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Forecasting cereals production based on regression and back-propagation (BP) network model in Eastern Province, Rwanda

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In developing countries such as Rwanda whose economy depends on agriculture and where more than 70% of the population relies on rain-fed agriculture for their livelihoods and which is among the highly populated countries in the world, changes in temperature, precipitation, humidity and arable land extremely affect the agricultural production. In response to these changing risks, forecasting cereals production study based on regression and back-propagation (BP) network model was carried out in Eastern Province of Rwanda. 22 years data from 1989 to 2010 of temperature, precipitation, humidity, percentage of cultivated area and cultivated area were taken as dependent variables and cereals production in the same period was considered as independent variable for the regression, while temperature, precipitation, humidity, percentage of cultivated area and cultivated area constituted the input variables to build BP Network model for forecasting cereals production. The model was consistently verified; results were efficient and showed that the general trend of cereals production in Eastern Province of Rwanda is increasing.

Key words: Cereals production, regression, back-propagation (BP) Network model, forecasting, Eastern Province of Rwanda.

INTRODUCTION

As reported by Hertz et al. (1991), artificial neural networks (ANNs) are used to solve a wide variety of problems in science and engineering, particularly for some areas where the conventional modeling methods fail, and a well-trained ANN can be used as a predictive model for a specific application, which is a data-processing system inspired by biological neural system.

The neurons can be classified into three types: input, output and hidden; input neurons are the ones that receive input from the environment, output neurons are those that send the signals out of the system and neurons which have inputs and outputs within the system are called hidden neurons (Poursina, 2008; Zhou and Kang, 2005). According to (Mrutyunjaya et al., 2011), the input signals are modified by interconnection weight, known as weight factor (w_{ij}), which represents the

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interconnection of i^{th} node of the first layer to j^{th} node of the second layer; the sum of modified signals is then modified by the transfer function. In this paper 'tansig' function was used. Similarly, output signals of hidden layer are modified by interconnection weight (w_{ij}) of k^{th} node of output layer to j^{th} node of hidden layer. The sum of the modified signals is then modified by another transfer function. This paper applied 'purelin' function and output is collected at output layer.

Among learning algorithms, BP algorithm is a widely used learning algorithm in ANNs and the BP neural network architecture is capable of approximating most problems with high accuracy and generalization ability based on the error-correction learning rule (Dutta et al., 2009).

An ANN is a mathematical algorithm which has the capability of relating the input and output parameters, learning from examples through iteration, without requiring a prior knowledge of the relationships of the process parameters, its structure is relatively simple, with connections in parallel and sequence between neurons, this means a short computing time and a high potential of robustness and adaptive performance (Torrecilla et.al., 2004; Palancar et al., 1998). Today, the Artificial Neural net is widely used for pattern recognition matters and it can be used to describe the nonlinear relationship between different parameters (Xing and Fuqiang, 2007; Kim and Kim, 2000).

BPANN is a computational tool that has found extensive utilization in solving many complex forecasting problems such as predicting flow stress, (Wu et al., 2001), forecasting rolling force, (Gunasekera et al., 1998), optimizing the irregular shape rolling process, (Kim et al., 2001), predicting spring back in metal forming, (Inamdar et al., 2000); predicting fatigue life of carbon steel, (Todd and Chopra, 2000), predicting fracture toughness in microalloy steel, (Haque and Sudhakar, 2002) and cereals production in this paper.

MATERIALS AND METHODS

Study area description

According to (MININFRA, 2004), Eastern Province occupies 37.26% of the total surface of Rwanda that is, 9,813 km^2 over 26,338 km^2 which is the total area of Rwandan surface and is made up of 7 districts; Bugesera, Gatsibo, Kayonza, Ngoma, Kirehe, Nyagatare and Rwamanaga. It is home to more than 2.1 million people, bordered in the north by Uganda, in the east by Tanzania and in the south by Burundi and it boasts fertile agricultural land, producing crops from cereals (rice, sorghum, maize, wheat) to strawberries, beans to coffee and vegetables to vanilla (MINAGRI, 2011). Note that Rwanda is located in the East of Central Africa between 1°04 and 2°51 latitude south, and between 28°45 and 31°15 longitude east (MINITERE, 2002). Eastern province's lush pastures support the cows which produce milk for the nation, as well as sheep, goats, poultry and bees and it is home to Akagera National Park shared by more than 500 species of bird, and animals including giraffe, elephant, rhino and hippopotamus (MINITERE, CGIS-NUR, 2007). Akagera National Park protects the myriad collection of lakes and marshes that are fed by the Akagera River (MINITERE, 2004). The Eastern Province is a relatively low-lying and flat region where the Albertine Rift descends into Tanzania and its climate is a bit humid and warmer than other provinces of the country (MININFRA, 2004).

According to (MINITERE, 2006), the degradation of environment and ecosystems in East province is a phenomenon caused by both the anthropogenic activities and climate disturbances. Normally in Rwanda, the principal factor that controls the rainy seasons is the inter-convergence zone (ITCZ), low pressures, the maximum of humidity and the convergence of winds characterize this one, it crosses Rwanda twice a year and determines two rainy periods: from mid-September to mid-December and from March to May. There are two dry seasons, a short dry season from January to February and a long dry season from June to September, as well as two wet seasons, one from October to December and another from March to May, (Okoola, 2001), but East province is the driest province of Rwanda with annual average rainfall of 600 to 1400 mm, temperature from 15 to 24°C, evapotranspiration of 1400 to 1700mm, relative humidity 50 to 80%, insolation of 6 to 6.5 h a day and wind of 4 to 6 km/hour, (Chemonics, 2003), while according to the same author, Rwanda as a country in general has a temperate continental tropical climate, in the course of the year, temperatures vary between 16 and 17°C in the high altitude region, between 18° and 21°C in the Central Plateau, and between 15 and 24°C in the lowlands of the East and West. Annual rainfall varies between 600 and 1400 mm in the lowlands of the East and West, between 1200 and 1400 mm in the Central Plateau, and between 1400 and 2000mm in the high altitude region. More details for the study area are shown on the Figure 1.

Methodology

This study used Matlab to generate regression and BP Network model. Matlab was also used to produce the representative figures in the whole process. (GIS) Arcmap 9.3 and origin pro 8 were also used to produce the study area map, figures and correlations between parameters. The precipitation, humidity and temperature data of 22 years from 1989 to 2010 were collected from Rwanda Meteorology Office while those of cereals production, percentage of cultivated area and cultivated area were collected from the Rwandan Ministry of Agriculture and Animal Resources. First we calculated the regression equations and lines for rainfall, temperature, humidity, percentage of cultivated areas and cultivated areas, next we used those equations to forecast those parameters. Finally those data from regression were used to forecast cereals production using BP Network model.

Design of BPANN model based on MATLAB

BP network generation and initialization

The function newff of MATLAB7.1 neural network toolbox was used to create BP Neural Network and the common format of that function was applied, as shown by the following equation: newff (P,T,[S1 S2...SN],{TF1 TF2...TFN}, BTF,BLF,PF) where P is the R × Q matrix of Q sample R-element input vectors, T is the SN x W matrix of W sample SN-element target vectors; Si is the size of i^{th} layer, for N layers (Output layer size SN is determined from T.); TFi is the transfer function of i^{th} layer. ('tansig' for hidden layers and 'purelin' for output layer have been used), BTF is the BP network training function ('trainlm was applied'); BLF is the BP weight/bias learning function ('learngdm' was utilized); PF is the performance function, ('mse' was used). The same methodology has been applied in other studies such as (Fu et al., 2002, Zhang et al., 2009; Xing and Fuqiang, 2006).

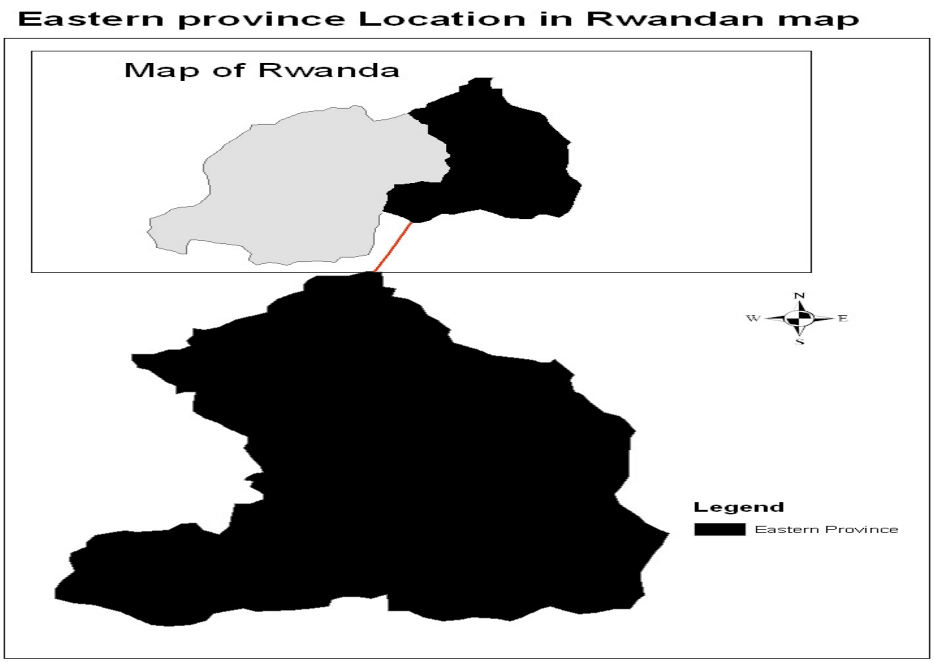

Figure 1. Location of Eastern Province in the map of Rwanda.

Training

The training process requires a set of examples of proper network behavior-network inputs p and target outputs t. During training the weights and biases of the network are iteratively adjusted to minimize the network performance function net perform Fcn. The default performance function for feed forward networks is mean square error mse which means the average squared error between the network outputs a and the target outputs t. In this paper the basic back propagation training algorithm, in which the weights are moved in the direction of the negative gradient was applied and the following train function was used. [net,tr] = train (net,p,t), The training record tr contains information about the progress of training and you can simulate the trained network to obtain its response to the inputs in the training set by a = sim (net,p). Note that p is the network inputs vectors while t represents the target output vectors. The same procedure was applied in other studies such as (Fu et al., 2002, Zhang et al., 2009, Xing and Fuqiang, 2006).

RESULTS AND DISCUSSION

To build BP network model, the following structure has been applied: Input layer node number: 5, Output layer node number: 1, hidden layer node number: 8 hence the topological structure of BP Network is 5:8:1.

The Neural Network Toolbox function *newff* was adopted to generate a BP Network, in the *newff*, some parameters were fixed. The *tansig* function was used as the transfer function between input layers and hidden layers, while that between output layer and hidden layer was *purelin*. The data from 1989 to 2005 were taken as training sample for fitting, while the remaining from 2006 to 2010 was used for forecasting. The maximum training number was set to 10000 and error performance goal was set to $10^{-5.}$ After 6 times training, the error tends to be steady. See figures for more details.

The model was consistently verified and results were efficient to forecast cereals production, since the fitting effect evaluation indexes: posterior error value was very small C = 4.0238e-005 as it is suggested that it should tend to zero, there has been small error frequency P = 1 which satisfies the requirement for P, relative mean square error E_1 = 0, and fitting accuracy E_2 = 1 also fulfilled the requirements for applying the model.

As shown by Figures 2 to 5 and Tables 1 and 2, cereals production in Eastern Province of Rwanda highly depends on percentage of cultivated area, cultivated area and less on the precipitation, temperature and humidity, either linear or polynomial correlations before or after forecasting revealed that dependence. The first two parameters tend to have more impact on the cereals production but they are related to the governmental policies and these recent years they were increasing but later they will not continue to increase as the country's land remains the same. Recently the government of Rwanda initiated new fields to grow cereals and established new policies of land consolidation and crop regionalization through crop intensification program where East Province was worthy to grow cereals.

According to (MINAGRI, 2011), due to the growing demographic pressure on land, in Rwanda, the agricultural lands are highly fragmented and the profitability for smallholder farmers can be enhanced only if the land fragmentation is overcome in order to ensure the best land management with maximum benefit and minimum land wastage. For this reason in 2007, through

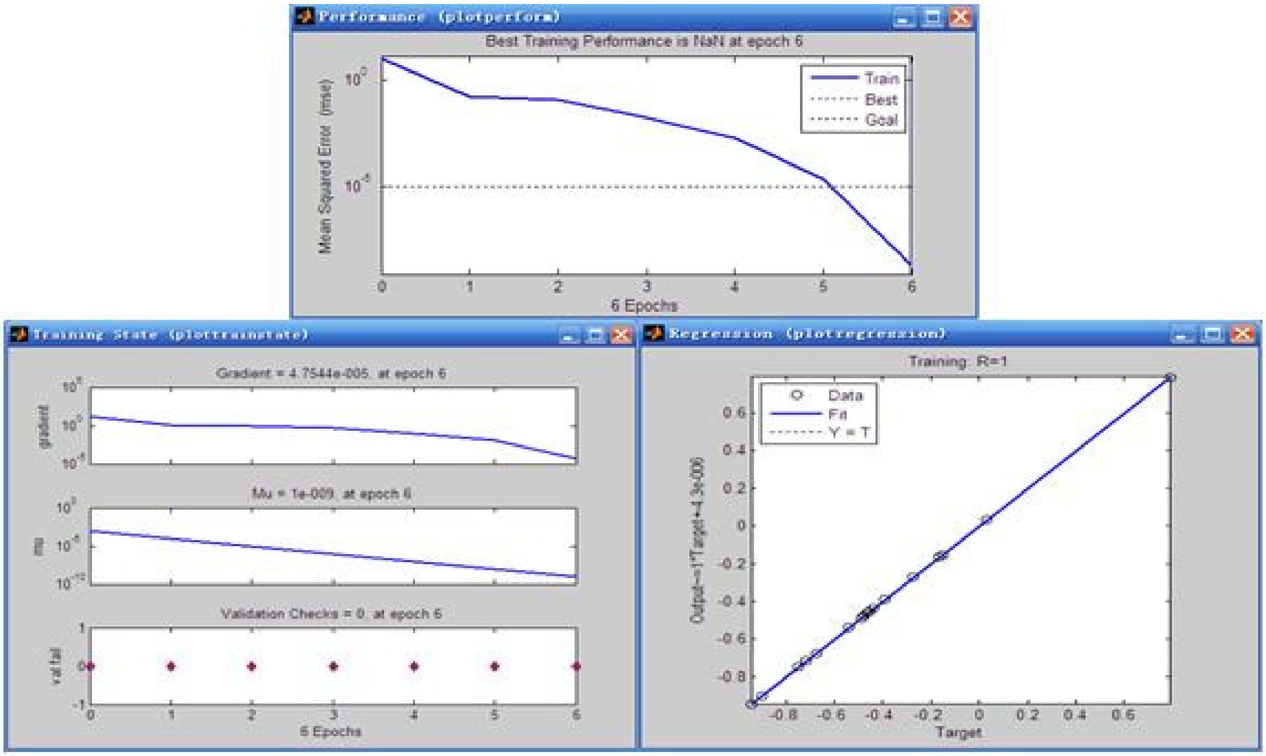

Figure 2. Solving process figures.

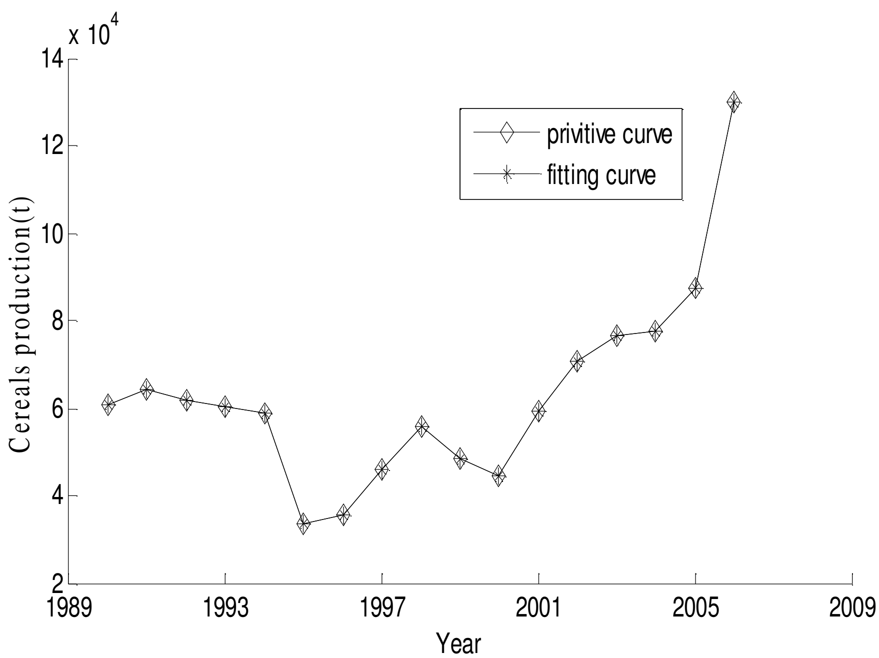

Figure 3. Primitive and fitting curves for cereals production

the crop intensification program, the regionalization of crops and consolidation of land use policies were launched as a pilot program with the main goals of increasing agricultural productivity in high-potential food crops and ensuring food security and self-sufficiency and cereals were among the first targets (IFDC/CATALIST

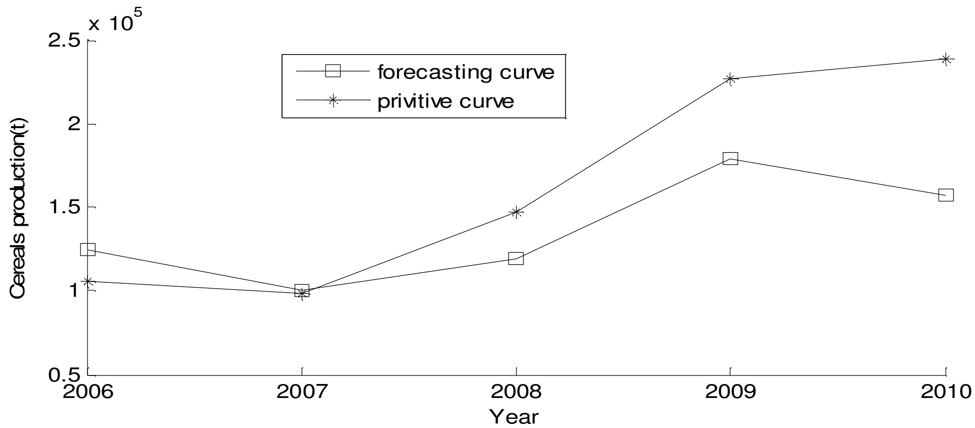

Figure 4. Forecasting testing figure.

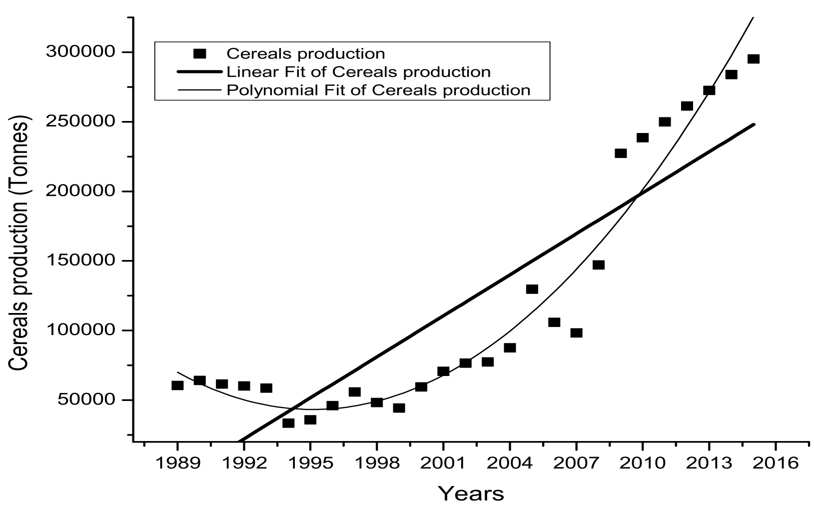

Figure 5. Cereals forecasting results and original data figure with trend lines.

Table 1. Forecasting results for all parameters.

Year	Cereals production (T)	Temperature (℃)	Precipitation (cm)	Humidity (%)	% of cultivated area	Cultivated area (ha)
2011	249967	19.942	77.249	73.073	21.882	102410.23
2012	261279	19.984	77.108	73.016	22.244	105504.79
2013	272591	20.026	76.967	72.959	22.606	108599.35
2014	283903	20.068	76.826	72.902	22.968	111693.91
2015	295215	20.11	76.685	72.845	23.33	114788.47

and MINAGRI, 2010). These policies involve successfully rearrangement of land parcels into consolidate use of farm holdings. Under this program, farmers in a given area need to grow specific food crops in a synchronized

Table 2. Correlations between cereals production and other parameters.

Parameter	linear correlation before prediction	Polynomial correlation before prediction	linear correlation after prediction	Polynomial correlation after prediction
Temperature	0.205	0.462	0.084	0.531
Precipitation	0.013	0.052	0.012	0.04
Humidity	0.02	0.175	0.009	0.037
Cultivated area (%)	0.929	0.934	0.712	0.854
Cultivated area	0.823	0.908	0.814	0.924

fashion that will improve the productivity and environmental sustainability, crop choice is motivated by agro-bio climate conditions and economic potential, and then there will be exchange of crops' productions between different regions. It also required the resettlement of family housing in a grouped settlement from the agriculturally productive lands. Among the advantages of land consolidation and regionalization of crops reported by (MINAGRI, 2011), we have the increase of arable land and crop productivity; increase of the accessibility of inputs by providing a focused market for farm inputs as the agro dealers can have a larger coverage; improvement of economic growth in rural areas by raising employment in the farms which represents the only means for the majority of poor people to satisfy their basic needs; increased coverage of proximity extension services; integrated and coordinated agricultural production efforts of individual landholdings; facilitation in the achievement of a unified production situation characterized by collaboration in types of crops grown, sale or processing of agricultural products and/or distribution and marketing of agricultural products and helps to address other issues such as erosion control under radical terracing scheme, rainwater harvesting and management, extension work, hillside irrigation, crop protection etc.

So considering all those advantages, it is very clear that land consolidation and regionalization of crops policies have a crucial role in forecasting agricultural production in Rwanda in general and cereals production in Eastern Province in particular as East province has been favorable for growing cereals. Thus because crops are planted where they are worthy and they are cultivated to the large areas, obviously their production will also increase.

As discussed above, one way which was used by Rwandan Government to improve the agricultural production in recent years is to increase the arable land, but this increasing has a limit and at last, it will be stable or reduced as it does not depend only on the government decision but also on the size of the cultivated area and country's total area in general, for these reasons other factors such temperature, rainfall, humidity and agricultural policies, should be given priority since they are changing and it is difficult to plan their changing as the world is facing a general serious problem of climate change. Another reason to support these factors is the physico-geography of the East province of Rwanda, which is the poorest region in rainfall with high insolation and dominated by lowlands (Chemonics, 2003).

As the previous forecasting figures show, even though the general trend of cereals production in East Province is positive but during the study period of 22 years there have been some variations. From 1989 to 1993, the production was almost the same with a little variation, from 1993 to 1996, the production decreased dramatically, the reason was the war which took place in Rwanda and many people were killed while others left the country to search for refuge in neighbor and other far countries, for that reason the cultivated area imposingly decreased also. From 1996 to 1998 the cereals production increased again and decreased in the period 1998-1999 due to climatic disturbance. From 2000 until now the production is increasing, this is the result of combined favorable climatic conditions, improvement of irrigation and new agricultural governmental policies.

The forecasting results show that the cereals production will continue to increase as shown on the fig.5 with correlation (R^2) for polynomial fit of 0.94 and 0.75 for linear fit, but in accordance with favorable precipitation, temperature, humidity and agricultural policies. Also agricultural techniques should continue to be improved to maximize the production considering that the arable land will not continue to increase while the demand for cereals will continue to rise as the number of the population increases.

CONCLUSION AND RECOMMENDATIONS

The results proved that, the regression combined with BPANN model was sufficient enough in predicting cereals production in Eastern Province of Rwanda. BPANN provided accuracy and simplicity in the analysis. The analysis provided good correlation between the predicted data from the BPANN and the measured ones. This model was efficient to forecast cereals production in Eastern Province of Rwanda since it takes into account the key determinant factors for agricultural production in that area. Even though the cultivated area and percentage of cultivated area seem to play an important role in cereals development in East Province of Rwanda because there are areas which are newly cultivated, and favorable new policies of land consolidation and crop regionalization; other factors such as precipitation, temperature and humidity should be the first to prioritize because they are and they will continue to change while at a certain period the cultivate areas and percentage of cultivated area will decrease or remain static.

East Province is the poorest province of Rwanda in precipitation and there is a lack of water especially during the long dry season June to September, so it is suggested to improve the techniques for harvesting or collecting raining water during the raining seasons in order to use it during the dry seasons especially in irrigation so that they can grow cereals the whole year. This is because in Rwanda, the climate is governed by the topography and the precipitation increases from East where the relief is characterized by lowlands to west which is dominated by high mountains and volcanoes.

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