Available online at www.sciencedirect.com
SCIENCE DIRECT®

Agricultural Systems 90 (2006) 272–292

AGRICULTURAL SYSTEMS

www.elsevier.com/locate/agsy

New technologies, marketing strategies and public policy for traditional food crops: Millet in Niger ☆

Tahirou Abdoulaye [a], John H. Sanders [b,*]

[a] *Agricultural Economist, INRAN/DESR/TT, B.P. 429, Niamey, Niger*
[b] *Department of Agricultural Economics, Purdue University, 1145 Krannert Building, 403 W. State Street, #609, West Lafayette, IN 47907-2056, USA*

Received 4 August 2005; received in revised form 10 November 2005; accepted 29 December 2005

Abstract

New technology introduction in this semiarid region of the Sahel is hypothesized to be made more difficult by three price problems in the region. First, staple prices collapse annually at harvest. Secondly, there is a between year price collapse in good and very good years due to the inelastic demand for the principal staple, millet, and the large changes in supply from weather and other stochastic factors. Thirdly, government and NGOs intervene in adverse rainfall years to drive down the price increases. Marketing strategies were proposed for the first two price problems and a public policy change for the third. To analyze this question at the firm level a farm programming model was constructed. Based upon surveying in four countries, including Niger, farmers state that they have two primary objectives in agricultural production, first achieving a harvest income target and secondly achieving their family subsistence objective with production and purchases later in the year. Farmers are observed selling their millet at harvest and rebuying millet later in the year. So the first objective takes precedence over the second. A lexicographic utility function was used in which these primary objec-

☆ An earlier version of this paper was presented at the Annual American Agricultural Economics Association meeting, 27–30 July 2003, Montreal, Canada with the title "Improving Marketing Strategies to Accelerate Technological Change for the Basic Cereal: The Niger Case."

* Corresponding author. Tel.: +1 765 494 4221; fax: +1 765 494 9176.
E-mail address: jsander1@purdue.edu (J.H. Sanders).

0308-521X/$ - see front matter
doi:10.1016/j.agsy.2005.12.008

tives of the farmer are first satisfied and then profits are maximized. According to the model new technology would be introduced even without the marketing strategies. However, the marketing strategies accelerated the technology introduction process and further increased farmers' incomes. Of the three marketing-policy changes only a change in public policy with a reduction of the price depressing effect (cereal imports or stock releases) substantially increases farmers' incomes in the adverse years. In developed countries crop insurance and disaster assistance is used to protect farmers in semiarid regions during bad and very bad (disaster) rainfall years. In developing countries finding alternatives to the poverty-nutritional problems of urban residents and poor farmers to substitute for driving down food prices in adverse years could perform the same function as crop insurance in developed countries of facilitating technological introduction by increasing incomes in adverse rainfall years in developed countries.

Keywords: Inventory credit; Marketing strategy; Inorganic fertilizers; Fertility depletion; Farm level programming; Micro-fertilization; Sidedressing

1. Introduction

A principal production requirement of agriculture is that to produce crops major and minor nutrients are required. Without sufficient nitrogen and phosphorus yields will stagnate and decline to low level equilibriums (for an estimate of this yield decline using simulation to take out weather effects see Ahmed and Sanders, 1998, p. 258). Providing adequate nutrients for crop production in Niger is not a risky option that farmers can avoid. It is a prerequisite for removing crop production from a downward cycle of fertility depletion and yield decline.

With continuing population pressure leading to the breakdown of traditional fertility replacement strategies, such as fallowing and migration to new areas, and the nutrient inadequacy of others, such as manure and rock phosphate, there needs to be a focus on increasing input purchases of nutrients (inorganic fertilizers, Sanders, 1989). For farmers to adopt these inputs, they need to be profitable. Moreover, the risks from low yields in adverse rainfall years need to be reduced with technology or policy.

In developed countries, such as the US, institutional development (availability of crop insurance managed by the private sector but with an important public sector subsidy plus disaster assistance for major drought years funded by the public sector-see Dismukes and Glauber, 2005) allows farmers in semiarid regions to lose fertilized wheat or sorghum or experience low yields in inadequate rainfall years without going bankrupt. Then in normal and good rainfall years these activities are often very profitable. Africa is more dependent upon semiarid crop systems than any continent except Australia (Shapiro and Sanders, 2002, pp. 270–274).

Using farm level programming we evaluate first whether farmers would adopt new technologies with higher fertilization levels. Secondly, we analyze the effects of the introduction of new marketing strategies and a public policy shift on farm level incomes and adoption. Finally, for an adverse rainfall year in which yields are substantially lower than in normal or good years are there policies that would protect farmers from taking losses?

In the next section we describe the region's production system, weather and price variability and new technology options. Then we define the farm model and detail the estimation of the parameters from fieldwork. The results section considers the various alternative scenarios discussed above. First, the potential for adoption of new technologies is analyzed. Then the farm response (model results) to resolving each of the three price problems and a public policy shift is evaluated. Further analysis of these options can be undertaken at the regional and national level. Here we focus on the farm level effects with prices varying by state of nature and period sold but exogenous prices.

Finally, in the conclusions the major results are synthesized. Then we make some inferences about poverty policies and the differences between bad rainfall and drought years.

2. The region

2.1. Household production systems in a marginal rainfall region

Niger is one of the poorest countries in the world with a per capita income of $200 in 2003 and a population of 11 million. In 2001 40% of the children in Niger were malnourished (World Bank, 2004, p. 255). In 1996 61% of the population earned less than 1$/day a day and 85% earned less than 2$/day. Moreover, in the main economic activity, agriculture, per capita productivity is falling (World Bank, 2005; pp. 257, 259, 261.). In the 1990s agricultural output growth of 2.6% did not keep up with population growth of 3.4% (World Bank, 2001).

Millet (generally grown in association with cowpeas in Niger) is the basic staple and is produced on 5.2 million ha in Niger as compared with 9.4 million ha in India and 6.1 million in Nigeria. Niger has the lowest yields (481 kg/ha) and is the only one of the top three major producers that has not substantially increased its yields. India has doubled its yields from the 1960s and Nigeria increased its aggregate yields by two thirds. In 2004 millet yields were 851 kg/ha in India and a metric ton/ha in Nigeria. In 2004 Niger produced 2.5 million tons while Nigeria had 6.1 and India 8 million tons (all data for the three countries above is from 2004; FAOSTAT Database Results, 2005).

The Fakara plateau (Fig. 1) is a typical region in this Nigerien production system. Farmers first settle the higher fertility river valleys and then move to the plateaus as land becomes scarce. But even farmers located in the valley want some land higher up to cover themselves for the risks of flood years. Similarly, Fakara farmers try to get access to some low lying land to cover the risks of the dry years.

On the Fakara plateau rainfall is low (an average of 450–500 mm over the period 1990–2000) and irregular. Soils are predominantly sandy with low nutrient levels and they are especially deficient in phosphorous, nitrogen, and organic matter. Water holding capacity of the soils is generally poor.

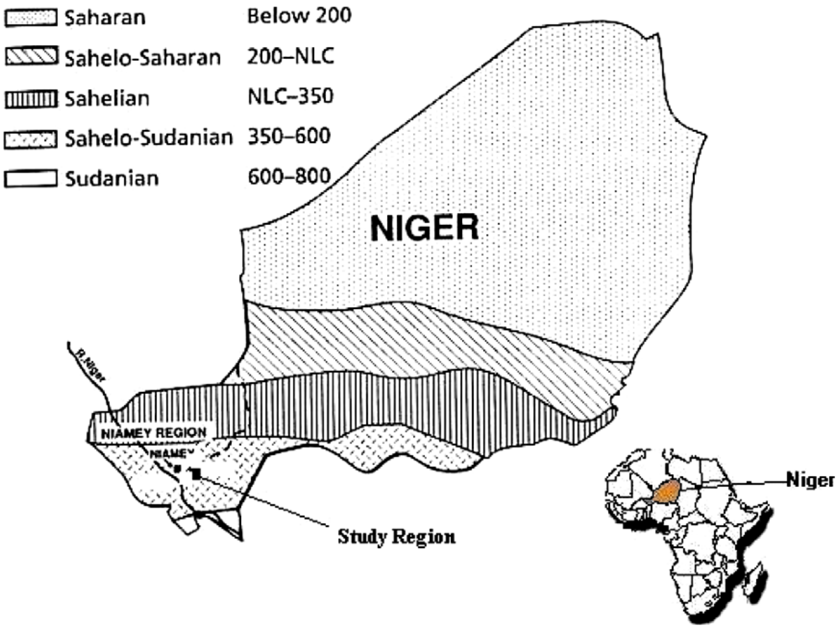

Fig. 1. Isohyets and study region in Niger. *Note*: NLC is the northern limit of cropping. The isohyets refer to 90% probability.

Farms average 7 ha which is very small for marginal rainfall regions. Households are a mixture of single and multiple families averaging 7 members (World Bank, 2001). All adults-above 14 years old-labor on the communal fields. Most adults also are given small areas (as 0.1 ha) for private fields in which they can work after their joint responsibilities on the communal fields are fulfilled. Women and men keep or sell the production on their private fields for their own use. Those with access to underground water can produce fruits or vegetables out of season.

Crop production provides 40–60% of household income with the rest from livestock and non-farm activities. Farmers raise goats, sheep and chickens. Non-farm activities include a range of commerce and semi-skilled professions (barbers, carpenters) demanded in the village.

2.2. Riskiness of agriculture: weather

Table 1 indicates the probabilities for the various types of years based upon rainfall data collected from the Dosso station on the edge of the Fakara plateau for the period, 1931–2000. In defining the periods there was a focus both on the total rainfall during the year and on the distribution of rainfall during August, when flowering and seed setting take place. Originally there were eight states defined and this was reduced to five states (for further details see Abdoulaye, 2002) very adverse, adverse, normal, good, and very good. In very adverse states farmers lose most of their har-

Table 1
Yields and prices in the different states of nature and the probabilities for each state from farm surveys and SIMA marketing studies

States of nature	Probabilities (%)	Millet yields – no fertilizer (kg/ha)	Millet yields – manure and 8 kg/ha of NPK (kg/ha)	Millet price at harvest ($/kg)	Millet price 6 months later ($/kg)
Adverse	17	288	332	0.18	0.23
Normal	43	359	415	0.13	0.16
Good	28	431	498	0.07	0.09
Very good	12	467	539	0.05	0.05
Expected value		379	438	0.11	0.14
Standard deviation		52	60	0.05	0.05

Source: Survey and trial data, SIMA (Système d'Information sur les Marchés Agricoles) database and authors calculations.
Note: Very adverse states are not included in the farmers' probability calculations. In these states farmers count on support from the public sector and NGOs. When these very adverse states are included, the probabilities are 14% for the very adverse state, 15% for the adverse state, 37% for the normal state, 24% for the good and 10% for the very good state. Very adverse states are the famous drought years such as 1971–1974, 1983–84, 1994–95 and 2004–2005. Farmers can plan on and do something about these four states of nature above.

vest. These major drought years are well known in the Sahel, 1972–74, 1983–84, 1994–95 and 2004–2005 or a little more frequently than once a decade. Farmers cannot include this very adverse state in their planning horizon as yields in general collapse and livestock either die or are sold at very low prices as few have sufficient pasture. In these years Nigerian farmers depend upon drought relief as American farmers depend upon disaster assistance and risk insurance (Dismukes and Glauber, 2005). So these very adverse or disaster years (14% probability) were excluded from farmers' calculation of expected values as farmers are unable to plan for these disaster years. Hence, only four states of nature are relevant. States of nature are the combined rainfall quantities and qualities defining the different types of year such that all possible year types are defined and the probabilities of the different types sum to one.

Expected yields are based on on-farm trial data at Goberi and Karabedji in the Fakara plateau from 1996 to 2000. Yields are mapped to the years that correspond to the given state of nature. The four states of nature included very good, good, normal, and very bad rainfall years. Since the trial periods (1996–2000) did not include very good years this year type was calculated as equal to 2 standards deviation above the overall mean.

2.3. Riskiness of agriculture: price variation

Besides the variation from weather, insects and disease farmers also face substantial price variation. Price variation partially offsets the yield variation since in good years prices collapse and in bad years prices become very high.

In the local regional market of Dosso during the 1999–2004 period the prices varied from 110 CFA/kg to 170 CFA/kg (Fig. 2) during the harvest season of October–

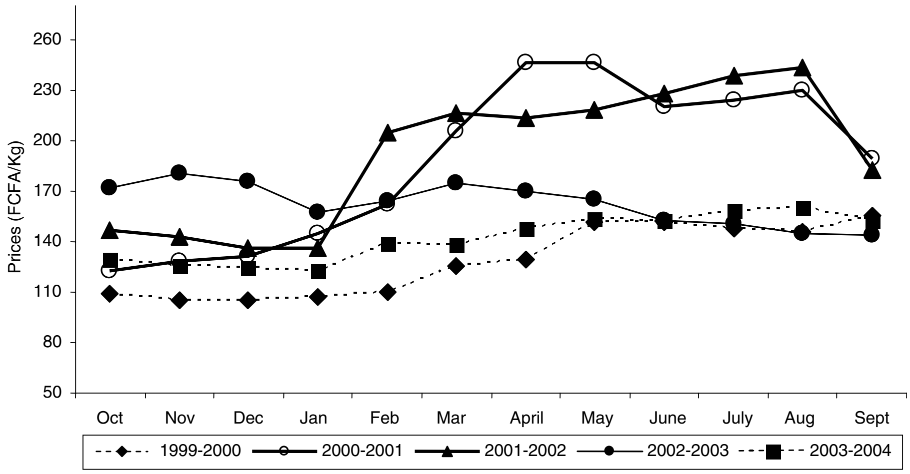

Fig. 2. Dosso Retail Monthly Millet Prices, 1999–2004. *Source:* SIMA database.

December. This demonstrates the price collapse that occurs with basic staples as weather and other stochastic factors result in substantial annual output shifts. Very bad and very good years are not represented in these five years. In very good years the millet price can fall to 50 FCFA at harvest.

Besides the between year price variation the annual price collapse at harvest (October–November) is clearly illustrated. Harvest prices should be compared with the "soudure"-hungry season prices in the June–August period. For good rainfall years such as 1999–2000 and 2003–2004 prices of millet increase from 110 to 150 and from 130 to 150, respectively, in this regional market. The second consecutive adverse year 2002–2003 prices started at 170 but there was substantial government selling of stocks and imports and the price fell to 140. Then in the following year, a normal year, the public sector bought substantial quantities and the millet price went to 230. So the returns to storage will be substantially influenced by what the public sector does. But there is substantial price variation both within years and between years.

The third cause of low prices is government and NGO interventions in bad cropping seasons. For example in July 2001, the government put 10,000 metric tons of millet on the market at a price of 100 FCFA/kg while the market price was 210 FCFA/kg in Niamey (Agence France Presse, 2001).

2.4. New technologies

One difference in the Fakara region from much of Niger has been the opportunity to observe fertilization. Since 1982 IFDC-ICRISAT (International Fertilizer Development Center-International Center for Research in the Semiarid Tropics) have had experiments in the region. In the late 1980s and early 1990s with active development programs here fertilizer use was much higher than now (Mokwunye and Hammond, 1992; Abdoulaye and Sanders, 2005).

In the last five years many Nigerian farmers have been using micro-fertilization. Small quantities of inorganic fertilizer (compound fertilizer of NPK: nitrogen 15%, phosphorous 15%, potassium 15%) up to 25 kg/ha are put in the planting hole along with manure and the seed. Farmers repeatedly point out that the micro-fertilization increases the vigor of the seedlings and therefore there is less replanting required. Moreover, there is now substantial empirical evidence for the significance of the yield gains from micro-fertilization and their profitability from widespread trials over two years (2002 and 2003, an adverse and a good rainfall year) in Niger, Mali, and Burkina Faso (Tabo et al., 2005, pp. 6–9).

Farm level diffusion of higher concentrate micro-fertilization is also on-going with diamonium phosphate (DAP with 18% N and 46% P) in the three country ICRISAT fieldwork. In the lower rainfall zones (<400 mm and 400–600 mm) 20 kg/ha of DAP and the DAP with 10 kg/ha of urea gave higher millet yields and were more profitable than obtaining the same level of P from the compound fertilizer (60 kg of 15–15–15) (Tabo et al., 2005, p. 9). So different methods of micro-fertilization were included as activities in the modeling.

Only a small quantity of fertilizer can be put in the hole without burning the seed so the next higher level of fertilization after 25 kg/ha will need to be sidedressed. Sidedressing is more efficient than broadcasting since the fertilizer is closer and more accessible to the plant. But sidedressing requires more labor and a separate operation as broadcasting and micro-fertilization are done at planting time. Since sidedressing can be applied with the first weeding, the farmer will already have some information about the rainfall for the season. Then he can adjust the level of sidedressing or skip

Table 2
Expected yields of cropping activities of present and new technologies from long term trials of ICRISAT/IDRC

	Monoculture	Intercrop	
	Millet (kg/ha)	Millet (kg/ha)	Cowpea (kg/ha)
A. Current practices			
No fertilizer	379 (52)		
Manure (1400 kg/ha) + 8 kg/ha of NPK	438 (60)		
Micro-dosage (3 kg/ha of NPK)		285 (39)	120 (54)
Moderate dosage (25 kg/ha of NPK)		424 (58)	135 (62)
B. New technologies			
Improved micro-doses (20 kg/ha of DAP)	544 (59)		
5 + New cultivars	633 (148)		
Improved moderate dosage (60 kg/ha of NPK)		520 (218)	261 (63)
Improved moderate dosage (50 kg/ha of SSP)		524 (211)	302 (85)
7 + New cultivars		630 (309)	370 (143)
8 + New cultivars		635 (301)	434 (176)

Source: ICRISAT/IFDC (International Center for Research on the Semiarid Tropics/International Fertilizer Development Center) farm trial data furnished by André Bationo (Standard deviations are presented in the parentheses above). Note that these are expected values for all four states of nature. DAP is diamonium phosphate with nutrient levels of (18-46-0). NPK refers to compound fertilizer containing 15% each of nitrogen, phosphorous, and potassium generally known in the Sahel as "cotton fertilizer." SSP is simple super phosphate with nutrient levels of (0-18-0).

Table 3
Expected returns ($/ha) to cropping activities presently practiced and to new technologies from survey data on prices and costs with yields of Table 2

	Monoculture			Intercrop		
	Cash cost	Total cost	Net return	Cash cost	Total cost	Net return
A. Current practices						
No fertilizer	0	25	14 (11)			
Manure (1400 kg/ha) + 8 kg/ha of NPK	2	33	15 (12)			
Micro-dosage (3 kg/ha of NPK)				2	33	15 (8)
Moderate dosage (25 kg/ha of NPK)				8	47	18 (11)
B. New technologies						
Improved micro-doses (20 kg/ha of DAP)	7	39	19 (17)			
5 + New cultivars	14	44	20 (15)			
Improved moderate dosage (60 kg/ha of NPK)				18	63	27 (11)
Improved moderate dosage (50 kg/ha of SSP)				12	59	38 (12)
7 + New cultivars				26	76	39 (18)
8 + New cultivars				19	73	52 (17)

Source: Authors' calculations; $1 = 711 FCFA (IMF, 2002).
Note: Numbers in parenthesis are standard deviations for the net returns.

it entirely. So this is a type of response farming reducing the risk by adjusting to the climatic events.

After raising fertilization levels the introduction of new cultivars, that are more responsive to higher fertility conditions than traditional cultivars, is the next logical step (Sanders and Shapiro, 2003). Table 2 reports on the expected yields over the four states of nature and the yield variability of present and new technologies. There are gains in profits from all the activities but the gains are very small for the micro-doses (Table 3). There is a fairly substantial gain for the sidedressing with SSP (Simple Super Phoshate) and new cultivars. Note that this is not sustainable over time as there will be a need for N and K soon.

3. The model

3.1. Basic equations

The farm programming model consists of the 10 equations below. The model maximizes expected wealth (Eq. (1)) subject to fulfilling a harvest income constraint (Eq. (2)) and a millet consumption goal (Eq. (3)) and resource availability (Eq. (5)). Millet for the consumption goal can be obtained both by own production and purchase.

$$\text{Max EW} = \sum_{s=2}^{5} \theta_s W_s \tag{1}$$

subject to

$$p_{1is}q_{1is} \geqslant \bar{I}, \quad (2 \leqslant s \leqslant 5) \quad \text{for all } i(\text{crops}) \tag{2}$$

$$C_s + B_s \geqslant \overline{C}, \quad (2 \leqslant s \leqslant 5) \tag{3}$$

Eq. (4) is an identity defining that total production of millet is used to attain the harvest income goal, for home consumption and then what is left is sold in the post harvest period.

$$C_{is} + q_{1is} + q_{2is} = Q_{is}, \quad \text{for all } s \text{ and } i(\text{crops}) \tag{4}$$

Eq. (5) is the resource availability and requirements for the crop, livestock, and non-farm sectors. Crop activities are responsible for 40–60% of household incomes (Abdoulaye, 2002).

$$\sum_i a_{ij}x_i + \sum_t a_{tj}x_t \leqslant b_j, \quad \text{for all } i \tag{5}$$

Eq. (6) is the crop production function of area of each crop activity times yields.

$$Q_{is} = \sum_t y_{is}x_i \leqslant b_j, \quad \text{for all } s \tag{6}$$

Eq. (7) represents the production functions for the livestock sector and the non-farm sectors. Both the livestock and non-farm production functions are based upon constant rates of return estimated in previous studies (Abdoulaye, 1995; Abdoulaye and Lowenberg-DeBoer, 2000). Upper level constraints were put upon non-farm activities as there are only so many kola nuts that a farmer could sell or hair that he could cut in the village. Within these constraints though the model allows the allocation of labor and capital to these three activities. The second term on the right represents the number of livestock or non-farm units and the first term the returns per unit.

$$r_t = \sum_t \alpha_t l_t \tag{7}$$

The "expected wealth" term is complicated here in the maximization process in Eq. (8) by the two constraints. The farmer must sell in the first period to obtain the harvest income goal and then retain or buy millet in the second period to obtain the food consumption goal. So then he maximizes second period income and deducts cash costs for total production from this. Since the farmer also needs to purchase millet in some years we include here transfers from remittances. The term $P_{2is}B$ allows him to purchase millet to get to his goal. Lambda is introduced here and is called the "own food production premium." Lambda will be discussed more in the calibration section below.

$$W_s = \sum_i p_{2is}q_{2is} + \sum_t r_t + M_s - \sum_i c_i x_i - \lambda P_{2is} B_s \tag{8}$$

Eq. (9) and (10) are definitions that enable us to return to a meaningful household income definition. First we take out the remittances, which are a transfer, and then eliminate the adjusted food purchases (Eq. (9)). Then we add back in the value of the sales and the value of the household consumption to attain the household income goal. The price of the millet for home consumption is a weighted average of the sale price. The weights are based on the percentages sold at the different periods. Note that this is still a linear programming concept of income, often called gross margin, as on the cost side only cash expenditures have been deducted (see Table 4).

$$W_s^* = W_s + \lambda P_{2is} B_s - M_s \tag{9}$$

$$\Psi = \sum_s \theta_s \left(W_s^* + \left(\sum_i p_{1is} q_{1is} \right) + p_{cs} c_s \right) \tag{10}$$

Table 4
Variable definitions

Variables	Definition
EE	The expectation operator
W_s	The value of after harvest sales plus net returns to other activities plus the remittances minus the costs of millet purchased later in the year adjusted for the own food production preference coefficient (λ) in state of nature s. The w without the subscript indicates the expected value
θ_s	The probability of state s with $\sum_s \theta_s = 1$
p_{2is}^{e}	Expected price for crop i in state s in the price recovery period (6 months after harvest)
q_{2is}	Quantity of crop i sold in the price recovery period (6 months after harvest) during state s
r_j	The revenue of the jth livestock or non-agricultural activity
c_{i}	The input cost per hectare ith crop activity
x_{is}	The number of hectares of the ith crop activity in state s
λ	Own food production preference coefficient
P_{1is}	The price in state s for crop i at harvest
q_{1is}	The quantity sold in state of nature s for crop i at harvest
$\bar{I}$	The income required at harvest
$\bar{C}$	The required quantity of millet for household subsistence
C_s	The quantity of millet produced for home consumption in state s
B_s	The quantity of millet purchased for home consumption in state s
Q_{is}	The total production of crop i in state s
y_{is}	The yield per hectare of activity I in state of nature s
p_{cs}	The price for millet produced and consumed by the household
Ψ	The expected total household income
a_{ij}	The technical coefficients
l_{ts}	Unit of other activities (livestock and non-agricultural) in state s
α_{ts}	Per unit return to other activities (livestock and non-agricultural) in state s
W_s^*	Household income includes income from crop, livestock, and non-farm activities. In the results we will present first income from crop activities and then total income
M	Remittances during the adverse state of nature
b_j	Availability of resource j

Note: The subscripts are: s for states of nature, i for crops, t for other activities, 1 and 2 for crop sale periods (1 is harvest and 2 is the price recovery period), j for resources and c for consumption.

3.2. Background on components of model and calculation of some exogenous values

Based on field studies in Niger, Mali, Senegal, and Mozambique (Abdoulaye, 2002; Vitale, 2001; Sidibé, 2000; Uaiene, 2004) farmers' principal objective is the harvest income goal, which takes precedence over their desire to set aside cereals for consumption during the year and over profit maximization. Not only did farmers say that this household income goal was more important than the storage subsistence goal but farmers were also observed selling off their primary staple and repurchasing it later in the year especially in adverse states of nature.

At harvest the farmer needs to have sufficient income to pay taxes, which are collected then, and school fees so his kids can attend school. He needs to repay his loans at harvest. Then he needs to pay household wages to family members. These are paid in the form of clothing, especially to female family members, and as advances to the male members of the household, who migrate to urban Niger or out of the country after the harvest and return the next year for the crop season. Weddings also take place after harvests. With their wide circle of close friends farmers have to pay for gifts even when their family members are not getting married.

With so many farmers selling at harvest, staple prices collapse. Millet prices then gradually recover climbing until they reach their peak in the "soudure" or "hungry season" (Fig. 2). The 'soudure" is the period when food reserves are almost gone and the new crops are not yet ready for harvest.

This household income goal is calculated from the actual expenditures of the households in a normal rainfall year and in the model was set at \$98 based upon field interviews with 100 families (Abdoulaye, 2002; using the February 2001 exchange rate of 711 FCFA/\$, IMF, 2002). This was 21% of total household income, the average observed in the sample. In continuing work we have estimated this harvest income requirement for different states of nature. In good and very good years farmers make more investments at harvest in human and physical capital, i.e. farmers pay for medical expenses and improvements to their housing (Baquedano, 2005).

The millet consumption goal ($\overline{C}$) was 200 kg/year for the adult male equivalent. This was based upon average consumption in normal years. This was adjusted for the gender and age of the family members in the household.

Remittances in Eq. (8) help in purchasing sufficient grain later in the year in adverse rainfall years. Remittances were estimated at the median in our sample as \$86 for adverse years and zero otherwise (Abdoulaye, 2002).

In the Sahelian production system many of the migrants to the urban areas of their country or to coastal cities come back and work on the farm for the rainfed crop season. Then they migrate again after the crop season (Rain, 1999). The migrants are paid after the harvest. These payments can be considered as labor payments and as a type of insurance since the farm households depend upon the remittances of the migrants. These remittances come either in the form of grains or cash but they help assure subsistence consumption especially in the bad rainfall years.

3.3. Model calibration

Low income farmers in difficult climatic regions are adverse to being dependent upon the market for the supply of their primary food staple. So in the model farmers continue producing millet even though they could buy it cheaper later in a normal year on the market. The rationale is that the price for millet six months after harvest is only the expected price. In adverse rainfall years the price will be substantially higher. Moreover, farmers will need to find the income for these purchases.

The "own food production premium" (λ) allows us to raise the shadow price of production of millet above the expected price six months after harvest to compensate for this desire of farmers to assure much of their own production without being dependent upon market purchases. With the "own food production premium" (λ) set at one the cost of production of the next kg of millet (opportunity cost) is equal to the expected purchase price ($p^{e}_{2is} = 113\ \text{FCFA/kg}$) in a normal season six months after harvest. At this level of millet production farmers are entirely dependent upon millet purchase in adverse years and leave part of their crop land idle. Neither of these model predictions is consistent with observed farmers' practices.

The value of λ is adjusted until the model prediction is consistent with farmers' observed behavior. Specifically, we observed how much of farmers' consumption of their millet staple comes from their own production in different states of nature and adjusted the model with lambda to reflect their continuing to produce millet beyond the point at which their marginal cost of production of millet is equal to the expected market price. Notice that this enables farmers to feel more food secure and less dependent upon purchases to achieve their consumption goals.

At $\lambda = 1.77$ crop area is fully occupied and farmers produce millet until their marginal cost of production is 200 FCFA/kg. This is the expected price in the "soudure" in a bad rainfall year (hungry season-the period right before the next harvest). In 2001, millet prices reaching 210 FCFA/kg and 220 FCFA/kg were reported in Niamey and other major cities of Niger (Agence France Presse, 2001). In Dosso the millet prices were well over 200 FCFA/kg in 2000–2001 and 2001–2002 (Fig. 2). In most of 2005 millet prices were well above 200 FCFA/kg.

This higher "own food production premium" enables farmers to continue producing millet until their costs of production are 77% higher than the expected purchase price for millet in normal years. But this value is consistent with the price of millet expected later in the year in adverse years. Moreover, in adverse years farmers still need to purchase 32% of their consumption requirements according to the model results. Millet purchases in adverse years and even in more favorable years have been regularly observed in Niger. The same phenomenon has been reported for basic food staples in other countries (Arndt et al., 2001; Barrett, 1996; Weber et al., 1998).

Besides the calibration here there is some validation by comparing income estimates of the modeling with other studies of nearby regions. Adjusting with the Consumer Price Index (IMF, 2002) for the same base year (1995) the model estimate here of \$578 (\$1 = 711 FCFA) in household income is reasonably close to the Hopkins-Reardon (1993) estimate of \$446 for northern Boboye (also in the Fakara Plateau).

4. Alternative scenario results

4.1. Introduction of new technologies

Farmers' current practices, either without or with micro-fertilization, have a common characteristic, which is their low out of pocket expenses (0 and $2/ha cash expenses, respectively). All improved fertilizer based technologies have higher costs than the current farmer practices due to the increased fertilizer costs and the additional labor required. Their higher expected revenues pay for the additional costs (Table 3).

If farmers have the alternative available to introduce higher micro-doses of fertilizer and/or 60 kg/ha of side dressing once the plants have germinated, farmers choose (model results) these activities. Then the model prediction is that they increase expected crop incomes 85% and expected household incomes 37% (gross margins as indicated previously – Table 5). The model predicts that the area in the types of fertilization was about equally divided between higher levels of micro-doses of fertilizer and side dressing. This technology raises incomes in all states of nature and was sufficiently profitable to be introduced even without changes in marketing strategy (model results).

As discussed earlier the farm decision model excludes the extreme drought years occurring with approximately 14% probability. In these types of years Nigerian and developed country farmers are dependent upon outside assistance in cash or kind as yields collapse and livestock die. In our analysis we distinguish between bad years and very bad (drought) years. In bad years there is substantial potential for the

Table 5
Farm plans and expected incomes with the current production system and new technologies (model results)

	Current system (no new technologies)	Introduction of new technologies
Current practices (ha)		
No fertilizer	2.26	–
Small doses of fertilizer	3.74	–
New technologies (ha)		
Micro-doses	–	2.70
Moderate doses	–	3.30
Expected household income (US$)	587	805 (37%)
Expected crop income	279	515 (85%)
Opportunity cost of capital	95%	130%

Source: Model results.
Note: Numbers in parenthesis are percent increases from current practices. Current practices, The no fertilizer practice is monoculture millet without any fertilization. Small doses of fertilizer are a millet/cowpea intercropped activity (3 kg/ha of NPK and manure plus 8 kg/ha of NPK). New technologies, micro-doses are monoculture millet fertilized with (20 kg/ha of DAP). Moderate doses activities include millet/cowpea intercropped activities with NPK (60 kg/ha) and also with SSP (50 kg/ha) both using improved varieties.

farmer to profit from the large seasonal price variation as long as the public sector does not intervene to drive down prices. In drought years the government needs to intervene. The difficulty is distinguishing between the two types of years and defining the types of intervention.

4.2. Harvest price collapses – storage and inventory credit

A primary price problem for farmers is the annual post harvest price collapse. Merchants purchase at harvest time and then store to take advantage of the price recovery later in the year. Farmers could also benefit from selling part or all of their harvest later. To put off the sale, farmers need credit or some other source of income during the period they are storing waiting for the price recovery.

There are two components to an inventory credit program. First, when farmers sell crops latter in the years, they receive higher prices. Second, by providing farmers with cash at harvest, inventory credit can eliminate the need for harvest time sales. This seasonal price increase corresponds to an increase in the price of millet from $0.13/kg (91 FCFA at harvest) to $0.16/kg (113 FCFA) in a normal year (Table 6). Price increases are substantially larger in the adverse climatic year. Price increases of 50% between harvest and the next planting season are common (République du Niger, 2000).

With inventory credit available farmers (model results) increase slightly the use of micro-fertilizer and reduce the side dressing (Table 7). There are also small increases in crop and household incomes as compared with new technology alone. These income increases then provide further incentives to use the new technologies and inventory credit. The opportunity cost of capital is still very high in the model results (130%) indicating that as farmers accumulate savings from these income increases or from the development of farmers' associations providing credit, there is a high return to continuing to make these investments. So there is a dynamic effect expected, which is larger than this comparative statics shift here, since this shift is still constrained by capital shortages. Moreover, the interest and storage costs of inventory credit pro-

Table 6
Expected millet prices ($/kg) for different states of nature and with different marketing strategies (SIMA data)

	New technologies	Inventory credit	Between year price collapse moderation	No government intervention in adverse years
Adverse	0.18	0.23	0.23	0.32
Normal	0.13	0.16	0.16	0.16
Good	0.07	0.09	0.16	0.09
Very good	0.04	0.05	0.16	0.05
Expected	0.11	0.14	0.17	0.15
Standard deviation	(0.05)	(0.06)	(0.03)	(0.08)

Source: SIMA database and authors' calculations; $1 = 711 FCFA (IMF, 2002).

Table 7
Land allocation, returns to capital, and income effects of current practices, new technologies, and the combination of new technologies and improved marketing strategies (model results)

	Without new technologies	With new technologies	New technologies and inventory credit	New technologies with less government (and NGO) intervention in bad years	New technologies and new markets
Current practices					
No fertilizer (ha)	2.26	–	–	–	–
Small doses of fertilizer (ha)	3.74	–	–	–	–
New technologies					
Micro-doses (ha)	–	2.70	2.65	2.39	1.52
Moderate doses (ha)	–	3.30	3.45	3.61	4.48
Household income ($)	587	805	835	914	939
Crop income ($)	279	515	550	633	657
Percent change in household income (from present practices)	–	37	42	56	60
Percent change in crop income (from present practices)	–	85	97	127	136
Opportunity cost of capital (%)	95	130	130	130	130

Source: Model results; $1 = 711 FCFA (IMF, 2002).

grams would be expected to decrease with experience resulting in further incentives to adopt these programs.

As more farmers and merchants do this storing and selling over time, the seasonal price variation can ultimately disappear. However, in reviewing the performance of inventory credit programs in Africa the main undermining factor in two inventory credit programs in Ghana and another in the Zambia has been "ad hoc interventions" by the state based upon food security objectives (Coulter and Onumah, 2002, pp. 330–332; Onumah, undated). In the adverse or bad weather years the public sector often intervenes to drive down food prices. In these model runs of the returns to inventory credit the public sector and NGOs drive down the food price in adverse years. This intervention will be eliminated in Section 4 below. That enables the calculation of the income effect to inventory credit without government intervention.

4.3. Good year price collapses and new markets

The second critical type of price collapse is the between year effect resulting from the production increases of good years. People can eat only so much of their basic staple, so it is difficult to increase consumption rapidly for the basic food staples or to find new markets once the price has collapsed. Economists refer to this classic problem of food staples as price inelasticity of demand. Moderating the price collapses of the basic food staples by developing new markets encourages a more rapid introduction of new technologies by shifting the demand and increasing the elasticity (Vitale and Sanders, 2005).

An important complementary activity to moderate price collapses is spatial integration of markets between regions and countries. Spatial integration of markets requires increased public investment in transportation and communication plus the reduction of the many check points taxing trade within and between countries. These spatial price differences still remain very large.

One of the fastest growing sectors in the Sahel is the food processing of the traditional cereals, millet and sorghum (Ouendeba et al., 2003). In developed countries rice and wheat consumption requires minimum time of the housewife because food scientists have developed labor savings methods of processing and preparation. In the urban Sahel the value of time of women has been substantially increased. Fortunately, for the consumption of locally produced staples these same labor saving innovations have now been developed by food scientists for millet and sorghum.

Packaged couscous and a series of other millet products are increasingly available across the Sahel especially in Dakar and Bamako. In Dakar, Senegal there are 11 local semi-industrial firms producing processed millet products including, tchakri-yogurt, arraw, dégué, flour and infant food (Ouendeba et al., 2003). Moreover, some of those small scale food processors are even exporting millet based products to West Africans in Europe and the US.

Given the importance of millet in both production and consumption the potential market size for processed food is not expected to utilize more than 5–10% of the supply. Nevertheless, a small sector of better producers are benefiting from the increased urban demand for processed traditional cereals. Besides the direct effect of market expansion an indirect effect on technology use by other farmers would be expected. So even farmers not involved in the new markets would have the demonstration effects of the new technologies and some technology adoption would be expected. For these farmers, producing for local markets and their own use, new technology adoption would have a food security increasing effect.

For market expansion programs (including both increased food processing and the use of cereals as feed) the price effects are substantial for the good and very good years (Table 7).The technology introduced (model results) is a continued shift out of micro-doses and to sidedressing with a net increase in fertilizer use. Household incomes are almost doubled as compared with new technology alone. Crop incomes are now increased by 136% and household incomes by 60% with the combination of new technology and improved markets (Table 7).

4.4. Public intervention in adverse and disaster rainfall years

Sahelian governments tend to respond quickly when food prices go up in bad rainfall years and sometimes even in normal rainfall years (Angé, 1997; cited in

Yanggen et al., 1998; Bates, 1981). Higher prices can have adverse welfare effects on both urban consumers and those farmers purchasing food supplies. Even in a normal cropping season, small farmers often shift from net food sellers at harvest to net food buyers later in the year (Barrett, 1996; Weber et al., 1998).

Traditionally, the government of Niger has responded with releasing publicly managed cereal stocks, imports and/or calls for food aid at the price for millet of 180–200 FCFA/kg. These are also the years in which the seasonal price variation is potentially the largest. In adverse or bad rainfall years the gains to inventory credit can be very important to farmers. In the poorer rainfall years there is much less gain from new technologies based on inorganic fertilizer and new cultivars. In the good rainfall years the gains from seasonal price variation are much less and often very small but the gains from these new technologies are substantial (for evidence on the gains to farmers from technologies and marketing strategies for these two different types of years see Ouendeba et al., 2003b; Ouendeba et al., 2004).

In our model with the government not intervening in the bad rainfall year the millet price went from \$0.18/kg (128 FCFA) to \$0.32/kg (228 FCFA) (first columns of Table 6). The model then predicts that the expected household income is increased by 56% from the combined effect of the new technologies, inventory credit and less governmental intervention in the bad rainfall year (Table 7). Even more important household incomes in bad or adverse years went from \$529 with just new technologies to \$775 (model results in Table 8). Of the four approaches evaluated here this policy shift had the largest effect in the adverse weather year.

The problem for the government of distinguishing between a drought year and an adverse or bad year is illustrated by the crop year, 2004–2005, in Niger. In 2004 European donors, international organizations, and the Prime Minister's office of the government of Niger updated an agreement (first signed in 1998) that Niger would not release any of its cereal stocks unless it were a disaster year ("crise alimen-

Table 8
Household incomes (in dollars) for different technology and marketing strategy for the different states of nature (model results)

	Without new technologies	With new technologies	New technologies and inventory credit	New technologies with less government intervention in bad years	New technologies and only moderate price collapse in good and very good years
Adverse	459 (159)	529 (244)	528 (246)	775 (478)	530 (249)
Normal	583 (278)	794 (504)	827 (543)	849 (574)	792 (511)
Good	647 (334)	914 (623)	955 (670)	1018 (736)	1146 (865)
Very good	640 (322)	977 (684)	1016 (731)	1107 (826)	1559 (1278)
Expected income	587 (279)	805 (515)	835 (550)	914 (633)	939 (657)
Standard deviation	64 (59)	141 (139)	155 (154)	112 (114)	310 (310)

Source: Model results.
Note: Numbers in parentheses are crop income.

taire grave'') (République du Niger, 2004; p. 5). This agreement reflects the increasing concern that the public sector can disrupt the food markets. Unfortunately, the distinction between a bad year and a disaster year was not made clear.

The 2004–2005 agricultural season included both low rainfall and regional locust attacks. Nigerien requests for food aid in November 2004 were ignored. Millet prices increased to 250 FCFA/kg in the spring of 2005 and reached the unheard level of 300 FCFA/kg in August. From the spring through the summer there was extensive international reporting of children suffering in the Nigerian villages. In August millet prices started to come down due to the food aid arriving rapidly from NGOs and the donors.

5. Conclusions

New fertilizer based technologies are adopted by farmers according to model results. Introduction of new marketing strategies results in an accelerated technology adoption and further income increases for farmers (model results). Only the public policy of not intervening in adverse rainfall years substantially increased returns in poor rainfall years. But this is a very important type of year to increase returns from the inventory credit since the new technologies do not perform well in low rainfall years.

Inventory credit is already being adopted in the Sahelian region as is the development of new markets for the traditional food crops especially in Senegal (Ouendeba et al., 2003a). Review of previous program performance (Coulter and Onumah, 2002) and our model results indicate the importance of the governmental sector not intervening in these adverse years to drive food prices down. This governmental policy choice not to intervene provides a substitute for the risk insurance used in developed countries for adverse rainfall years in semiarid regions.

Distinguishing between an adverse year and a disaster year will continue to be important in Niger and the other Sahelian countries. The short run choices open to Niger and other countries are often very difficult as indicated in 2004–2005. For the definition of a disaster year a millet price of 200 FCFA/kg may be too low and 300 FCFA/kg too high. Clearly, donors want less public intervention and more incentives through higher prices for farmers. The televised images in 2005 of village level suffering will probably push the intervention price lower leading to more rather than less intervention over the short term. In turn this will make the implementation of inventory credit programs more difficult (Coulter and Onumah, 2002).

Are there some general inferences about food prices and poverty policy? Poverty is a function of the incomes of poor people and the prices they pay. Policy instruments that focus on the incomes of poor people rather than the prices they pay will have less negative effects on the incentives of farmers attempting to use new technologies and invest more in their farms.

Is it possible to identify policy instruments that will have less negative effects in reducing the use of inputs and investments in agriculture? Specific payments to poor people in cash or kind as with Food for Work programs seem to fit in this category. The purchase of food commodities in the target country to be distributed or sold in other regions also gives incentives at least to the farmers in the selling region.

This paper presents a farm level evaluation of the benefits of different policies without evaluating the aggregate effects of widespread adoption on prices or the financial and welfare costs of alternative policies. For the adverse year this analysis does not quantitatively compare the benefits to farmers selling with the losses to consumers and to food buying farmers. So the public sector will need to take the welfare of these different groups into consideration in making policy decisions. In the long run increasing farmers' incentives to use inputs and to make investments in their farm operations would be expected to benefit both selling farmers and consumers. Consumers would benefit from the lower food prices than in the absence of farmers' investments in new technologies.

Acknowledgement

We are grateful for the support of INRAN (Institut National de la Recherche Agronomique du Niger), USAID (US Agency for International Development) through INTSORMIL (Grant #AG-G-00-96-90009-00) and the USAID/USDA Collaborative Agreement (#58-3148-6-082) for the research reported. We are also grateful to Dr. André Bationo of TSBF formerly at ICRISAT/IFDC and his staff for trial data and partial financial support for the fieldwork for this study. We are grateful for two series of comments from two reviewers for the journal, who substantially improved the exposition with their detailed requests and suggestions. Robert Kagbo of the regional USAID office in Accra also helped with his observations.

References

Abdoulaye, T., 1995. Impact of opportunity cost of capital on adoption of new technologies in the Birni N'Konni region of Niger, M.S. thesis, Department of Agricultural Economics, Purdue University, West Lafayette, IN, USA.

Abdoulaye, T., 2002. Farm level analysis of agricultural technology change: Inorganic fertilizer use on dryland in western Niger. Ph.D. dissertation, Purdue University, Department of Agricultural Economics, West Lafayette, IN, USA.

Abdoulaye, T., Sanders, J.H., 2005. Stages and determinants of fertilizer use in semiarid African agriculture: The Niger experience. Agricultural Economics 32, 167–179.

Abdoulaye, T., Lowenberg-DeBoer, J., 2000. Intensification of Sahelian farming systems: Evidence from Niger. Agricultural Systems 64, 67–81.

Agence France Presse, 2001. Famine: le gouvernement va fournir 10.000 tonnes de céréales à des prix réduits. Niamey, 27 Juillet. Available from: http://www.afp.com/ext/francais/coope/niger/010727181111.wndtyfpw.php.

Ahmed, M.A., Sanders, J.H., 1998. Shifting from extensive to intensive systems: A case study in Sudan. Agricultural Systems 58, 253–268.

Angé, A.L., 1997. Les systèmes pilotes de distribution de l'engrais contrainte et perspectives en Afrique Sub-Saharienne. FAO, Rome, Unpublished mimeo.

Arndt, C., Schiller, R., Tarp, F., 2001. Grain transport and rural transport in Mozambique: Solving the space time problem. Agricultural Economics 25, 59–70.

Baquedano, F.G., 2005. The economics of inventory credit in western Niger, unpublished Masters thesis, Department of Agricultural Economics, Purdue University, West Lafayette, IN.

Bates, R.H., 1981. Markets and States in Tropical Africa. University of California Press, Berkeley, CA.

Barrett, B.C., 1996. Urban bias in price risk: The geography of food price distributions in low-income economies. The Journal of Development Studies 32, 830–849.

Coulter, J., Onumah, G., 2002. The role of warehouse receipt systems in enhanced commodity marketing and rural livelihoods in Africa. Food Policy 27, 319–337.

Dismukes, R., Glauber, J., 2005. Why hasn't crop insurance eliminated disaster assistance?. Amber Waves 3 (3) 34–41.

Hopkins, J., Reardon, T., 1993. Agricultural price policy reform impacts and food aid targeting in Niger. Report to the USAID, INRAN-IFPRI, Washington DC, USA.

IMF, 2002. International Financial Statistics. International Monetary Fund, Publication Services, Washington DC.

Mokwunye, U., Hammond , L., 1992. Myths and science of fertilizer use in the Tropics, In: Lal, R., Sanchez, P.A. (Eds.). Myths and Science of Soils of the Tropics. SSSA special publication No. 29, Soil Science Society of America and American Society of Agronomy, Madison, WI, USA.

Onumah, G.E., undated. Improving access to rural finance through regulated warehouse receipt systems in Africa, Natural Resources Institute, Greenwich, England, mimeo, 15 pages.

Ouendeba, B., Abdoulaye, T., Sanders, J., 2003a. Production and marketing strategies: Concept Note 1. In: Ouendeba, B. (Ed.), Marketing and New Food Crop Technologies in the Sahel. INTSORMIL, Lincoln, NE.

Ouendeba, B., Abdoulaye, T., Sanders, J., 2003b. Impact of technologies and marketing strategies on farmers' incomes, Progress Report *1. In: Ouendeba, B. (Ed.), Marketing and New Food Crop Technologies in the Sahel. INTSORMIL, Lincoln, NE.

Ouendeba, B., Abdoulaye, T., Sanders, J., 2004. Accelerating technology intgroduction by increasing farmers' incomes with new marketing strategies. Progress Report 2, Department of Agricultural Economics, Purdue University, West Lafayette, IN, mimeo, 20 pages.

Rain, D., 1999. Eaters of the Dry Season: Circular Labor Migration in the West African Sahel. Westview Press, Boulder, CO.

République du Niger, 2000. Le warrantage: Une technique intéressante de crédit. l'expérience de Mayahi. Direction de l'Agriculture, Projet Intrant, Niamey, Niger.

République du Niger, 2004. Accord cadre entre l'etat et les donateurs, Relatif au renforcement du dispositif national de prevention et de gestion des crises alimenataires. Cabinet du Premier Ministre, Niamey, Niger.

Sanders, J.H., 1989. Agricultural research and new technology introduction in Burkina Faso and Niger. Agricultural Systems 30, 139–154.

Sanders, J.H., Shapiro, B., 2003. Crop technology introduction in semiarid Sub- Saharan Africa: Performance and future strategy. Journal of Crop Production 9 (2), 559–592.

Shapiro, B.I., Sanders, J.H., 2002. Natural resource technologies for semiarid regions of Sub-Saharan Africa. In: Barrett, C.B., Place, F., Aboud, A.A. (Eds.), Natural Resource Management in African Agriculture: Understanding and Improving Current Practices. CABI Publishers, New York, NY, pp. 261–274.

Sidibé, M., 2000. A farm household analysis of technological change and structural adjustment policies in the peanut basin of Senegal. Ph.D. dissertation, Department of Agricultural Economics, Purdue University, West Lafayette, IN, USA.

Tabo, R., Bationo, A., Diallo Maimouna, K., Kassane, O., Koala, S. 2005. Fertilizer microdosing for the prosperity of small scale farmers in the Sahel: Final report, International Crop Research Institute for the Semiarid Tropics (ICRISAT), Sadore, Niger.

Uaiene, R,. 2004. Maize and sorghum technologies and the effects of marketing strategies on farmers' incomes in Mozambique. MS thesis, Department of Agricultural Economics, Purdue University, West Lafayette, IN, USA.

Vitale, J., 2001. The economic impacts of new sorghum and millet technologies in Mali. Ph.D. dissertation, Department of Agricultural Economics, Purdue University, West Lafayette, IN, USA.

Vitale, J.D., Sanders, J.H., 2005. New markets and technological change for the traditional cereals in semiarid Sub-Saharan Africa: The Malian case. Agricultural Economics 32, 111–129.

Weber, M., Staatz, J.M., Holtzman, J.S., Crawford, E.W., Bernsten, R.H., 1998. Informing food security decisions in Africa: Empirical analysis and policy dialogue. American Journal of Agricultural Economics 70 (5), 1044–1052.

World Bank, 2001. World Development Reports, 2001, 2004, 2005. Oxford University Press, New York.

Yanggen, D., Kelly, V., Reardon, T., Naseem, A., 1998. Incentives for fertilizer use in Sub-Saharan Africa: A review of empirical evidence on fertilizer response and profitability. Michigan State University, International Development Working Paper No. 70, East-Lansing, MI.