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Determinants of crop production in Musanze District, Northern Rwanda

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Preface

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Determinants of crop production in Musanze District, Northern Rwanda

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Abstract

This study estimates the Cobb-Douglas production function with reference to crop production in Musanze district in northern Rwanda. It uses a structured questionnaire to collect cross-section data through a survey of 107 farmers randomly selected from the study area. It uses both descriptive (mean, variance, standard deviation) and the ordinary least squares approach for analyzing the data. The results of the analysis show that crop production was positively correlated to the inputs used -- labor, fertilizers, seeds and pesticides. The test of significance of the estimated parameters shows that inputs in the form of labor, fertilizers and seeds were highly significant ($p \leq 0.05$) factors contributing to production as they explained 66 percent of the variations in crop production. Also, the significance and the normality test of residuals shows that the results of the estimated model are reliable for forming policy. The sum of input coefficients (0.99) indicates that agriculture is recording decreasing returns to scale. Based on the results of this study, we recommend that farmers should achieve least production costs through a more rational use of available inputs. The government should enhance and extend the supply of subsidized fertilizers. Land protection should also be improved to maintain or increase its productivity. The government and other agricultural development agencies should promote actions that guarantee markets for farmers, for example, through contract farming and facilitating access to proximity extension services.

Keywords: Crop production, Cobb-Douglas function, ordinary least squares, Rwanda;

JEL Classification Codes: C21; O13; P46; Q12; Q18

1. Introduction

As in many other countries in Africa, agriculture is the backbone of economic development in Rwanda. Statistics show that the agricultural sector contributed 33.6 percent of the nominal GDP (NISR and BNR, 2013) and 73 per cent of the employment (NISR, 2012). As a development priority in Rwanda, agriculture has been recognized as an engine for primary growth (IMF, 2008; Republic of Rwanda, 2004). It has been chosen as the first and strongest leverage to put the country on a path of sustainable development and for fighting poverty. Investment policies in the agricultural sector will contribute to changes in the structures, methods, marketing and efficiency of agricultural activities with a high impact on the earnings of a majority of the population and most of the poor; it will also impact exports and GDP.

Agricultural systems in most developing countries are rural-based with the primary objective of building food security even when productivity is low (Johnston and Mellor, 1961).

Economic theory tells us that a production function describes the technical relationship that transforms inputs (resources) into outputs (commodities) (Debertin, 2012). Poudel et al., (2010) used a Cobb-Douglas form to estimate the crop production function and resource use condition of organic cultivation in different farm sizes and altitude categories in the Hill Region of Nepal by using the OLS method and cross-section data collected in 2010 covering 280 coffee farming households selected randomly from 400 households in 12 village development committees (VDCs) in Gulmi district. The data was for the 2009 normal coffee growing year and organic farms were classified according to farm size and altitude. The variables included in their model are coffee output, farm size, labor used, fertilizers used, inter/shade crops, the number of coffee trees, sex of the coffee farm managers, household size, extension training for coffee farm managers, age of the coffee farm managers, farm experience and labor costs. Their results show the great significance of the labor employed and of organic fertilizer application.

Their study also observed increasing returns to scale in all the categories when summing the elasticities. Labor was overutilized while the remaining factors were underutilized. Therefore, available inputs need to be rearranged effectively for enhancing technical efficiency.

For their research on the production function of rice in Morang district in Nepal, Bhujel and Ghimire (2006) used a semi-structured questionnaire through face-to-face interviews to collect information necessary to estimate this function. They found that human and bullock labor did not have any significant effect on production. The nitrogen effect on production was significant at the 1 percent level and had a negative value which indicates excess application and use of a variety which is not very responsive to a higher dose of nitrogen; however, the use of phosphorous and potash can be increased.

Hussain and Saed (2001) assessed and evaluated the crop production function parameters in the Jordanian agricultural sector during 1981-96. The main objective of their study was finding the relationship between output per ton and the level of inputs (area, labor and capital) and testing the hypothesis that reallocation of resources with farm capital intensity bias promoted growth, employment and agricultural productivity in Jordan. The authors used the Cobb-Douglas production function to estimate this production function. The estimated production function shows increasing returns to scale. Their analysis indicates that agriculture was characterized by intensive labor since the elasticity of labor was greater than that of capital (0.455 and 0.130 respectively).

Echevarria (1998) did a study in Canada to estimate value added in agriculture as a constant returns-to-scale function of the three factors of production (land, labor and capital) using data for 1971-91. After estimating a constant returns-to-scale production function, the author calculated the average of the factor of change of the Solow residuals using a Cobb-Douglas function. The results show that agricultural production functions in Canada, both at provincial and national levels, registered constant returns to scale because the sum of partial elasticities is unity.

A number of other scholars have also empirically estimated agricultural production function around the world. These include Hoch (1962), Ike (1977), Ecchevaria (1998), Hussain and Saed (2001), Hu and McAleer (2005), Olubanjo and Oyebano (2005), Armagan and Ozden (2007), Arene and Mbata (2008), Moussavi-Haghighi et al. (2008), Olujenyo (2008), Alao and Kuje (2010), Poudel et al. (2010), Onoja and Herbert (2012) and Wakili and Isa (2015).

In Rwanda, (Mpawenimana, 2005) did a research to define the determinants of the banana production function with a focus on the relationship between output and socioeconomic factors that affect banana production in Kanama district while Maniriho and Bizoza (2013) assessed agricultural profitability in Musanze district.

The Government of Rwanda (Republic of Rwanda, 2002) considers the agricultural sector to be important both for survival and for commercial purposes. The sector mainly supplies food stuff and in case of sufficient production farmers manage to sell their excess produce in the market. Like many other governments, the Government of Rwanda (GoR) has subsidized agriculture to ensure adequate food supplies. These agricultural subsidies are often linked to the production of certain commodities such as wheat, corn (maize), rice, soybean and milk (Cantore, 2011).

In the last century, agriculture was characterized by enhanced productivity, the use of synthetic fertilizers and pesticides, selective breeding, mechanization, water contamination and farm subsidies (Howard, 1943). Proponents of organic farming such as Howard (1943) argued in the early 20th century that the overuse of pesticides and synthetic fertilizers damaged the long-term fertility of the soil. This thinking was dormant for decades but as environmental awareness increased in the 21st century, there was a movement towards sustainable agriculture by some farmers, consumers and policymakers.

In Rwanda, this led to controversies between MINAGRI and the Rwanda Environmental Management Authority (REMA). While MINAGRI (2004) supports the intensive use of fertilizers and the use of marshlands to increase the land surface for agriculture to achieve high agricultural productivity, REMA (2009) highlights that the use of fertilizers and agricultural chemicals pollutes water and agricultural activities and general mismanagement of the wetlands have further degraded and destroyed the natural resources by leading to soil erosion and vulnerability to climatic shocks.

As one of Rwanda's development priorities, agriculture has been recognized as the engine for primary growth (IMF, 2008; Republic of Rwanda, 2004). It has been chosen as the first and strongest leverage to put the country on a sustainable development path and for fighting poverty. Investment policies in the agricultural sector contribute to changes in the structures, methods, marketing and efficiency of agricultural activities with a very high impact on the incomes of a majority of the population and most of the poor; they also impact exports and GDP. The major agricultural policies adopted by the Government of Rwanda to transform and mechanize agriculture by developing modern agriculture include the promotion of more intensive agricultural practices through increased use of agricultural inputs, agricultural professionalization that promotes high enterprise profitability, promoting soil fertility and protection, improved marketing initiatives and reinforcing agricultural research including a greater role for farmer cooperatives and associations (Bingen and Munyankusi, 2002). Another government policy known as Economic Development and Poverty Reduction Strategy (EDPRS) (Republic of Rwanda, 2007) identifies the agricultural sector as a crucial area for growth and calls for energetic public action in collaboration with private and non-governmental development partners to encourage greater input use and to assist in the provision of services as also their monitoring.

All these efforts have improved the Rwandan economy in general and the agricultural sector in particular. The government's initiatives have improved the situation of Rwandan agriculture but forming appropriate economic policies is still of interest. The question is getting to know the extent to which these improvements have contributed to the development of the agricultural sector. Besides, farmers do not know how to measure the relationship between inputs and output. The suitability of crops planned for each region in the context of crop intensification with a focus on land use consolidation still require more explanation. As a part of the response to these questions, our study analyzes the agricultural production function in a sample district. Our results inform policy about where efforts are needed to sustain the on-going agricultural development process in the country.

Agricultural production function: Conceptual framework

Picard (2002) and Descamps (2005) conceptually describe the production function as the relationship between the amount of inputs used and the maximum level of output to be produced. The production function represents a set of technical constraints that a firm is facing. Output is achieved by combining certain amounts of different inputs. According to Mudida (2003) a simple agricultural production function is obtained by using labor and land as inputs and by recording alternative outputs per unit of time. Ahuja (2006a, 2006b) highlights that a production function, especially an agricultural production function, can be extended to include more than two factors like land, irrigation and fertilizers.

In Rwanda's context, making appropriate economic policies is still of interest. In the agriculture sector, farmers do not know how to measure the relationship between inputs and output. They also need information about the differential effects of the inputs used as well as the profitability of their cropping systems. Another problem has to do with the effect of the government's agricultural policies on poverty alleviation. Our study throws light on the benefits of crop intensification with a focus on consolidating land use.

It is expected that the results of our study will be used by agricultural decision makers, agriculture planners and farmers when planning inputs and output. Knowing the main determinants and profitability of agricultural production, decision makers will also get to know where more efforts are needed and planners will be able to predict both inputs and output for a specific time in the future. Farmers will be able to use the estimated econometric model to plan for the inputs needed and the output. For researchers and academicians, the results of our study will contribute to existing knowledge related to agricultural economics in Rwanda.

Our study identifies the determinants of crop production in Musanze district in northern Rwanda. It specifically aims to: (1) estimate the crop production function, and (2) compute the returns to scale of agricultural investments in Musanze district.

The rest of this paper is organized as follow. The next section concentrates on the materials and methods used for the study. This is followed by an estimation of the crop production function and a discussion of the findings. The last section gives the conclusion and policy implications.

2. Methodology

Study area

The Republic of Rwanda is located in east-central Africa between latitudes 1°04' and 2°51' south and longitudes 28°45' and 31°15' east. It is the 149th largest country in the world and the fourth smallest in Africa. It is divided into five provinces (Kigali City, Southern, Western, Northern and Eastern provinces), 30 districts and 416 administrative sectors. Administrative sectors are further sub-divided into cells, which in turn are divided into villages. With a size of 26,338 square kilometers, Rwanda is bordered by the Democratic Republic of Congo on the west, Uganda on the north, Tanzania on the east and Burundi on the south. It is a country with many hills and mountains at high altitudes where the lowest point is at 950 meters above sea level. The population of Rwanda was estimated at 11,689,696 in 2012 with a population density of 415; 83.5 percent of the population lived in rural areas and 28.6 percent households were female headed (NISR, 2012). The projected life expectancy at birth was 66.6 years.

Musanze district is one of the five districts in the Northern Province. It has a surface area of 530.4 km^2 of which 60 km^2 is in the Volcano National Park and 28 km^2 is the Ruhondo Lake. The average altitude is 2,000 meters including the chain of the volcanoes Kalisimbi (4,507 km), Muhabura (4,127 km), Bisoke (3,711 km), Sabyinyo (3,574 km) and Gahinga (3,474 km) which offer beautiful and attractive tourist sites. Musanze district has a tropical climate of the highlands with a mean temperature of 20ºC. It generally gets adequate rain throughout the year; precipitation varies between 1,400 mm and 1,800 mm.

Two main and two small seasons characterize the study area -- rainy and dry seasons: from June to mid-September is the great dry season and from January to mid-March is the small dry season; from mid-March to the end of May is the great rainy season and from mid-September to end-December is the small rainy season. In terms of physical characteristics, the soil is by and large volcanic which is essentially fertile. The main crops grown in the district are Irish potatoes, beans, corn and wheat (District de Musanze, 2007). Figure 1 and Appendix A describe the study area.

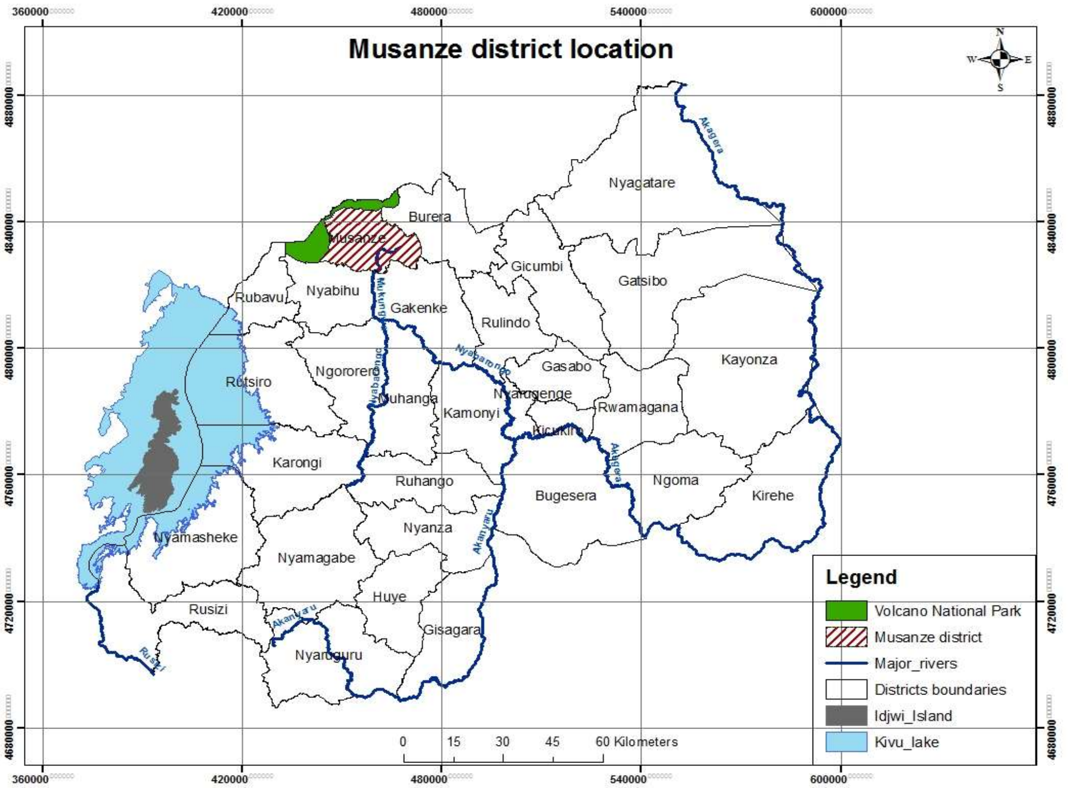

Figure 1: Location of Musanze district

Data Collection Methods

We did a field survey in the district to collect data for our study during August and September 2012. The survey had a sample of 107 farmers' organizations assisted by the *Programme de Développement Rural du Nord*, DERN, in Musanze district. Besides the field survey using a self-administered questionnaire, we also used the documentary method for collecting data.

In 2012 the population of Musanze district had an average density of 592.6 inhabitants per km^2. The population composition shows that there were more women (166,763) than men (147,479) (53 percent and 47 percent respectively). The overpopulated sectors were Muhoza and Cyuve with densities of 1,722.3 and 903 inhabitants per km^2 respectively. Kinigi sector had the lowest population at 274.8 inhabitants per km^2. Table 1 shows the population distribution in Musanze district's sectors.

Musanze district has a predominantly young population (60 percent of the total active people are under than 25 years old). Living conditions differ according to zones: the urban zone where the habitats are planned and the rural zone which is dominated by agglomerations and dispersed houses. Estimates show two rural sectors -- Kinigi and Nyange – where more than 90 percent of the population lives in agglomerates. Increasing the cultivable surface and facilitating access to basic infrastructure (drinking water, management of the environment, roads, health centers) are pressing issues for the development of the habitats.

Table 1: Population distribution

Sector	Remera	Kimonyi	Muhoza	Musanze	Muko	Nkotsi	Gataraga	Busogo
Population	19,112	15,589	51,878	31,864	18,937	13,546	22,710	21,512
Percentage	5.19	4.23	14.09	8.65	5.14	3.68	6.17	5.84
Sector	Shingiro	Cyuve	Kinigi	Nyange	Gashaki	Rwaza	Gacaca	Total
Population	21,162	39,091	27,221	27,466	13,648	20,926	23,605	368,267
Percentage	5.75	10.61	7.39	7.46	3.71	5.68	6.41	100.00

Source: NISR (2012).

Twenty-six percent of the district's population is at the primary school level. The working population (20 to 59 years) is distributed in different branches of industry which are mainly agriculture and husbandry, craft industry, trade and liberal professions.

The households are capitalized by cattle. The animal livestock comprises of bovines, sheep, caprines, porcines, rabbits and poultry and bee-keeping; smaller livestock enjoy a significant place in the households. In addition, a family of four has at least one cow. Such a situation is not helpful in a primarily agricultural economy.

Descriptive statistics

Data for this research was collected both in real terms and in monetary values. The monetary value was computed by multiplying the quantity of an item by its unit cost. The descriptive statistics include the mean, median, maximum, minimum, standard deviation, skewness, kurtosis and Jarque Bera and its probability as well as the number of observations for each variable. Table 2 gives the crop production in Musanze district and shows that crop production (Y) was RWF 185,905 and its cost was RWF 39,140 for labor (L), RWF 28,464 for fertilizers (F), RWF 48,408 for seeds (S) and RWF 10,626 for pesticides (P). This adds up to a production cost of RWF 10,317 and the costs of RWF 2,172 for labor, RWF 1,580 for fertilizers, RWF 2,686 for seeds and RWF 590 for pesticides per are.

Table 2: Descriptive statistics of crop production in Musanze district

	Y	L	F	S	P
Mean	185,905.3	39,139.72	28,463.87	48,407.99	10,626.24
Median	116,400.0	25,500.00	19,720.00	24,500.00	4,000.000
Maximum	1,200,000.	170,000.0	233,950.0	450,000.0	184,000.0
Minimum	7,500.000	4,250.000	1,000.000	100.0000	0.000000
Std. Dev.	235,228.4	38,283.55	35,018.29	71,806.90	22,360.21
Skewness	2.947173	2.010700	3.737338	3.054826	4.953687
Kurtosis	12.34640	6.416958	19.34468	14.53104	35.64035
Jarque-Bera	544.3558	124.1523	1440.128	759.2220	5187.487
Probability	0.000000	0.000000	0.000000	0.000000	0.000000
Observations	107	107	107	107	107

Source: Calculated by the authors based on the field survey data (October 2012), (summarized using EViews).

Definitions of variables and specification of the model

Table 3 summarizes the definitions, symbols and measurements of both dependent and independent variables. The dependent variable is agricultural output and the independent variables include the labor used, fertilizers, pesticides and seeds. Each independent variable is positively related to the dependent variable. This means that the signs of the coefficient are expected to be positive.

For the model specification we followed Gujarati (1995) and Gujarati and Sangeetha (2007) who classified the Cobb-Douglas production function as the best production function along with the constant elasticity of substitution production function. Its stochastic and log-linear forms are respectively:

$$Y = \beta_1 X_{2i}^{\beta_2} X_{3i}^{\beta_3} e^{u_i}$$

(1) $LogY = \beta_0 + \beta_2 LogX_{2i} + \beta_3 LogX_{3i} + u_i$

where Y is a dependent variable, Xs are independent variables, *Log* stands for the Neperian logarithm, e is the Neperian number equal to 2.72121, u_i is a disturbance term, β s are parameters to be estimated and $\beta_0 = Log\beta_1$ are the intercepts. Following Gujarati (1995), the model to be estimated for our study is:

(2) $LogY = \beta_0 + \beta_1 LogL + \beta_2 LogF + \beta_3 LogS + \beta_4 LogP + U$

where *LogY* stands for agricultural output in RWF, *LogL* is labor in RWF, *LogF* is the value of fertilizers in RWF, *LogP* is the value of pesticides in RWF, *LogS* is the value of seeds in RWF, *Log* means natural logarithm, U stands for the disturbance term and β_0 to β_4 are parameters to be estimated.

In a Cobb-Douglas production function, the input coefficients are qualified as output elasticities with respect to inputs which express the effects of inputs on output in percentage terms (Bourbonnais, 2005). The sum of all elasticities describes the level of returns to scale (RTS). If this sum is less than one, it is a case of decreasing RTS; if it is equal to one, it is a case of constant RTS; and if this sum is greater than one, it is a case of increasing RTS (Picard, 2002).

3. Results and discussion

Estimation of the agricultural production function in Musanze district

Table 3 identifies the determinants of the agricultural production functions of the main crops grown in Musanze district. These crops are Irish potatoes, beans, corn, wheat, tomatoes, onions and cabbage. It shows that a positive relationship exists between log of crop production (*LY*) and log of labor (*LL*), log of fertilizers (*LF*), log of seeds (*LS*) and log of pesticides (*LP*). This implies that as more of these inputs are used, there is an increase in agricultural production. The sum of coefficients is 0.99 which shows decreasing returns to scale. The test of significance shows that land, fertilizers and seeds are statistically significant at the 5 percent level of significance. The R^2 is estimated as 0.66 which shows that 66 percent of the variations in agricultural production are explained by the explanatory variables included in the model. The first input that contributes significantly to agricultural production is fertilizers as it has an elasticity of 0.49, followed by labor and seeds with an elasticity of 0.24 each.

Table 3: OLS Estimates of Crop Production Function in Musanze District

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.773846	0.879471	2.016947	0.0463
LL	0.235565	0.081082	2.905266	0.0045
LF	0.493556	0.084081	5.870036	0.0000
LS	0.239079	0.046996	5.087212	0.0000
LP	0.024414	0.043813	0.557222	0.5786
R-squared	0.668593	F-statistic		51.44459
Adjusted R-squared	0.655596	Prob(F-statistic)		0.000000
Durbin-Watson stat	1.946314	Observations		107

Note: C is constant, LL is log of labor, LF is log of fertilizers, LS is log of seeds and LP is log of pesticides.

Source: Authors' estimation based on field survey data (October 2012).

As per Table 4, the exponential form of the Cobb-Douglas production function by using the OLS estimated coefficients is of the form described by:

(3) $Y = 5.85 L^{0.24} F^{0.49} S^{0.24} P^{0.02}$

where 5.85 is β_0 as $Log\beta_0$ is 1.77. Equation 3 can be used to predict agricultural production in Musanze district. Even though the predicted values are slightly smaller than the actual ones, its results are valuable.

Table 4: OLS Estimates of Bean Production Function in Musanze District

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	7.114207	1.800357	3.951554	0.0006
LL	-0.061536	0.216016	-0.284867	0.7782
LF	0.064238	0.173136	0.371024	0.7139
LS	0.624093	0.200962	3.105526	0.0048
LP	-0.149238	0.116931	-1.276295	0.2141
R-squared	0.677625	F-statistic		12.61185
Adjusted R-squared	0.623896	Prob(F-statistic)		0.000012
Durbin-Watson stat	1.098353	Observations		29

Note: C is constant, LL is log of labor, LF is log of fertilizers, LS is log of seeds and LP is log of pesticides.

Source: Authors' estimation based on field survey data (October 2012).

As far as an analysis of the determinants of individual crops is concerned, the estimates in Equation 3 show a positive relationship between bean output and fertilizers and seeds used. This means that bean production increases with an increase in fertilizers and seeds. On the other hand, a negative relationship exists between bean production and labor and pesticides. This could be due to a poor mix of labor and pesticides with other inputs. The sum of coefficients is 0.48 which shows decreasing returns to scale. The test of significance shows that only seeds are statistically significant at the 5 percent level of significance. The R^2 estimated as 0.67 shows that 67 percent of the variations in bean production are explained by the explanatory variables included in the model. The estimated equation 3 shows that the only input that is significantly related to bean production is seeds whose elasticity is 0.62, and the corresponding probability value is 0.00.

Table 5: OLS Estimates of Irish Potato Production Function in Musanze District

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-1.051648	1.302492	-0.807412	0.4231
LL	0.110544	0.142062	0.778138	0.4400
LF	0.549744	0.100531	5.468407	0.0000
LS	0.507781	0.101079	5.023619	0.0000
LP	0.077987	0.067624	1.153243	0.2541
R-squared	0.775833	F-statistic		44.99260
Adjusted R-squared	0.758590	Prob(F-statistic)		0.000000
Durbin-Watson stat	1.882819	Observations		57

Note: C is constant, LL is log of labor, LF is log of fertilizers, LS is log of seeds and LP is log of pesticides.

Source: Authors' estimation based on field survey data (October 2012).

Tables 4 and 5 show that crop production functions recorded decreasing returns to scale. The equations 2 and 3 estimated can be considered as reliable on the basis that at least one of the input coefficients are significantly different from zero at the 5 percent level of confidence.

In addition, the reliability of the estimated model of crop production is also guaranteed by the results of the test of normality of errors given in Figure 2. This figure shows that the JB statistic (1.377011) is not significantly different from zero at the 5 percent level since its probability is 0.502326, that is p>0.05. This implies that the errors of the estimated agricultural production function are normally distributed. Consequently, the model estimated is reliable and can be used for making predictions and also for forming policy.

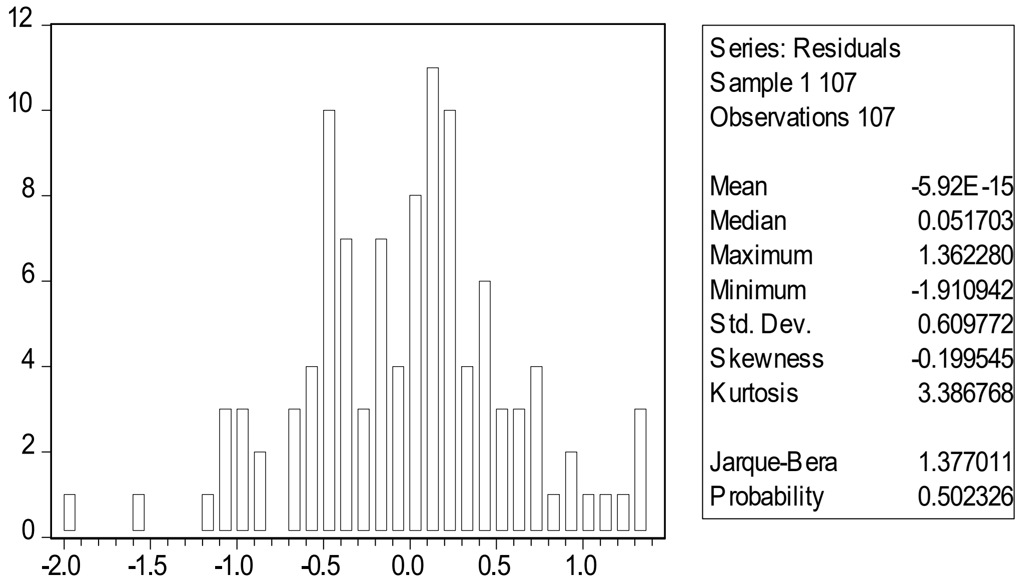

Figure 2: Histogram of residuals of estimated agricultural production function in Musanze district

The results in Table 3 are transformed and presented in Equation 4 so that they can be used for making predictions.

(4) $Y = 1204.56L^{-0.06}F^{0.06}S^{0.62}P^{-0.14}$

The estimated equation 4 shows a positive relationship between potato output and labor, fertilizers, seeds and pesticides. This means that potato production increases with an increase in labor, fertilizers, seeds and pesticides. The sum of coefficients is 1.25 which shows increasing returns to scale.

The test of significance shows that fertilizers and seeds are statistically significant at the 5 percent level of significance. The R^2 estimated as 0.77 shows that 77 percent of the variations in potato production are explained by the explanatory variables included in the model. The first input that contributes significantly to potato production is fertilizers as it has an elasticity of 0.55, followed by seeds for which the elasticity is 0.51.

The results in Table 4 can be used to predict potato production in Musanze district by referring to the exponential Cobb-Douglas production model described by:

(5) $Y = 0.35L^{0.11}F^{0.55}S^{0.51}P^{0.07}$

From this estimation, both the overall crop production function and the bean production function record decreasing returns to scale whereas the potato production function records increasing returns to scale. The equations 2 through 4 estimated (including the overall estimation of production function) can be considered as reliable because at least one of the input coefficients is significantly different from zero at the 5 percent level of confidence.

In addition, the reliability of the estimated model of crop production (overall estimation) is also guaranteed by the results of the test of normality of errors given in Figure 2. This figure shows that the JB statistic (1.377011) is not significantly different from zero at the 5 percent level of significance since its probability (0.502326) is greater than the level of significance. This implies that the errors of the estimated agricultural production function are normally distributed. Consequently, the model estimated is reliable.

Determinants and returns to scale of agricultural production in Musanze District,

Our study shows that the labor input is positively and significantly correlated to crop production ($\beta_1 = 0.24$ and p-value =0.0045). This is supported by Ike (1977), Bhujel and Ghimire (2006), Olujenyo (2008), Wakili and Isa (2015), Fakkhong and Suwanmaneepong (2016) and Fawole and Rahji (2016); and contrasted by Mpawenimana (2005), Armagan and Ozden (2007) and Alao and Kuje (2010).

Fertilizers are positively and significantly correlated with the agricultural production function ($\beta_2 = 0.49$ and $p-value = 0.0000$). These results are supported by the findings of Ike (1977), Mpaewenimana (2005), Bhujel and Ghimire (2006), Armagan and Ozden (2007), Wakili and Isa (2015) and Fawole and Rahji (2016). Seeds are also positively and significantly related to agricultural output in the study area ($\beta_3 = 0.24$ and $p-value = 0.0000$). This is supported by Armagan and Ozden (2007) and Wakili and Isa (2015).

Pesticides also show a positive but not significant correlation with agricultural production ($\beta_4 = 0.024$ and $p - value = 0.5786$). This positive relationship between pesticides and agricultural production is supported by Armagan and Ozden (2007) and Wakili and Isa (2015). Fawole and Rahji (2016) also support this relationship when they consider fungicides, but our findings are in contrast when these two authors assess the effects of insecticides on agricultural production in their study area.

The sum of input elasticities with respect to agricultural output is 0.99, which shows that agriculture recorded decreasing returns to scale. This is supported by Ike (1977), Olujenyo (2008) and Fawole and Rahji (2016).

4. Conclusion and policy recommendations

Our study examined the effects of input allocation on agricultural production with special focus on crops grown by farmers' organizations in Musanze district. We analyzed cross-section data collected in August-September 2012 mainly using the ordinary least squares method. The overall crop production function is positively related to inputs used which include labor, fertilizers, seeds and pesticides. The test of significance shows that the significant inputs were fertilizers, labor and seeds at the 5 percent level of significance. The production function for potatoes showed a positive relationship between output and labor, fertilizers, seeds and pesticides. The test of significance shows that the significant inputs were fertilizers and seeds at the 5 percent level of significance. In the same way, the production function for beans showed a positive relationship between bean output and fertilizers and seeds and a negative relationship between output and labor and pesticides. The negative relationship between bean output and fertilizers could be due to the low use of fertilizers in bean production whereas the negative relationship between bean output and seeds could be explained by the use of traditional seeds instead of high-yielding varieties. The test of significance showed that the significant input was only seeds.

As some inputs are statistically significant, the estimated production functions are considered reliable. In addition, the overall production function recorded decreasing returns to scale of 0.99, and the individual production functions recorded 0.48 and 1.25 for the bean production function and potato production function respectively. The decreasing returns to scale imply that individual farmers' organizations have not achieved the least-cost combination of inputs.

For further improvements in agricultural production in the study area we make the following recommendations: Farmers, farmers' organizations and agricultural partners should enhance the use of fertilizers; farmers and farmers' organizations should reallocate inputs rationally so as to attain the least cost-input combination; and farmers and farmers' organizations should improve their equipment by adopting modern agricultural tools and new technological methods through the introduction of motor driven equipment where applicable. Farmers should also have more access to extension services to get more information on farm management; land protection should be improved to maintain or increase productivity. The government should enhance and extend the use of subsidized fertilizers. Land protection should be improved to maintain or increase productivity. Finally, the government and other agricultural development agencies should promote actions that guarantee markets to farmers through, for example, contract farming.

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Appendix A. Operation zone of program *DERN* in Musanze district