricultural sector is a key sector in Zimbabwe. The sector contributes on average 20% of gross domestic product (GDP) per year and has crucial backward and forward linkages as for instance, it acts as a major input provider for the manufacturing sector contributing about 60% of its raw materials and a market for the manufacturing sector. In terms of export earnings, the agricultural sector contributes more than 40% of total export earnings with the key export earner being tobacco. Generally, the agriculture sector is a source of livelihood for about 70% of the total population.

Livestock production as a constituent sub sector of the agriculture sector has proven a crucial system in Zimbabwe as it provides food, traction and manure, and performs other social and economic functions such as customary rituals for the household participation in the

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production systems albeit an increase in revenue leading to an increase in the general standard of living of the rural population. Livestock production in Zimbabwe is undertaken at both large scale and smallholder level. Smallholder dairy production, is encouraged since it helps communal farmers to spread risk by diversifying (Government of Zimbabwe, 2010).

Smallholder dairy farming was supported and promoted by the government with the goal of reducing income disparities and particularly addressing problems facing the smallholder dairy farmers. Thus, the Zimbabwean Government under the Ministry of Agriculture (MoA) introduced a program aimed at influencing the participation smallholder dairy farmers through the Dairy Marketing Board (DMB) to encourage smallholder farmers to take part in milk production. The board created a program known as the Peasant Sector Development Program, which later became the Dairy Development Program (DDP) with the help of NORAD, DANIDA, Africa Now and Heifer International. The DDP projects which was managed by Agricultural Development Authority (ADA) focused on commercial farmers with the aim of improving the technology base used in dairy production. The key purpose of the program was to improve milk production and marketing strategies in the sector thus the participation of smallholder farmers (Government of Zimbabwe; 2004).

Prior to independence, the smallholder dairy production was characterized by subsistence farmers. The composition of the breeds was dominated by indigenous breeds among small scale farmers. Since heralding of the program, 10 dairy projects across the country has been established through the use of financial, technical and informative aid (Government of Zimbabwe, 2004) Nonetheless, even with these diverse efforts, production level within the established projects still remains as low as 3% of total milk output (Hanyani et al., 1998; SNV, (2012).

Among the ten dairy projects are Marirangwe smallholder farmers who benefited under the Dairy development scheme. Marirangwe farming area falls in natural farming region 2b and ventures intensely in both crop production and dairy farming and is participating in the project of the DDP and thirty smallholder farmers are participating in dairy production. The area receives on average 700 mm of rainfall per year making it ideal for dairy farming. However, despite the concerted efforts to boost smallholder production by both the donor community and the government, growth of the smallholder farmers measured in terms of production is not motivating and as such this study seeks to establish the factors affecting their inefficiency levels. For instance, milk production is said to have plummeted from the high of 2.7 million litres in 1990 to 1.13 million litres in 2011. Despite having acquired and adopted the best technologies in milk production, MSDP has not significantly improved their output levels and as such a study that tries to identify the key and significant factors for boosting milk production. Studies by Mupunga and Dube (undated), Ngongoni et al. (2006) and SNV (2012) focused on establishing the factors affecting the general operations and output of the smallholder farmers in Zimbabwe. No effort was directed towards determining the efficiency levels of the farmers under the different programs.

MARIRANGWE SMALLHOLDER DAIRY PROGRAMME: AN OVERVIEW

Marirangwe smallholder dairy programme was established in 1983 following the initiatives of the government and the donor community. Like other dairy development programs, Marirangwe dairy project is governed by the Dairy act of 1977. It has a membership of 31 smallholder farmers and since the year 2010, the project has immensely benefitted from new market linkages with Keffalos, which is an established dairy processing entity and also form a heifer loan from the EU Stabex/NADFprogramme (SNV, 2012).

Marirangwe smallholder dairy project, (hereafter MSDP) is one of the best performing smallholder dairy schemes with a milk delivery to the milk collection centre of 900 L per day. However, it is argued that two members contribute more than 60% of this milk output (SNV, 2012). MSDP, flourished during its early years producing more than 250 000 L of milk per year. The harsh economic conditions of 2000 – 2009, which culminated into the hyperinflation of 2008, negatively affected the project. Production decreased to a low of 100000 litres of milk in 2003/2004 season.

Suggested as reasons for this noticeable decline were import pressures, low farm level productivity, poor commercialization, weak institutional support, low herd sizes and viability constraints. Ngongoni et al. (2006) also identified unavailability of costly protein rich concentration, feed sources and water sources as factors affecting milk production among smallholder dairy farmers.

MEASUREMENT OF TECHNICAL EFFICIENCY: THEORETICAL FRAMEWORK FOR STOCHASTIC FRONTIER MODEL

The measurement of technical efficiency was provoked by Farrell (1957). Since then there has been a proliferation of refinements to the mechanics of measuring technical efficiency. Technical efficiency can be defined from the output oriented and input oriented approaches. In the input oriented approach, technical efficiency is measured as the ability of a decision making unit to increase its output levels given the same level of inputs. The input oriented approach asserts that a decision making unit is technically efficient if it can produce the same level of output given a reduced input bundle (Coelli et al., 1998). Parametric and non-parametric methods have been developed to measure efficiency. The common used measures from the theoretical perspective are the data envelopment analysis (DEA) and the stochastic frontier analysis (SFA). The stochastic frontier approach uses econometric methods of estimation and the data envelopment analysis uses mathematical programming methods (Coelli, 1995).

The stochastic frontier model

The stochastic frontier model was suggested independently by Aigner et al. (1977) and Meeusen and van den Broeck (1977). The model has been used by many different scholars involving cross-sectional data in the measure of efficiency with early empirical work employing a two stage formulation. Recent empirical work uses the one step approach to the estimation of efficiency. According to the stochastic frontier model, technical efficiency can be modelled as:

$$y = f(x;\beta)e^{\varepsilon_i} \quad and \quad \varepsilon = v_i - \mu_i \tag{1}$$

Where, y is maximum potential output on the frontier, $\boldsymbol{x}$ is the vector of the levels of inputs used, β are the unknown parameters and ε_i is the stochastic composed error. The two components of the composed error term are assumed to be independently and identically distributed. The component v is a symmetric normally distributed error term capturing output variation due to factors beyond the control of the farmer and μ is a one sided error term capturing inefficiency of the decision making unit.

Technical efficiency is algebraically measured as follows:

$$TE = \exp(x_i\beta + v_i - \mu_i) \backslash exp(x_i\beta + v_i) \tag{2}$$

$$TE = \exp(-\mu_i) \tag{3}$$

If $\mu_i = 0$, the farm is assumed to be efficient implying that the actual output is equal to the possible output. The farm will be lying on the production function hence technically efficient.The parametric model is estimated in terms of the variance parameters;

$$\delta^2 = \delta_v^2 + \delta_u^2 \tag{4}$$

and

$$\gamma = {\delta_u^2}/{\delta^2}\,. \tag{5}$$

Where $0 \le \gamma \le 1$ and is a variance measure fundamental in determining whether a stochastic frontier model is best over the traditional average production function. In the case of cross-sectional data, the technical inefficiency model can only be estimated if the inefficiency effects for μ_i's are stochastic. The maximum likelihood estimator approach which involves specification of the distribution of the error terms used in the model is surely the most common approach used in the estimation of stochastic frontiers (Battese and Tessema, 1997).

The stochastic frontier approach to econometric modelling of technical efficiency can be done in either the one step approach or the two step approach. The one step approach treats all variables as firm specific incorporating them into the maximum likelihood estimate. However, there are certain factors that are not firm specific which the firm cannot have due influence on. As such modelling these factors incorporating them into the maximum likelihood estimate might compromise the measure of technical efficiency. The two step approach which first estimates the production function and generating the levels of efficiency that are then regressed against another set of variables which are not firm specific is criticized on the potential of inducing a persistence bias that will be carried forward to the second stage thus affecting the estimates of efficiency (Wang and Schmidt, 2002). This study adopts the two step approach of measuring technical efficiency using the stochastic frontier modelling technique. The stochastic frontier modelling technique is adopted because it captures stochastic effects independent of the decision making unit.

AN ECONOMETRIC STRATEGY OF ESTIMATING TECHNICAL EFFICIENCY

The data used in this study was collected from 27 participating smallholder dairy farmers. The data analyses the production behaviour of the farmers for the season 2013/2014. MSDP has 31 smallholder farmers with 27 actively participating. Thus, all the participating smallholder dairy farmers were incorporated into this study. To measure efficiency for the farmers we adopt the Battese and Coelli (1995) technical inefficinecy model using cross sectional data. The model is specified as follows:

$$y_i = exp(x_i\beta + v_i - u_i) = exp(x_i\beta + v_i)\exp(-u_i) \tag{6}$$

Where; $y_i$is the output for the farmer i , x_i represents a $(1 \times K)$ vector whose values are functions of inputs and other explanatory variables for the sample farm, β represents a $(K \times 1)$ vector of parameters to be estimated, $v_i$represents independent and identically distributed random errors with a mean of zero and variance δ^2, u_i is assumed to be non-negative unobservable random variables associated with the technical inefficiency of production.

Since the approach adopted in this study is a two-step approach, a stochastic production function is estimated in a log linear form and this is given as follows:

$$Log\ output_i = \beta_0 + \beta_1 Capital_i + \beta_2 labor_i + (v_i - \mu_i) \quad (7)$$

Where $\log output$ is the logarithm of output measured in liters and capital is proxied by herd size and labour is measured as the sum of family and hired labour during the 2012/2013 farming season. A priori, $\beta_1 > 0, \beta_2 > 0$. i represent the i^{th}dairy farmer,v_i is a stochastic error term and μ_i is a one sided error term measuring inefficiency.
The residuals generated from equation two are then modelled as technical inefficiency in a model generally proposed as follows:

$$\mu_i = \delta_0 + \delta_1 Z_i \quad (8)$$

Where Z_i represents $(1 \times M)$ vector of explanatory variables associated with the technical inefficiency effects in the sample farm. δ is an $(M \times 1)$ vector of unknown parameters to be estimated in the model.

Equation 8 estimating technical inefficiency in this particular case is estimated as follows:

$$\log efficiency = \alpha_0 + \alpha_1 Age + \alpha_2 Gender + \alpha_3 Fexp + \alpha_4 Mperf + \alpha_5 Vetex + w_i \quad (9)$$

$\log efficiency$ is the logarithm of technical inefficiency, age is measures as the number of years since birth of the responded, gender is a dummy variable for the sex of the responded and $Fexp$ is farming experience measured as the number of years the responded has been involved in dairy farming, $Mperf$ is market performance and measures the perception of the farmer on the performance of the market and $Vetex$ is veterinary and extension services measuring the quality and availability of the extension services to the farmer.

RESULTS AND DISCUSSION

Definitions and summary statistics of farm and non-farm specific variables

A detailed summary of the output and input variables involved in the stochastic frontier production and inefficiency models for different farms in Marirangwe showing the sample means and standard deviations as well as the definitions of the variables used in the study are shown in Table 1. The dependant variable for the stochastic production frontier model is the output which was measured in terms of milk units produced by each farmer in the 2012/2013 farming season. The independent socio-economic variables that were used as factors affecting the production of output and the levels of inefficiency are also summarized in Table 1.

Approximately 87% of the farms are headed by males while the other 13% are headed by females. Age was captured grouped in ranges in which 1 represented the age group of less than 25 years, 2 represented the age group of 25 to 40 years and 3 represented the age group of 40 years and above. The mean age group was that of 25 to 40 years with a standard deviation of 0.61 implying that the majority of the farmers are in their middle ages.

Farming experience was measured in terms of the number of years the respondent have been engaged in agriculture. The overall mean for the farming experience of the respondents was at 15.23 years and this had a standard deviation of 0.43. This indicates that the majority of the farmers has vast knowledge in dairy farming. The herd size was captured as a measure of the number of cows the respondent have at the time of the data collection period. A mean of 9 was recorded on herd size with a standard deviation of 5.05. Labour was measured in terms of the number of hours used per week and the mean labour unit was 198.5 with a standard deviation of 320.25 and this is the variable with the greatest level of variability as compared to all the other variables. It means that farmers devote too much time looking after dairy cattle per week. Market performance had a mean of 0.67 and a standard deviation of 0.48, veterinary and extension services had a mean of 0.37 and a standard deviation of 0.49.

Stochastic production frontier model estimation results

Maximum likelihood estimates of the Stochastic Frontier production function are given in Table 2 and are obtained using Stata 11. The signs of the estimated parameters are as expected a priori except for labour which has a negative effect on output. Though the coefficient is negative and statistically significant its contribution to output of milk is quite negligible. In addition, another suspect is that the labour is uneducated in the field of dairy farming. With respect to herd size, the more cattle the farmer has the more output is likely to increase holding other things constant confirming the expected positive relationship between herd size and output.

Since assumptions are to be made on the distribution of the inefficiency term, the stochastic production frontier models as in many studies was estimated with an inefficiency term assumed to have a half normal distribution. Results of the model are presented in Table 2. The likelihood ratio is 3.22 with a p-value of 0.036. The significance of the likelihood ratio test confirms the presence of the one sided error term in the composite error term. In that regards the diagnostic checks confirms the relevance of the stochastic parameter production function and the use of the maximum likelihood estimation as an estimation technique for both one sided error term distribution assumption. Simply put, these results indicates the presence of technical inefficiencies in production.

Determinants of technical efficiency

In the determination of the factors affecting inefficiency, the predicted technical inefficiency terms was modeled

Table 1. Definitions and summary statistics.

Variable	Definition of variable	Mean	std. dev	Min	Max
Gender	dummy for the sex of respondent (0=female; 1= male)	0.87	0.35	0	1
Age	age in years (1= < 25; 2 =25 to 40; 3= >40)	2.33	0.61	1	3
farming experience	farming experience (in number of years)	15.23	14.22	5	40
herd size	herd size (number of cows)	9.03	5.05	3	23
Output	yield in unit of milk (measured in liters)	17387.4	25451.3	1800	118800
market performance	market performance (0="poor"; 1= "fair")	0.67	0.48	0	1
veterinary and extension	veterinary and extension services performance (0="poor"; 1= "good")	0.37	0.49	0	1
Labor	labor (measured in terms hours of hired and family labour per week)	198.5	320.25	56	1825
Sample Size		27			

Table 2. Maximum likelihood estimates of the stochastic frontier production function.

Logout put	Half normal
Herd size	0.156***
	(8.01)
Labor	-0.000880***
	(-2.67)
_cons	8.755***
	(38.84)
Insig2v	
_cons	-2.868***
	(-3.45)
Insig2u	
_cons	-0.153
	(-0.39)
N	27

t statistics in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3. Determinants of technical efficiency.

Login efficiency	
Middle age	0.606***
	(4.33)
Old age	0.910***
	(7.29)
Gender	-0.330*
	(-1.90)
Experience	-0.0312**
	(-2.55)
Market performance	-0.416*
	(-2.03)
Veterinary and extension services performance	0.380**
	(2.71)
Constant	-0.575*
	(-1.90)
Observations	27
R^2	0.534

t statistics in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

against a vector of variables including age, gender, farming experience, market performance and access to veterinary and extension services. Results are presented in Table 3.

The estimated coefficient of age (middle age and old age) are positive and statistically significant indicating that as the farmer gets older the less efficient they tend to become. This suggest that young dairy farmers are more efficient than older farmers. These results are consistent with the results by Mugera and Featherstone (2008) and Pitt and Lee (1981). More so, the results are consistent with the findings of Abdulai and Huffman (1998) which states that older rice farmers in Northern Ghana were less efficient than young farmers.

Gender measured as a dummy states that males are more efficient than females. Veterinary and extension contact also measured as a dummy suggest that more veterinary and extension contact leads to more technical inefficiency. The results could be explained on the basis of a poor program design on the part of the extension department or a lack of a participatory approach and beaucratic inefficiencies in delivering extension to dairy farmers. Market performance and farming experience positively contributes to improved technical efficiency.

CONCLUSION AND POLICY IMPLICATIONS

The study investigates the farm level technical efficiency of production and its determinants in Zimbabwe dairy farming using the case of Marirangwe smallholder dairy farmers in Seke district of Mashonaland East province. The study was undertaken on a sample of 27 smallholder dairy farmers in the farming season 2012/2013. The mean technical efficiency was estimated to be 54.9% for the sampled data indicating gross inefficiencies on the part of dairy farmers. Using a stochastic frontier production function, the empirical evidence suggests the critical factor in explaining output is herd size. In establishing the factors affecting farm level technical efficiency: faming experience, gender, age, market performance and veterinary and extension services are particularly important determinants.

In particular, the findings suggest that to stimulate efficiency, aged people should enrolled into dairy training programmes to improve their efficiency levels. More so, in terms of supporting activities, empirical evidence suggest that males are more technically efficient as compared to female and as such for policy purposes more males should be trained about dairy farming as this will improve production efficiency. Furthermore, for veterinary and extension services, results suggest that the services need to be placed on constant check with the programs clearly designed and being participatory in nature. Also, the performance of the market is a critical determinant in determining efficiency levels of the farmers. If the prices in the market are poor there is no motivation for the farmers to become efficient. Therefore, if the prices are regulated then they need to be gazetted at prices that will motivate farmers to increase their efficiency levels. Otherwise letting the forces of demand and supply determine the prices will help farmers to be more efficient.

Thus, technical efficiency can be improved by dovetailing dairy farming training programs to the middle aged and old aged farmers, propagate and expedite veterinary and extension services in a participatory approach and encouraging more man to participate in dairy farming.

Conflict of Interest

The authors have not declared any conflict of interest.

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