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Innovations for Plant Production in the Risky Environment of Semi-arid Niger: A Multi-level Modelling Assessment

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Abstract

The paper deals with the problem of economically sustainable technological innovation for agriculture in the risky environment of Niger's Sahelian zone smallholders. For these farmers, low-input mineral fertiliser technologies have been developed in the nineties in order to increase the productivity of their millet farming systems. As economic assessment cannot be restricted to plot or farm assessment alone but has to take into account also markets and marketing patterns, a sequence of models has been applied: On plot level, production functions of intercropping systems were estimated, in order to determine yields and their variability of the major crops. These data were fed in a Markowitz-Portfolio-model type by means of nonlinear programming to test the innovations, first at stable prices, then at declining prices that were obtained from an interregional trade model. The latter was shocked by the excess obtained from the yield gains of the innovations. This shock was depicting the sales from farmers even at declining prices, when they have to cover their costs of production, especially the fertiliser they used when applying the proposed innovations. The results show that due to risk aversion and high price volatility of output markets, farmers adopt mineral fertiliser innovations to a lesser degree than expected. Instead of that, they switch to other low-input techniques, like field management, that require less financial inputs.

Keywords: Agricultural development, Niger, small scale farming, agricultural markets in SSA, risk management

1 Introduction: Aim and scope of the study

Investments in agriculture are the world-wide lowest in Sub-Saharan-Africa (SSA). New varieties, for example, are only cropped on 26 percent of the agricultural area in SSA, compared with 52 percent in Latin America and even 80 percent in Asia (ANONYMUS 2001, p.3). This paper will try to discuss the problem of innovation adoption in SSA. It throws some light on the background of innovation adoption in the SSA agriculture by exemplifying it with the case of smallholder millet systems in Niger. Within the special research program "Adapted Farming in West Africa" (SFB 308) of the University of Hohenheim, several innovations have been developed during 15 years of research from 1985 to 1999. These innovations have been especially designed for small scale farmers in marginal areas. Amongst them are fertiliser inputs, mechanisation of labour or intensification of animal feeding and improved management of herding. This automatically implies the need for improved marketing and market attendance in order to generate cash to purchase the inputs related with these innovations (MCINTIRE ET AL. 1989) and to allocate the surplus gained from the application of the innovations. Consequently, the study described here assesses the innovations on all level, from plot to market, taking into account those constraints – mainly market and production risks – that are expected to keep farmers from doing adopting innovations.

Framework of the study

The farming systems in Niger are still characterised by subsistence, perpetual droughts and what one could describe as “distress affected” farming. The specific systems investigated in the study are situated in the Southwest of Niger, where a panel of about 100 farmers from four villages were subject to farm and household surveys. Farming systems are based on pearl millet, frequently intercropped with cowpea (for closer descriptions of production systems in Niger see ABELE AND GRINI 1999). The systems are primarily subsistence oriented (BAIDU-FORSON AND WILLIAMS 1996, MCINTIRE ET AL. 1989).

Analysis of these systems entails a broad scope of requirements. It has to cover all the levels of production and marketing. Starting from the plot, production functions for the prevailing inter-cropping systems have to be determined, so that the variability of the system that features in the synergy and competition effects of the different crops and in their reaction to environmental variables, such as rainfall, can be analysed. On the farm level, decision making can be depicted by means of algebraic models that base on the information gained from the production functions. Further, as these systems are subsistence oriented and operate in a risky environment, the farmers’ attitude towards risk has to be incorporated in such models, as it must be assumed that subsistence oriented farmers are more risk averse than market oriented agricultural entrepreneurs. The production and supply that is generated by these decisions has to be confronted with demand in a market model in which the institutional shortcomings like distress sales and seasonality of production decisions and the resulting asymmetries of supply and demand are incorporated.

Graph 1 shows the modelling sequence and the respective data flows the following analysis is based on.

Graph 1: Modelling sequence and information flow

Level 1, plot: Estimation of production functions for intercropping millet/cowpea systems **Aim:** To detect the impact of rain, fertiliser and inter-crops on crop productivity **Model:** Equation system **Method:** Three-stage-least-squares estimator

Feedforward: *Information for farm models: Yields, intercropping effects and production risks induced by rainfall variability*

Level 2, farm: Assessing innovations **Aim:** To measure competitiveness of innovations under risky conditions **Model:** Markovitz-Portfolio-Model **Method:** Quadratic programming

Feedforward: *Surplus quantities sold to reimburse expenditures*

Feedback: *Impact of price changes induced by a widespread introduction of innovations*

Level 3, market: Assessing the impact of increased quantities of products on markets and market processes **Aim:** Quantifying price reactions on markets **Model:** Interregional trade model **Method:** Nonlinear programming

Source: Abele 2001.

Production function analysis

In Niger yields are of a high variability, due to a number of factors: First, input intensity is of a high variability. Further, it can be said that not only a temporal variability, but also a high spatial variability of climatic factors and soil quality can be observed. Finally, synergetic or competitive effects between inter-crops have to be taken into consideration. Yield variability is an appropriate measure to quantify risk, as cropping risk can be defined as the variance and covariance of the cropping portfolio. Consequently, it is necessary to generate information on the determinants of yield variability in inter-cropping systems from farm data, so that this information can be used in further farming systems analysis. It thus had been decided to estimate production functions of an inter-cropping system for the nine main crops and crop by-products that are produced by the farmers. The database used for the analysis covers data on production in millet-based inter-cropping systems. The sample used is about 1,800 plots of farms in four villages in Western Niger. They were taken from an ICRISAT/IFPRI research program in the eighties that focused on improving the millet production system in Niger on the sites described above. The main crop is pearl millet, both sole and intercropped with cowpea, sorghum, groundnut as well as bambara groundnut, okra and hibiscus. Different intensity levels of phosphorous fertilizer, applied as SSP and rock phosphate and other fertilisers can be observed. The database represents a time series from 1982 to 1987, including daily rainfall data over these years (MCINTIRE ET AL. 1989).

The estimation of the simultaneous equation system shows the expected results (Table 2). Yields can be explained as a function of seeds and rainfall distribution. Considering rainfall, response differs across crops: Some respond more to the rain in June and July, others more on the later rain. Further factors influencing certain crops are phosphorus fertiliser application, e.g. millet or sorghum and, for some crops, the amount of inter-crop seeds applied on the same plot. Also, effects of inter-crops can be seen, as the output of e.g. millet and red sorghum is related to the output of inter-crops.

Table 2: Results of estimation

Explanatory / Dependent	Millet yield[a]	Cowpea grain yield[a]	Cowpea hay yield[a]	Groundnut grain yield[a]	Groundnut hay yield[a]	White sorghum yield[a]	Red sorghum yield[a]	Hibiscus yield[a]	Okra yield[a]
Cowpea grain yield[a]	-7.6 (-1.5)		-5.5 (-2.5)				-0.05 (-1.6)		
Groundnut grain yield[a]					-5.0 (-19.6)				
White sorghum yield[a]	-0.5 (-1.7)								
Hibiscus yield	19.8 (5.5)								
Millet seed[a]	1.8 (13.5)		0.2 (2.7)						
Cowpea seed[a]	99.1 (12.3)	0.7 (3.3)	55.7 (14.79)						
Groundnut seed[a]				2.4 (59.8)	15.4 (25.1)				
White sorghum seed[a]						7.7 (19.8)			
Red sorghum seed[a]							27 (53)		
Hibiscus seed[a]								2.0 (15.4)	
Okra seed[a]									19.7 (11.1)
P-fertilizer[a]	16.8 (4.3)					0.7 (1.2)	0.03 (1.9)		
P fertilizer squared[a]	-0.1 (-4.2)					-0.04 (-1)			
Rain in May[b]	-3.5 (-3.9)	0.13 (4.7)				-0.3 (-3.0)			
Rain in June[b]	23.5 (7.2)	0.04 (1.5)	6.5 (3.8)			0.7 (1.7)			0.2 (1.3)
Rain in June squared[b]	-0.1 (-5.3)		-0.04 (-3.0)			-0.005 (-1.5)			
Rain in July[b]		0.1 (4.8)							0.1 (1.5)
Rain in August[b]							0.003 (1.4)		-0.08 (-1.4)
Rain in September[b]	3.2 (4.5)		1.14 (3.3)	0.4 (3.4)	2.1 (6.5)	0.2 (1.8)	0.01 (2.3)	0.03 (3.3)	
Rain in October[b]		-0.2 (-2.2)							
Constant	-751.9 (-6.5)	-9.8 (-3.8)	-271 (-4.5)	-13.6 (-1.7)	-88.6 (-2.9)	-17 (-1.1)	-0.9 (-2)	-1.3 (-1.8)	-8.4 (-0.7)

[a]$kgha^{-1}$, [b]mm in respective month, System R^2 = 0,97, t-values in brackets, source: Own calculations based on ICRISAT Data

Having detected the output functions of the inter-cropping system, the next step would be to simulate a yield series that describes the response of the crops to rainfall variability and therefore finally the risk induced by rainfall variability. At this state, it is possible to create a "ceteris paribus" situation when keeping the independent variables, except rainfall, constant. These yields are the base of further modelling that consists of two components: The first is a nonlinear *Markowitz* portfolio farm-model, which is applied to assess the profitability of the above mentioned innovations. The results are fed into an interregional trade model, to determine price and quantity reactions on markets and their impact on the decision making of farmers.

The farm model

The farm model is of a *Markowitz* type where risk is included in the objective function of the farmer. Risk is assumed to be of significant importance for farmers' decision making, as a farmer is not only interested in maximising profits but also in keeping a basic level of security (VON BLANCKENBURG AND SACHS 1982, HEDDEN-DUNKHORST 1993). The primary risk is production risk, which is induced by rainfall variability and diseases. Also, market risks due to price volatility must be added. Based on the assumption that Nigerien farmers are risk averse, the farm model can be formulated as the following nonlinear program:

$$\text{Max } U = C'X - \phi(X' \Omega X)^{1/2} \qquad (1)$$

with U the utility to be maximised, X a vector of activities, C'a vector of gross margins, Ω the variance-covariance-matrix of the activities' gross margins, ϕ a risk aversion coefficient that is positive for the case of risk aversion (then the term including the matrix becomes negative) or zero in case of mere profit maximising

s.t.

a) Resource constraints

$$CX \leq D$$

with C a vector of the activities' resource requirements, X a vector of activities, D a vector of resource endowment

b) Nutrition requirements

$$AX \geq \nu B$$

with ν: the FAO adult equivalent, A a vector of nutrition values (protein, fat, carbohydrates), X a vector of activities and B a vector of basic nutrition requirements for protein, fat and carbohydrates

The model now is calibrated by adjusting ϕ, so that the optimal solution of the nonlinear program reflects the observed production program of the farms.

After the calibration, the following technical innovations (hereafter called technical options, TO) were integrated into the programme in order to test their economic feasibility:

TO1: Pocket-placed phosphate fertilisation with 1.5 kg P ha^{-1}, or 20 kg SSP fertiliser respectively

TO2: Selective weeding by leaving specific shrubs on the field

TO3: Mulching with crop residues in form of millet stalks and

TO4: The combination of TO 3 and TO 1.

TO1 is one of the options with the highest yield increases but at the same time bares a relatively high risk, as fertiliser has to be bought, which affects questions of liquidity and of profitability[1]. TO2 is an option which requires no further input, increases yield (to a much lower extent than TO1) but is restricted to plots that are owned by the farmer, as shrubs or bushes planted by the tenant could indicate an ownership claim. TO3 is yield increasing but relatively costly as, millet stalks have a market value, because they are used for construction and partly also for feeding. TO4 is the option with the highest yield increase but at the same time accumulates the costs and opportunity costs of TO1 and TO3.

4.3 Linking farms and markets

Prospected supply changes have to be integrated in a market model that endogenously calculates prices of the commodity under investigation. Such market models can be formulated as trade models that optimise welfare through interregional exchanges of commodities with respect to transport cost as well as demand and supply restrictions (VON OPPEN ET AL. 1996). Prices are in these models endogenously calculated as shadow values of demand and supply balances. Traded goods are in the present model millet, sorghum, cowpea, maize, wheat and rice.

The assumptions are integrated into a set of models that reflect two subsequent cropping and trading periods. The models depend on each other in a way that both quantity and price information is exchanged between them. Quantities to be marketed in the first period are taken from the farm model and extrapolated for the whole region before being fed into the trade model. The prices of the farm model in the second period are the calculated prices from the trade model in first period. The two types of models that are thus linked together are those formulated above. In order to depict the above mentioned asymmetries and irreversibility of supply after harvest, the trade model's supply is fixed at the quantities harvested under optimal condition, so that only demand can react flexibly to post-harvest changes. The next step is then to allocate the millet surplus from the farms gained through the application of the technical innovations. Here, it is assumed that at stable prices the whole surplus is put into the markets, while at declining prices, farmers do not allocate more than necessary to cover their fertiliser expenses. However, it is clear that the more prices decline, the more millet has to be allocated. This is modelled by increasing the fixed supply quantities stepwise until the turnover of millet covers the costs for fertiliser used

[1] For a more detailed description of the technical options see HAIGIS ET AL. (1998).

for production. The scenario result is of the latter character: Millet prices decline sharply throughout Niger. It is interesting how farmers react to this decline in millet prices within the next cropping season. Table 4 shows the results of the *Markowitz* farm model after optimisation with the new market prices in comparison to the reference scenario (without innovations). It can be shown that the decline in prices results in a sharp reduction of intensity. First, the application of pocket-placed fertiliser is reduced to 28 % of the cultivated area. At the same time, the application of crop-residue mulch is reduced to zero. Instead of these applications, the zero-input technology of selected weeding is applied up to the limit of self-owned plots. When risk indifference is assumed, the combination of mulch and pocket placed phosphate is still the first choice of the farmers. It is thus risk that determines the production decision and leaves even the low-input options unattractive.

Table 4: Gross margins and production portfolio in different scenarios

Reference run: At old prices without innovations	
Total gross margin[1]	355,378
Production portfolio (percentage of area cultivated)	
Millet sole cropped	40
Millet inter-cropped with cowpea	60
Scenario 1: At old prices with innovations	
Total gross margin[1]	540,297
Production portfolio (percentage of area cultivated)	
Millet inter-cropped with cowpea, application of pocket placed phosphorous fertiliser and mulch of crop residues	100
Scenario 2: At new prices with innovations	
Total gross margin[1]	295,837
Production portfolio (percentage of area cultivated)	
Millet inter-cropped with cowpea under selective weeding	72
Millet inter-cropped with cowpea, application of pocket placed phosphorous fertiliser	28
Scenario 3: At new prices with innovations, assumption of risk-indifference	
Total gross margin[1]	330,930
Production portfolio (percentage of area cultivated)	
Millet inter-cropped with cowpea, application of pocket placed phosphorous fertiliser and mulch of crop residues	100

[1]Gross margins are FCFA ha^{-1} Source: Own calculations based on ICRISAT data.

5 Conclusions

The first point gained from the analysis is that the reasons for low innovation adoption in SSA can be well explained by the above mentioned set of models. It can be shown that it is mainly risk, both production and market risk that keeps farmers from introducing innovations. Risk aversion seriously affects even technologies like small amounts of pocket-placed fertiliser, a technology that would be sustainable even at low output prices, if only risk indifference is assumed. On the other hand, there are technologies that fit well even into a risk-averse farmer's portfolio, like selective weeding. This technology is a zero cost option as it increases yields without additional expenses.

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