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Modelling agricultural production of small-scale farmers in sub-Saharan Africa: A case study in western Kenya

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Abstract

Small-scale farmers are known to produce the greater proportion of food consumed in the Third World, especially in sub-Saharan Africa. The various national and international agricultural research centres located in these parts of the world have developed agricultural packages which have been proven, at experimental levels, to be highly productive. However, small-scale farmers in these areas continue to produce at levels far below the capacities of these packages as predicted from experimental results. Consequently, these farmers, despite their relatively large number, could not produce enough to feed themselves let alone the general population.

To improve the quality of life of these farmers in particular, and the population of the Third World in general, there is a need to study the various factors responsible for low agricultural production at the household level. Models relating production to the various factors need to be formulated to improve our understanding of the functional relationships. This in turn could lead to relevant national and international policies with respect to small-scale farmers in the Third World. In this paper, we develop models to predict production given these factors. For simplicity, the parameters of the models are limited to land size (or herd size), environmental effect and management effect.

A statistical examination of our model fitted to a set of survey data on this subject revealed that improving the farmers' management level could greatly enhance their production. Further statistical analysis of the data set showed that the various factors constituting the farmers' management level could broadly be classified into three groups: resources (labour and farm implements), personal characteristics (educational level and age) and external assistance (contact with extension agents/assistance) in that order of importance. We discuss the importance of these findings in the formulation of policies concerning small-scale farmers in sub-Saharan Africa.

1. Introduction

Agricultural production in Africa has virtually been dominated by small-scale farmers who are known to produce up to 90% of the food consumed in some countries of the continent (Lambert, 1989; IFAD, 1993). Africa's small-scale farmers make up at least 73% of all rural Africans (Garrison, 1990; IFAD, 1993). Despite the fact that such a high percentage of the population are farmers, food demand cannot be met from this source (IFAD, 1993). In many developed countries, relatively small numbers of farmers produce adequate food to meet domestic needs as well as to export to the developing world. Unlike in the pre-independence era, sub-Saharan Africa is no longer able to feed itself (Garrison, 1990; IFAD, 1993). According to the World Bank, agricultural growth fell to less than 1.5% $year^{-1}$ in the 1980s—way behind the population growth rate of 3.3% (Kinley, 1990). The central issue, therefore, is how to accelerate the agricultural production growth rate to meet the food needs of the

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ever-growing population (Shields et al., 1993). This makes the problem of resource-poor farmers' more urgent (Sims, 1993).

Agricultural development in sub-Saharan Africa is still very far from being a success despite years of agricultural research and planning by national and international organisations. Various agricultural technologies have been released to farmers after being proved to be high yielding and potentially capable of solving the food shortage problem (Garrison, 1990; Robson, 1991). However, the problem persists since the farmers in sub-Saharan Africa still produce at levels far below the predicted capacities of the new packages. The unfortunate consequence is that the farmers, and the population at large, remain in abject poverty and continue to import food, or beg for food aid, from the developed countries. How long such a situation should persist is a question yet unaddressed.

Inadequate understanding of farmers' goals and resource limitations has been identified as one important factor causing the food shortage problems in sub-Saharan Africa (Jahnke et al., 1986; Kiros, 1993).

Agricultural production in Africa is constrained by multiple problems which can vary widely, even within fairly restricted farming regions (Ssennyonga, 1989). Kiros (1993) classified the various factors determining the level of agricultural production by farmers in sub-Saharan Africa into six groups: (1) endowments of basic factors of production; (2) agro-ecological factors; (3) access to modern know-how and production inputs; (4) ownership of livestock; (5) structure and diversity of production activities; (6) gender-related and other personal characteristics of producers. Another equally important factor is institutional arrangements that shape farmers' incentives.

Institutional factors and policy issues have been the subject of many important publications on African agriculture and rural development (e.g. Ghai and Samir, 1977; Hyden, 1980; Johnston and Clark, 1982; Ghose, 1983; Kiros, 1985; Berry, 1986; Hyden, 1986; Eicher and Staatz, 1990; IFAD, 1993; Desai and Mellor, 1993; Singh and Hazell, 1993). There can be no doubt that institutional factors such as land tenure play a fundamental role in determining agricultural production in sub-Saharan Africa. Such issues are often addressed at the macro-level, whereas the focus of the present study is on the household or the micro-level. An example of the latter is the work of Singh and Hazell (1993) where the authors have applied micro-level factors comparable to those in the present study in their analysis of the determinants of per capita income. However, the two levels of analysis are obviously interrelated, as can be appreciated from the publications of Hyden (1986) and Berry (1986).

The need to study the various factors responsible for the low production of sub-Saharan Africa farmers cannot be overemphasised. Any breakthrough in improving the quality of life of the sub-Saharan Africa farmers and the people at large will not be sustainable unless the relationships of these factors to production are well understood. It is essential to develop models relating production of small-scale farmers to these factors for better understanding of the functional relationships. This is the objective of this paper. There can be no doubt that such models will facilitate the formulation of relevant national and international policies with respect to small-scale farmers in sub-Saharan Africa and the Third World in general. Such policies are necessary if sub-Saharan Africa is to achieve food sufficiency and improve its quality of life.

2. Model formulation

The list of factors responsible for the low agricultural production by farmers in sub-Saharan Africa may not be exhaustible. Categorisation of the factors may also not be generalisable. For simplicity, however, the main parameters of our model are limited to three, representing land (or herd) size, environmental and management effects.

Consider the production, Y, of a small-scale sub-Saharan Africa farmer as a function of land (or herd) size, L, environmental effect, E, and management effect, M, represented as

$$Y = f(L)\, g(E)\, h(M) \tag{1}$$

where f, g and h are functions relating L, E and M, respectively, to Y. We propose and develop these functions.

2.1. Land area

Land is usually measured in hectares. The relationship between crop production and land area, L, has been found to be best described by the power function (Cochran, 1977)

$$f(L) = \alpha L^{\beta} \quad (2)$$

where α and β are constants. In the case of dairy production, L could well represent herd size. Given all other conditions as fixed, Y is expected to increase with increase in L at a power rate of β. Hence, β will necessarily be greater than zero.

2.2. Environment

Environmental factors include rainfall, soil type, humidity, temperature, erosion and vegetation. These factors are location-specific. In most socio-economic surveys, these factors are represented by ordinal scales such as good/bad, high/medium/low, etc. (Lomperis, 1991; Yanaihara, 1993; Flaherty and Jenglalern, 1995). For more meaningful modelling, our approach will be to transform these to continuous scales using the uniform-rank transform method. This is performed by ranking the data for each variable in ascending order and then dividing by the total sample size. The mean of the uniform-ranks over all the environmental variables is then obtained for each sample to represent the environment as an index. Hence, the environmental index, E, is distributed in the interval [0, 1]. We propose an exponential model of the form

$$g(E) = \gamma e^{\theta E} \quad (3)$$

where γ and θ are constants. Since the data were ranked in ascending order of favourability to production, both γ and θ will be positive. A similar model was used by Bourdet (1995) who employed a multiple linear regression to relate rice production (converted to natural logarithm scale) to harvested land area, labour force, number of buffaloes, effect of bush slashing and burning, and cooperative intensity.

2.3. Management

Various factors regarded as constituting management include both physical properties and personal qualities possessed by the farmers. These include number of work implements, work force, literacy level, external assistance on production aspects and other resources needed for production. All these variables will also be treated as the environmental variables since many of them are measured on ordinal scales. That is, the samples will be ranked in ascending order with respect to each variable, while the resulting uniform-ranks will be averaged over all variables to represent the management index for each sample. Given the management index, M, for each farmer, we propose a model similar to the environmental model to relate production to M, as

$$h(M) = \lambda e^{\eta M} \quad (4)$$

where λ and η are positive constants.

2.4. General model

The general model relating production, Y, to land size, L, environmental index, E, and management index, M, may be written as

$$Y = aL^{b}\exp(cE + dM) + \varepsilon \quad (5)$$

where a, b, c and d are positive constants and ε is the residual.

The fact that institutional factors have not been treated separately in our model does not mean that they are absent or are inoperative. The amount of land cultivated by a farmer is determined by various institutional factors such as land tenure, pricing and marketing policies and related issues. Hence, the effects of these institutional aspects are in part reflected in the model via land size. Similarly, some of the specific factors considered under the umbrella of 'management', such as educational level and external assistance also in part reflect the effects of national or regional policies in these spheres.

3. A case study

Data collected in a rural survey undertaken by the Social Science Interface Research Unit (SSIRU) of the International Centre of Insect Physiology and Ecology (ICIPE) were used to examine the proposed model. The survey covered the Oyugis and Kendu Bay Divisions, South Nyanza, western Kenya, and took place during the period January to March 1992. In total, 801 farmers, who are homestead heads (approximately 60% male, 40% female), were interviewed during the survey aimed at identifying 'resource-poor farmers'. Information collected from each interviewed farmer included marital status, age, number of household members with their ages, educational qualification, crops grown, amount of land owned, size of land cropped, land fertility level, livestock number, types and number of farm implements, production and income from each crop, proportion of production directly used by homestead, and assistance from extension services agents.

Details of the survey, including the background, sampling and interview procedures are contained in Kiros (1993).

For this modelling case study, only farmers having cropped land were considered. Land fertility level, the only environmental variable recorded in the survey, was used to represent the environmental effect. The use of this factor is appropriate since the quality of land can vary within a relatively small geographical area as compared with other agro-ecological factors. Educational level, age, number of oxploughs, number of jembes (hoes), number of pangas (cutlasses), number of wheelbarrows, number of spades, number of forks, external assistance, and work force constituted the management effect. Crop production was converted to economic values to represent the dependent variables, Y, in the model.

Table 1
Parameter estimates ($\pm$SE) of the proposed model fitted to the case study data

Parameter	Estimate
a (constant)	214.619 ± 11.88
b (land size effect)	0.549 ± 0.054
c (environment effect)	0.471 ± 0.129
d (management effect)	3.312 ± 0.441

Table 1 shows the parameters of the model fitted to the data. All the parameters are highly statistically significant. A plot of the residual obtained after fitting the model showed no obvious pattern, indicating a good fit of the model to the data.

3.1. *Sensitivity of model to management index: a simulation*

The management level of farmers is probably the most easily controllable of the three independent

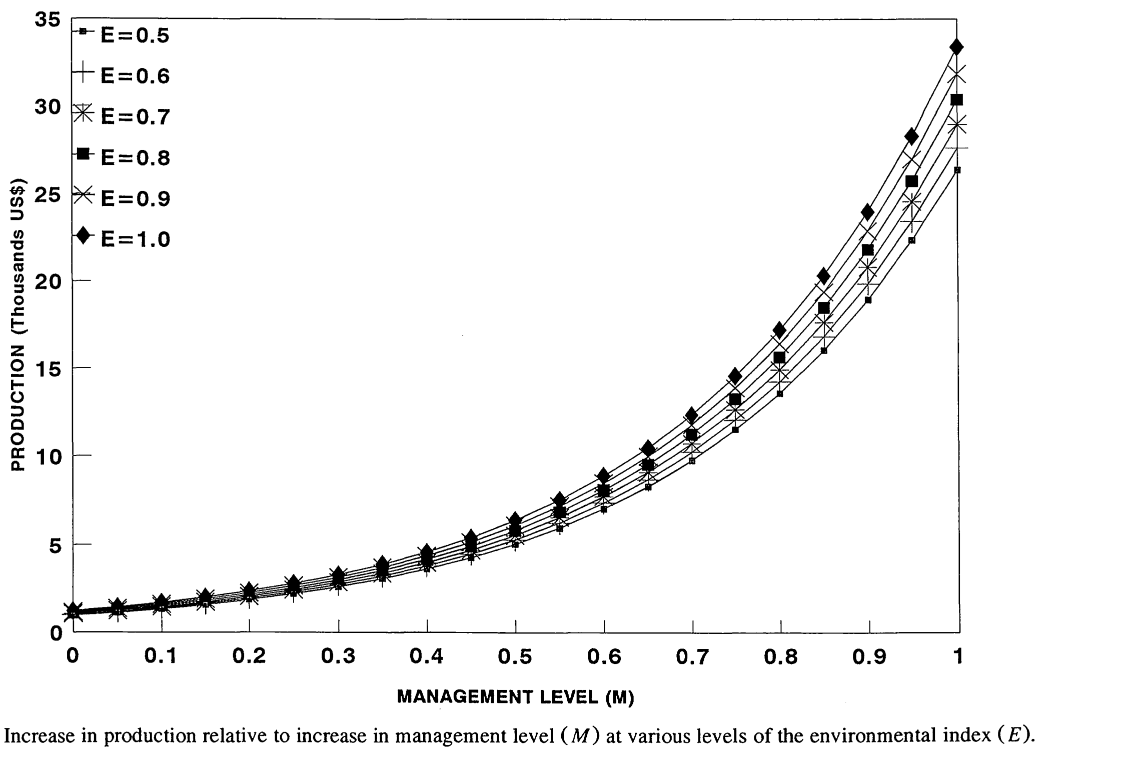

Fig. 1. Increase in production relative to increase in management level (M) at various levels of the environmental index (E).

variables used in the model. It is therefore necessary to investigate the effect on production of changing the management level. A simulation was carried out using the parameter estimates obtained from the data and varying the management index, M, within the interval [0, 1]. Fig. 1 shows simulated production plotted against M at different E levels. Improving the management level by 0.1 multiplies production by the factor $e^{0.1d}$ ($= 1.39$) which represents a 39% increase in production.

How much effort would be required to achieve an improvement of 0.1 in M is a subject of interest. It is not impossible for this to be achieved by different measures such as making all farmers contact other farmers, giving extension assistance to all farmers at least quarterly and educating all farmers to at least secondary school level. Simulation results of how changes in these factors and their combinations would affect production given our model, is presented in Table 2 for the case study data. For example, M will increase by 0.03, yielding an increase of about 10.5% in production if all farmers have 9–12 years of formal education (about secondary school level). If this educational level attainment is combined with access to extension services at least once every quarter, the increase in M will be about 0.048, resulting in an increase in production of over 17%. Given the cost per farmer of improving each of these factors, policies by governmental and non-governmental organisations can be sharply focused on the reduction of costs and achievement of optimum results.

3.2. Further analysis

To study further the various factors constituting farmers' management level, a factor analysis was carried out using the 11 management variables in the case study data set. The aim was to classify these variables in terms of the amount of variability among the farmers accounted for by each group. Using the principal component method, three factors with eigenvalues greater than unity were retained. Table 3 shows the pattern of the factor scores for each variable. Factor 1 consists of numbers of jembes, hoes, spades, wheelbarrows, pangas, oxploughs and forks as well as the work force. These variables can generally be called resource (labour and implements) variables. They explained over 25% of the variation in the management levels of the farmers. Factor 2 consists of farmers' age and educational level, both explaining about 13% of the total variation, while factor 3, consisting of extension services assistance and contact between farmers and extension account for about 12% of the total variation. Hence, the differences in management level between farmers are

Table 2
Changes in production and management levels given changes in some management factors

Variable	Mean value	Increase in management level	% increase in production
Normal (as obtained from case study data)	0.713	–	–
Ed. level ≥ 1	0.723	0.01	3.37
Ed. level ≥ 2	0.739	0.026	8.99
Ed. level ≥ 3	0.743	0.03	10.45
Ext. asst. ≥ 3	0.728	0.015	5.09
Ext. asst. ≥ 4	0.731	0.018	6.14
Make all farmers contact farmers	0.720	0.007	2.35
Ed. level ≥ 1 and Ext. asst. ≥ 3	0.738	0.025	8.63
Ed. level ≥ 2 and Ext. asst. ≥ 3	0.754	0.041	14.54
Ed. level ≥ 3 and Ext. asst. ≥ 3	0.758	0.045	16.07
Ed. level ≥ 1 and Ext. asst. ≥ 4	0.742	0.029	10.08
Ed. level ≥ 2 and Ext. asst. ≥ 4	0.757	0.044	15.69
Ed. level ≥ 3 and Ext. asst. ≥ 4	0.761	0.048	17.23

Ed. level refers to the amount of formal education the farmers have received: 1, 0 years; 2, 1–4 years; 3, 5–8 years; 4, 9–12 years; 5, over 12 years.
Ext. asst. refers to the frequency with which assistance or advice is given to farmers from extension agents: 1, never; 2, rarely; 3, bi-annually; 4, quarterly; 5, monthly.

Table 3
Factor pattern of the management variables in the case study data

Variable	Factor 1	Factor 2	Factor 3
Educational level	0.428	−0.733	0.132
Age	0.116	0.867	−0.017
Oxplough	0.543	0.265	−0.104
Jembe	0.716	0.005	−0.053
Panga	0.557	−0.003	−0.203
Wheelbarrow	0.579	0.063	−0.248
Spade	0.583	−0.037	−0.371
Fork	0.411	−0.021	−0.256
Extension assistance	0.451	0.083	0.687
Contact farmer	0.396	0.117	0.698
Work force	0.492	−0.049	0.065

basically a result of differences in farm implements and labour sources. It therefore seems that access to farming implements will go a long way to making the farmers produce more. A similar conclusion was arrived at in a study carried out in Swaziland by Shields et al. (1993) who suggested that 'technology transfer' should serve to alleviate labour shortages.

4. Conclusions

The economics of transition in Third World countries cannot overlook an analysis of the agricultural sector (Bourdet, 1995). According to Shields et al. (1993), increases in agricultural production in sub-Saharan Africa have relied heavily on expanding land utilisation rather than adoption of modern yield-increasing management technology. However, with the increasing population pressure on the land and resource depletion in favoured areas (Sims, 1993), the introduction of new technology is a must if the region is to achieve sustainable increase in food production.

An understanding of the functional relationship between agricultural output and various production factors will no doubt directly lead to efforts aimed at increasing the yield of small-scale producers, thereby leading to the enhancement of food self-sufficiency and improved welfare. This could be achieved through the formulation of appropriate national and international policies and measures relevant to the farmers of sub-Saharan Africa. The present study is a step in this direction and could form a basis for further development of models of the type presented. Future studies could address the incorporation of more factors and re-classification of the factors into narrower categories to enable policy-makers and development practitioners to address the production constraints facing small-scale producers.

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