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Multivariate Typology of Farm Households Based on Socio-Economic Characteristics Explaining Adoption of New Technology in Rwanda.

J.C. Bidogeza[a], P.B.M.Berentsen[a] , J.De Graaff[b] and A.G.J.M. Oude Lansink[a]

[a] Business Economics Group/Wageningen University, Netherlands.

[b] Erosion and Soil and Water Conservation Group/Wageningen University, Netherlands

Abstract

The challenge for agricultural policymakers and planners, particularly in the context of Rwanda with high population density and consequently food insecurity, is how to enable farmers to adopt new technology. It is known that adoption of new technology may vary among farm households because of socio-economic characteristics. This paper intends to typify farm households in Rwanda based on the exploration of factors explaining adoption of new technology. Ultimately, typical farms obtained from the typology will be used, later as basis to develop representative mathematical programming models. Multivariate statistical techniques offer the means of creating such typologies, particularly when an in-depth database is available. This multivariate analysis approach, combining principal component analysis (PCA) and cluster analysis (CA), has allowed us to identify clearly five typical farm households and their socio-economic characteristics explaining adoption of new technology.. Multivariate statistical techniques, such as PCA and CA, are great tools to envisage building mathematical programming models on the basis of typical farm households.

Introduction

The challenge of achieving economic and sustainable use of natural resource in the face of high population density and consequently food insecurity is overwhelming for Rwanda. The population density has risen rapidly over the last three decades and is now the highest in Africa with an average of 380 people per km^2 arable land. Rural densities of more than 700 people km^{-2} are no exception (Service National de Recensement, 2005). The augmenting population pressure on land and water resources leads to the degradation of these resources, which often results in the loss of the production capacity and increasing food insecurity. Rwanda's farmers have responded to land use pressure and affiliated declining productivity by farming extensively and pushing onto the fragile bottomlands and steep slopes. This situation has led to an overexploitation of natural resources and increased soil loss due to erosion, and, along with it, declining soil fertility.

Research has focused, for nearly 20 years, on the development and promotion of low cost technology such as agroforestry, fast-growing nitrogen-fixing legumes for improved fallows, inter-or relay-cropping of green manure, farmyard manure, composting, mulching systems and combining green manure and others fertilizers (Drechsel et al., 1996 and Drechsel and Reck, 1998). However, despite the positive effects of these new technologies on nutrient cycling, reduction of soil loss, crop yields, fodder and firewood production, their adoption has remained low (Drechsel et al., 1996). Raquet and Neumann (1995) concluded that according to the experiences of Projet Agro-pastoral in Southern Rwanda the concept of improving soil fertility with new technology such as green manure has failed. Promoted new technology has not matched with socio-economic circumstances. There is a tendency to assume homogeneity in farming population, particularly with respect to socio-economic variables. So far no study has been undertaken to get insights into the farm households' profile with regards to the adoption of new technology. Differences in adoption could, therefore, be highlighted by farm typology. The resulting farm types will be used as basis for developing representative mathematical programming models of typical farms in Rwanda to study different aspects of adoption of new technology.

It is known that adoption of new technology may vary among farm households because of differences in their socio-economic characteristics (Feder and Umali, 1993 and Graaff, 1996). A farm typology study can be used to classify groups of farm households with similar, socio-economic characteristics with respect of adopting new technology. Typology constitutes an essential step in any realistic evaluation of the constraints and opportunities that exist within farm households. Typological studies can therefore be of great importance for exploring factors explaining adoption of new technology (Kostrowicki, 1977). Multivariate statistical techniques offer the means of creating such typologies, particularly when an in-depth database is available. Use of multivariate statistical techniques, such as principal component analysis and cluster analysis, for identifying farm household types has been applied before by Gebauer (1987), Hardiman et al. (1990), Köbrich et al (2003), Usai et al. (2006).

The objective of this paper is to develop a typology of farm households in east region of Rwanda, based on the exploration of factors explaining adoption of new technology. The different types of farm households obtained from the typology development will yield specific key information needed to understand and diagnose problems and opportunities for change with regards to the adoption of new technology. For the purpose of this study, a new technology will be considered as any agricultural practice or input that may have abilities to increase productivity directly or indirectly.

Materials and methods

Area of study

The research for this study was conducted in Umutara, a former province located in the eastern part of Rwanda. Umutara belongs almost entirely to the driest agro-climatic region of Rwanda. The province, with an altitude between 1,000 and 1,500 m, enjoys two rainy seasons annually. The annual range is 800 – 1000 mm.

In the context of Umutara, a household is principally defined as a nuclear family consisting of father, mother and children. In some households relatives mainly orphans who lost their parents during the genocide or from HIVs are adopted into nuclear family. The average size of the household is 5 – 8 individuals (Mowo et al., 2006). On average, land size per household ranges from 0.25 to 2.0 ha. Land is generally owned by men. In case of death, widows become land owner.

The main source income is from the sale of crop and livestock products. Others sources of income especially for men include: crafts work, construction/masonry, selling of labor to other farmers. Iinformal trade is an important source of income for both genders. Both men and women spend their income on medical services, self-sustenance, clothing and leisure. Expenditure on leisure is higher for men than women. A wide range of crops is grown in Umutara mainly for subsistence purpose. Mixed cropping is common. Choice of crops is dictated by climatic conditions, availability of market outlets and ease of crop management. Maize and beans are the most important crops. Use of inorganic fertilizers is rare due to their limited availability and high prices. Due to the importance of animal husbandry in the area, organic manure is used, at large extent, to fertilize various crops.

Data collection

The information from the former Umutara province was collected in 2004 and 2005 by the National Institute of Statistics of Rwanda within the scope of agricultural farm survey held twice (corresponding to two rainy seasons) every year. These farm household-level data were recorded using a structured questionnaire which was completed by 96 farm households selected randomly in Umutara. The selection of farm households incorporated all kind of farming practices in Umutara. Data collected includes both qualitative and quantitative information and cover the socio-economic characteristics of farm households, farm characteristics, resource availability, technological options, etc. Approximately, 100 variables have been recorded for each farm household. In addition to this information, a small survey was conducted in 2006 through informal interviews regarding characteristics of farm households, state of new technology adoption, production orientation, accessibility to market and credit, price formation, major constraints to farming, etc. The survey is supposed to help us to understand the outcome of this research.

Multivariate statistical analysis

Farm household data were analyzed and farm household typologies were constructed by using two multivariate statistical techniques, respectively Principal Component Analysis (PCA) and Cluster Analysis (CA). The purpose of PCA is to transform linearly an original set of variables into a substantially smaller set of uncorrelated variables that represents most of the information in the original set. A small set of uncorrelated variables is much easier to understand and use in cluster analysis than a larger set of correlated variables (Jolliffe, 1986). Prior to the analysis with PCA, it was necessary to check whether the data set is appropriate to be factored. In other words, is PCA appropriate for our data set?

Table1: Description and summary statistics (mean and standard deviation) of the variables used with PCA

Name of variable	Description	Mean	Std. Deviation
Personal attributes of Head of Household			
Sex	=1 if HH is male, 0 otherwise	.66	.47
Age	=Farmer' age in years	43.34	16.91
Family size	=Number of Household members	4.8	2.36
Farm size			
Farm size	= Farm size in Ha	1.73	3.29
Education			
Literacy of the head of household	=1 if Literate, 0 otherwise	.54	.50
Level of Education of the head of household	=1 Finished primary and post primary, 0 otherwise	.25	.43
Educated family member	= Number of educated Household member	.80	1.04
Risk perception and risk attitude			
Off farm activity	=1 if participate in off-farm activity, 0 otherwise	.55	.49
Crops per season	=Number of average crops per season	5.64	1.85
Income			
Returns per hectare	=Total returns (crops&livestock) per hectare in thousands of Rwandese francs	566.79	1266.05
Off farm member	= Number of off farm household members working outside of the farms	.79	1.00
Labour Availability			
On farm member	= Number of on farm household members working on the farms	2.20	1.06
Land Tenure			
Tenure	=1 Ownership, 0 if otherwise	.93	.24
Technological Attributes			
Fallow	=1 if applying, 0 otherwise	.43	.49
Manure	=1 if applying, 0 otherwise	.31	.46
Compost	=1 if applying, 0 otherwise	.30	.46
Green manure	=1 if applying, 0 otherwise	.32	.47
Mulching	=1 if applying, 0 otherwise	.28	.45
Improved seed	= Quantity of improved seed in Kilogram	2.8	11.36
Fertilizers	= Quantity of Chemical fertilizer in Kilogram or Litres	.21	1.57
Pesticides	=Quantity of Pesticide in kilogram or litre	.64	2.73
Improved livestock	=Number of improved livestock	.23	1.58

The Bartlett's sphericity has been performed to address this question (Lattin et al, 2005 and Field, 2005). Selection of 23 variables (Table 1) were used to construct factors using PCA. The number of factors has been retained according to Kaiser's criterion that suggested retaining all factors with eigenvalues greater than 1.

This has been emphasized by research indicating that Kaiser's criterion is accurate when the number of variables is less than 30, which is the case for our data set (Field, 2005). This approach should allow a large part of the total information to be concentrated in a small number of uncorrelated variables

Next, factors retained from the PCA, were used in cluster analysis. Cluster analysis seeks to typify entities (farm households) *M = (M1, M2, M3…)* according to their (dis)similarity in terms of their attributes represented by the variables chosen *N1, N2, N3…€ M* (Everitt, 1993 and Alfenderfer and Blashfield, 1984*)*. Entities within a certain group (cluster or class) should be very similar to each other and entities belonging to different classes should be very dissimilar.

Results and Discussion

The preliminary Bartlett test has been performed in order to check whether the data set of 96 farm households and 23 variables can be factored or not. Results of the test have shown that Bartlett's sphericity is highly significant, and the test statistic is much greater than the critical value. This means that it is justified to perform some form of dimension reduction.

PCA was undertaken on 23 variables shown in Table 1. Nine principal components with eigenvalues greater than 1 have been retained for cluster analysis. These new variables (components or factors) explained 72% of the total original variability

The nine components retained were used in cluster analysis, both with the hierarchical and the partitioning method in order to ensure the stability of clusters (Hair, 2006). Firstly, the nine components were used for cluster analysis with Ward's technique as the clustering method. The number of clusters to be retained should be realistic, conformed to the real situation, and accepted as a meaningful classification. Nine clusters, among which three were single clusters and 1 pair cluster, are retained. The three single clusters and the cluster with two entities are discarded as we concluded that they are too different from the rest of the sample. The remaining five clusters seem to be realistic, and furthermore conform to the real situation according to the information from our field work conducted in 2006. The results obtained for the 5 clusters are reported in Table 2 with test-statistic of one-analysis of variance .

Given the typology established, a question might be posed: what are the characteristics to be expected to differ across the 5 clusters with respect to adopting new technology. Factors sex, age, literacy, level of education, off farm activity, off farm member, tenure, farm size, seems to be significantly important in differentiating all clusters with respect to adoption all technological options except pesticides (Table 2).

Cluster I, which accounts for 26% of the farm households, is dissociated from others by the strong discriminating power of the variable sex. Thus, cluster I counts largely female-headed household. These female headed household are either widows due to the genocide or have husbands in prison on account of suspected participation in the genocide. Furthermore, the cluster is more or less lacking off farm activities, but has relatively high returns per hectare. The cluster practices farming with an outstanding use of compost, green manure and improved seed. In the light of this cluster compared to other clusters, being male and female headed household do not make a difference in the adoption of some technologies e.g. fallow, manure, compost, green manure, mulching, improved seed, SWC; but difference can be seen in the rate of adoption. Constraints faced by female headed household like low level of education and small farm size prevent them to adopt some technologies, e.g. chemical fertilizer which is costly and requires possession of greater technical knowledge.

Cluster II comprises 7% of the farm households. The variable tenure has high discriminating power in distinguishing cluster II from other clusters. Farm households are landless, they are land tenants. Moreover, the cluster has the smallest farm size with an average of 0, 3 hectare. However, high returns per hectare and high ratio of labour use over farm size are observed in that cluster. Farm households intensify farming with a relatively high use of green manure. It is widely believed that green manure is an effective way of improving soil fertility and is high labour demanding technology (Drechsel and Reck, 1998).

Table 2: Characteristics of selected clusters and test statistic of one-way analysis of variance.

	Cluster I N=24 Female Headed Household	ClusterII N=6 Tenant Farm Household	ClusterIII N=28 Male&Literate Farm Household	ClusterIV N=17 Illiterate& Full farm Household	ClusterV N=16 Large Farm Household	Cluster Means	Standard Deviation	P Value
Personal attributes of Head of Household								
Sex	0.16	0.5	1	0.8	0.6	0.65	0.47	0.00
Age	48.9	41.5	31	48.2	52.6	43.4	17.2	0.081
Family size	3.9	4	4.3	5.6	6.06	4.7	2.3	0.69
Farm size								
Farm size	0.53	0.30	0.75	0.92	6.43	1.69	3.34	0.00
Education								
Literacy of the Head	0.5	0.66	0.96	0.11	0.25	0.53	0.50	0.00
Level of Education of the Head	0.2	0.16	0.60	0.00	0.00	0.25	0.43	0.00
Educated family member	0.66	0.66	1.17	0.52	0.62	0.79	1.05	0.44
Risk perception and risk attitude								
Off farm activity	0.33	0.50	0.71	0.17	0.93	0.53	0.50	0.00
Crops per season	5.45	5.58	6.33	6.17	4.2	5.6	1.88	0.71
Source of cash								
Returns per hectare	555.68	755.83	514.66	431.11	123.78	457.05	545.94	0.07
Off farm member	0.41	0.50	0.92	0.17	1.43	0.71	0.92	0.05
Labour availability								
On farm member	1.5	1.8	2.1	3.2	2.2	2.17	1.07	0.09
Land tenure								
Tenure	1	.00	1	1	1	0.93	0.24	.00
Technological Attributes								
Fallow	0.5	0.33	0.5	0.58	0.06	0.43	0.49	0.00
Manure	0.37	0.16	0.1	0.58	0.18	0.28	0.45	0.00
Compost	0.66	0.16	0.14	0.35	.00	0.29	0.45	0.00
Green manure	0.54	0.66	0.25	0.29	0.00	0.31	0.46	0.00
Mulching	0.29	0.16	0.39	0.17	0.12	0.26	0.44	0.001
Improved seed	1.87	0.00	1.5	0.58	0.00	1.06	4.17	0.027
Fertilizers	0.00	0.00	0.17	0.05	0.00	0.06	0.38	0.004
Pesticides	0.28	0.16	0.46	0.65	0.16	0.38	0.98	0.244
Improved livestock	0.04	0.00	0.00	0.00	0.43	0.08	0.43	0.00
Soil and water conservation measures	0.41	0.33	0.46	0.82	0.00	0.32	0.47	0.00

Thus, affordability and labour requirements of the green manure should be the reason that farm households of this cluster have adopted it. The smallness of the land holdings and the insecurity of land tenancy prevent farm households of this cluster to adopt other technologies. Subsequently, the overexploitation of land through high labour use and fewer inputs (only green manure) could lead to the exhaustion of soil fertility, further decreasing the returns per hectare.

For cluster III, which contains 31% of the farm households, the main distinguished features are the variable sex and education with strong discriminating power. Farm households classified into this cluster are male-headed households, younger and more literate compared to others clusters. These attributes have led to a substantial adoption of costly technologies (rate of adoption above the average) such as improved seeds and chemical fertilizers. From this finding, it was considered that being a male, educated and young head of farm household could be a prerequisite for the adoption of new technologies, especially those that require searching out information and effective combination of inputs. Off farm activities are also relevant but not unique in distinguishing cluster III from clusters I, II, and IV. This could indicate that farm households classified into cluster III have relatively more economic options which allow them to afford the technologies aforementioned.

Cluster IV is consisting of 18% of the farm households. This cluster represents farm households with a high level of illiteracy and quasi absence of off-farm activities. Moreover, farm households classified into cluster IV have a relatively high ratio of labour use over farm size compared to clusters I, III, and IV. Farm households intensified farming with a relatively high use of fallow, manure and SWC measures. Illiteracy and absence of off farm activities as another source of income prevent farm households to adopt costly technologies such as improved seed, chemical fertilizer and improved livestock. The highest adoption of SWC technology which is labour demanding technology is due to the availability of labour observed in the cluster.

Cluster V is consisting of 17% of the farm households. The cluster is associated with a large farm size with an average of 6.43 hectares, and a high rate of off-farm activities. The cluster is also characterized by a large number of households' members working outside the farm. The only outstanding technology adopted in this cluster is improved livestock. Almost no other technology was adopted except improved livestock. It seems that farm households classified into this cluster have devoted their farm to pasture. Despite the largest farm size, the lowest return per hectare is observed in this cluster. Return per hectare of this cluster is six times less to the highest return per hectare of cluster II (having the smallest farm size). The empirical findings highlighted in cluster V confirmed the statement made by several studies on land issues in Rwanda that people in east province are acquiring land for the purpose of speculation rather than agricultural production, and these people comprise political elite and military officials who are using their high positions to access and control more land (Pottier, 2006).

Conclusions

Data on 23 variables obtained from 96 farm households are evaluated by multivariate statistical methods. This multivariate analysis approach, combining principal component with cluster analysis, allows us to identify five typical farm households with respect to new technology adoption within the former Umutara province. The first group is characterized by female headed farm households with a relatively high use of compost, green manure, and improved seeds. The second group represents tenants with the smallest farm size. These farmers intensify farming with a high use of green manure. The third group embodies male headed farm households, younger and literate. These farmers intensify farming by using much chemical fertilizers and improved seeds. The fourth group includes illiterate and full-time farm households. The technologies they use most are fallow, manure and SWC. The fifth and last group embodies large farm households with the lowest returns per hectare. The only technology being adopted by them is improved livestock.

In conclusion, multivariate statistical techniques, such as PCA and CA, are great tools for identifying important socio-economic characteristics of typical farm households' underlying adoption of new technology. This should help us to build mathematical programming models on the basis of typical farm households, which is the next step forward.

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