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Household Behavior Under Market Failures: How Natural Resource Management in Agriculture Promotes Livestock Production in the Sahel

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Household Behavior Under Market Failures: How Natural Resource Management in Agriculture Promotes Livestock Production in the Sahel

by

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Abstract

Improved water harvesting and soil erosion control using the remarkably simple practice of contour stone bunding is shown to increase grain yields by 41% in low rainfall regions of Burkina Faso. Empirical results show that yield increases in food crops help food-buying farm households import substitute in food consumption, reduce livestock production, and increase seasonal migration which is more compatible with seasonal agriculture than with the yearlong livestock activity. Self-sufficient households, by contrast, can take advantage of higher yields to free resources from food production and allocate these to expand their livestock economy, thus benefiting more from the region's comparative advantage. We also show that greater effectiveness in cooperation in the management of common property resources helps increase income derived from livestock for all categories of households. However, not all forms of cooperation are effective. When cooperation is only formal, individual activities such as crops, non-agricultural employment, and seasonal migration are pursued as opposed to livestock activities that rely on effective community management of common property resources.

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1 Introduction

Livestock and crops are the main sources of income for rural households in the Sahelian zones of Africa. In the Sahelian zone of Burkina Faso under study here, they represent 45% and 33% of household income, respectively. Non-agricultural activities (9% of household income in the study area) and seasonal migration (13% of household income) are additional sources of income, but they only provide a modest fraction of household income compared to farming. Low productivity in crops and livestock production implies that these households are almost universally in poverty. With poor soils, highly erratic rainfall, and lack of sources of water for irrigation, the region has comparative advantage in livestock production. However, high transactions costs on food markets imply that there is pressure on households to increase food production in order to reduce high priced food purchases and achieve food self-sufficiency. As a consequence, there are demands to increase productivity in food crops, even if livestock is the preferred activity.

Sahelian households typically have access to land through two forms of property rights: individual land plots assigned by village authorities on which agriculture is practiced, and common property resources (CPR) with maintenance and use regulated by the community on which livestock is grazed. This implies that there are two instruments that can be used to raise productivity in farming activities. One is technological: capture productivity gains in agriculture through improved natural resource management, in particular by adopting water harvesting and soil erosion control techniques. The other is institutional: improve the capacity of communities to cooperate in the management of common property pastures used to graze livestock and thus raise livestock productivity.

While nearly all households in the region are poor, there is a high degree of heterogeneity across households in their asset positions and in the quality of the contexts that determine the income potential of these assets. As a consequence, these households follow different food market participation strategies: while most households are net sellers of livestock products and labor power (which constitute their two main cash earning activities), some manage to achieve food self-sufficiency (13% in the region under study) while most (87%) are net buyers of food.

The thesis of this paper is that, due to high transactions costs in food markets, productivity gains in food production through improved natural resource management (NRM) techniques help support expansion of the livestock economy and capture regional comparative advantages in that activity. This reasoning on farm household behavior under food market failure had been predicted in a generic model constructed by de Janvry, Fafchamps, and Sadoulet (1991). Results in this paper support the model's conjecture that responding to households' demands for productivity gains in agriculture helps them successfully develop their livestock economies.

In this paper, we first develop a model of household behavior that evidences the origin of complementarities between food and livestock activities when there are high transactions costs on food markets and households endogenously select food market participation strategies (Part 2). We then turn to a community and household survey for the Sahelian zone of Burkina Faso to determine how households choose market participation strategies (Part 3). This depends in particular on the communities' capacity to cooperate in the management of CPR and on the role of NRM in sustaining yields in food production. We then use this to analyze how NRM and cooperation affect households' income generation strategies and the levels of income achieved according to their particular market participation regime (Part 4). Conclusions about the interrelated roles of NRM in food production and promotion of the livestock economy follow from this analysis.

2 A model of household behavior in the context of transactions costs

In order to identify the impacts of (1) technological change in crop production and (2) cooperation in common property resource management on individual household production and consumption decisions, we construct a static model that ignores several important aspects of the household's decisions, notably the roles of risk and intra-annual credit constraints.

Consider a household that engages in two activities, food crop and livestock production. Food production is done on individual land plots. We assume that land and labor are the only variable inputs in crop production and, for simplicity, that they are used in fixed proportions. This assumption is quite close to what is observed in African villages where agricultural technology is very simple, so that considering a more flexible production technology would not qualitatively change the results of the model. In the region we are analyzing, all land is held under customary tenure.[1] Land privately cultivated in any one given year has been allocated to the household by the community. Cattle's grazing is, by contrast, done on community land held unassigned for common use. Livestock production depends on the number of animals the household puts to graze and on the quality of the common pasture. Labor needed for cattle herding is largely determined by the number of animals, hence for simplicity is also considered in fixed proportion with herd size. There is almost no local labor market in the area under study, and hence we assume no labor market in the model. Given a total amount of labor $\overline{L}$ at its disposal, the household's production decision consists in allocating its labor endowment between food crops L_f and livestock L_l production.

The household consumes two commodities, food c_f and non-food c_{nf}. For simplicity, we assume that non-food can only be purchased. As livestock is mainly a cash activity, we assume that all livestock production is sold at price p_l. With large transactions costs on the food market due to remoteness of the region from major food production areas, the purchase price for food p_f^b is substantially higher than the price p_f^s received by a potential seller. Because of these transactions costs, households may choose market participation strategies where they may enter markets as seller or buyers, or remain in self-sufficiency, only producing what they consume.

The household problem is to choose consumption $\left(c_f, c_{nf}\right)$ and labor allocation $\left(L_f, L_l\right)$ to maximize its utility (1) subject to (2)–(7):

(1) $$u\left(c_f, c_{nf}; z_u\right)$$

(2) $$\left(p_f^s \delta^s + p_f^b \delta^b\right) m_f + p_l q_l + T - p_{nf} c_{nf} = 0$$

$$\delta^s = 1 \text{ if } m_f > 0, 0 \text{ otherwise}$$

$$\delta^b = 1 \text{ if } m_f < 0, 0 \text{ otherwise}$$

(3) $$q_f - c_f - m_f = 0$$

(4) $$q_f = q_f\left(L_f; z_f\right) \text{ and } A_f = \alpha L_f$$

(5) $$q_l = q_l\left(L_l; z_l\right) \text{ and } x = \beta L_l$$

(6) $$L_f + L_l = \overline{L}$$

(7) $$c_f, c_{nf}, L_f, L_l \geq 0,$$

[1] "Land tenure law in Burkina Faso rules that all land belongs to the State. Although private ownership of land is recognized, it is seen as an exceptional situation and land title can only be obtained through complex and extremely expensive procedures which makes such a form of tenure relatively rare". H. Ouédraogo and C. Toulmin, (2002).

where z_u, z_f, and z_l are exogenous shifters in utility and in food and livestock production, respectively; T is exogenous transfers and other incomes; δ^s and δ^b are indicator variables that single out sellers and buyers of food, respectively; q_f and q_l are production of food and livestock; m_f is marketed quantity of food (sale if positive and purchase if negative); A_f is the land area cultivated; and x is the number of animals grazed. Equation (2) is the household budget constraint and (6) is the labor allocation constraint. Production technology is defined in (4) and (5) for food and livestock, respectively, and (3) defines the net market transaction for food. Technological change in crop production, in our case construction of contour stone bunds for rainwater harvesting and soil erosion control, is an element of the shifters z_f.

Cooperation in the management of common property pastures consists essentially in actions to improve the provision of forage through rules of rotation of animals, dates of entry and exit in cultivated fields, access to water, maintenance of fences, and plantation and maintenance of trees in sylvo-pastoral systems. As opposed to other communities in the world that regulate extraction from common property pastures, there are here no rules on the number of animals that each community member can graze in the commons. For this reason, cooperation enters the household model as a shifter z_l in the productivity of the livestock production function.

2.1 Land allocation conditional on food market participation

Faced with large transactions on food markets, households must endogenously determine whether they will gain from participating in markets and, if they do, whether they will participate as buyers or sellers. Following Key, Sadoulet, and de Janvry (2000), the solution to the household land allocation and consumption problem is consequently decomposable into two steps. In a first step, the optimal production and consumption decisions within each of the three food market participation regimes are determined. In a second step, the market participation regime that leads to the highest level of utility is chosen.

Writing the first order conditions for the Lagrangian associated with the household model shows that the solution in all three regimes can *analytically* be written with the same expression. Define the decision price as follows:

$$p_f = \begin{cases} p_f^s & \text{if } m_f > 0, \text{ seller,} \\ p_f^b & \text{if } m_f < 0, \text{ buyer,} \\ p_f^* = \dfrac{\mu}{\lambda} & \text{if } m_f = 0, \text{ self-sufficient,} \end{cases}$$

where μ and λ are the Lagrange multipliers associated with the commodity balance (3) and the budget constraint (2), respectively. When food is not traded, the decision price is the unobservable internal shadow price p_f^*. When food is traded, the decision price is the market price facing the buyer or the seller. Using these prices, the solution can formally be written like that of a separable consumer and producer model (although it is clear that the model is not separable in the case of food self-sufficiency since the shadow price of food is itself endogenous). The production decisions result from a profit maximizing behavior under land constraint, leading to a system of output supply q_k and derived input demand for labor L_k and land for crop production A_f:

$$q_k = q_k\left(p_f, p_l, z_f, z_l, \bar{L}\right) \quad \text{for } k = f, l,$$

$$L_k = L_k\left(p_f, p_l, z_f, z_l, \bar{L}\right) \quad \text{for } k = f, l,$$

$$A_f = A_f\left(p_f, p_l, z_f, z_l, \bar{L}\right). \qquad (8)$$

The consumption decisions result from utility maximization under budget constraint, leading to a consumer demand system:

$$c_k = c_k\left(p_f, p_{nf}, y, z_u\right) \qquad \text{for } k = f, nf,$$

where income is computed with the appropriate decision prices:

(9) $$y = p_f q_f + p_l q_l + T = y\left(p_f, p_l, z_f, z_l, \overline{L}, T\right).$$

For the self-sufficient regime, an additional equation defines the shadow price p_f^*:

(10) $$c_f\left(p_f^*, p_{nf}, y, z_u\right) = q_f\left(p_f^*, p_l, z_f, z_l, \overline{L}\right).$$

2.2 Food market participation

We can now establish the conditions that define the optimal market participation regime. Because the solution to the optimization problem can be formally written in the same way in all three regimes using the relevant decision prices, the maximum utility that can be obtained in each regime can also be formally written with the same indirect utility function. Let $V(p, y, z_u)$ be the indirect utility function associated with the consumption preference. The three levels of utility to be compared are:

$$\begin{aligned} V^s &= V\left(p_f^s, p_{nf}, y\left(p_f^s, \ldots\right), z_u\right) && \text{if seller,} \\ V^b &= V\left(p_f^b, p_{nf}, y\left(p_f^b, \ldots\right), z_u\right) && \text{if buyer,} \\ V^* &= V\left(p_f^*, p_{nf}, y\left(p_f^*, \ldots\right), z_u\right) && \text{if self-sufficient,} \end{aligned}$$

where the arguments of the income function other than the food price are those of (9). It can be shown that the indirect utility function is increasing in the market price for sellers and decreasing in the market price for buyers. In addition, because these utility level are all derived from the same utility function,

$$\begin{aligned} V^s &= V^* \quad \text{if} \quad p_f^s = p_f^* \\ V^b &= V^* \quad \text{if} \quad p_f^b = p_f^*. \end{aligned}$$

From this we derive that the household will optimally choose to be buyer only when the purchase price is lower than its own shadow price, and to be a seller only when the sale price is higher than its own shadow price. With sale price lower than purchase price for any household, a household is classified in the three regimes by the position of its shadow price p_f^* relative to its effective market prices p_f^s and p_f^b:

(11) Market participation regime: $$\begin{cases} \text{seller if} & p_f^* < p_f^s \\ \text{self-sufficient if} & p_f^s \le p_f^* \le p_f^b \\ \text{buyer if} & p_f^b < p_f^* \end{cases}$$

Figure 1 illustrates the solution to the choice of regime. It shows the indirect utility functions of three households in the three possible regimes, as function of the market price (i.e., given shifters z_u, z_f, and z_l, transfers *T*, total labor $\overline{L}$, and prices for nonfood and livestock). Consider for example household

A with indirect utility functions V_A^s if seller, V_A^b if buyer, and V^* if self-sufficient. The indirect utility under self-sufficiency is independent of the market price, and thus represented by a vertical line. Utility is an increasing function of the market price if the household is a seller, and a decreasing function if the household is a buyer. The three utility curves intersect at the point where the market price would be equal to the shadow price p_f^* of the household, point A_0 on the figure. For this household, the indirect utility obtained under the three conditional optimal choices is V^* if it decides to remain in self-sufficiency, $V_A^s\left(p_f^s\right)$ if it chooses to be a seller (point A), and $V_A^b\left(p_f^b\right)$ if it chooses to be a buyer (point D). It is clear from the graph, and can easily be shown mathematically, that household A gets the greatest utility from being a seller at A, which is to the right of the V^* line. Two other households with same autarkic utility V^* are represented on the graph. For household C with the highest curves, the situation is reverse: its V_C^s function intersects the seller's price to the left of V^*, while its V_C^b function intersects the purchase price to the right of V^* at C. Its optimal choice is thus to be a buyer. Finally, the intermediate household B gets a higher utility in remaining self-sufficient at B_0 than in buying at the high purchase price or selling at the low sale price.

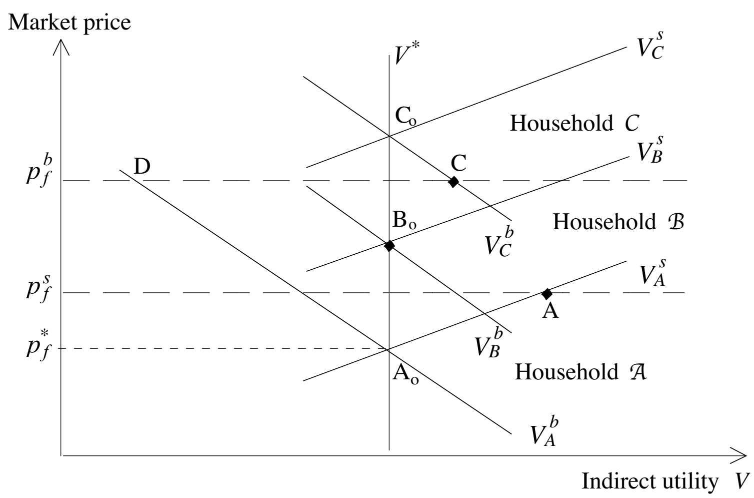

Figure 1. Market participation regimes for three households

2.3 Summary of the model and empirical strategy

In summary, the household's production and consumption decisions depend on its endogenous choice of food market participation. The corresponding empirical model will proceed with a reduced form estimation of the market participation decision, and with estimations of land allocated to food crop, income, and other production or consumption decisions, conditional on market participation. In the sample of households in our survey, we do not observe households selling food. We thus restrict our empirical strategy to participation in the food market only as a buyer.

a) Combining the determination of shadow price from (9) and (10) with the selection equation (11) gives an estimable equation for market participation choice:

(12) $$\delta^b = 1\left(p_f^*\left(p_{nf}, p_l, z_f, z_l, z_u, \bar{L}, T\right) - p_f^b > 0\right).$$

b) Land allocated to food production is then estimated conditional on the choice of regime as:

$$
(13)\quad \begin{array}{ll} A_f^* = A\left(p_f^*, p_l, z_f, z_l, \overline{L}\right) = A_f^*\left(p_{nf}, p_l, z_f, z_l, z_u, \overline{L}, T\right) & \text{if } \delta^b = 0 \\ A_f^b = A\left(p_f^b, p_l, z_f, z_l, \overline{L}\right) & \text{if } \delta^b = 1. \end{array}
$$

Income from activity $k = f, l$ is similarly estimated as:

$$
(14)\quad \begin{array}{ll} y_k^* = p_k q_k\left(p_f^*, p_l, z_f, z_l, \overline{L}\right) = y_k^*\left(p_{nf}, p_l, z_f, z_l, z_u, \overline{L}, T\right) & \text{if } \delta^b = 0 \\ y_k^b = p_k q_k\left(p_f^b, p_l, z_f, z_l, \overline{L}\right) = y_k\left(p_f^b, p_l, z_f, z_l, \overline{L}\right) & \text{if } \delta^b = 1 \end{array}
$$

While the model has been written for two activities, it can easily be generalized by considering several activities in lieu of livestock production. In the empirical study, we will include two other activities: migration and non-farm income, which are each undertaken by 47% of the households. The variables used in the model are regrouped into categories as follows:

- z_f includes household characteristics and factors that may affect crop productivity and the land potential in agriculture.

- z_l includes household characteristics and factors that affect household productivity in non-crop activities. Among specific factors for cattle production are total pasture area available for grazing and quality of cooperation in CPR management.

A number of assets, and notably human capital assets and general cooperation in the village, are production shifters in all activities, although they may have stronger effects in some activities than in others. The empirical study will elucidate their roles.

- z_u are shifters in household preferences, such as family size.

- T is exogenous sources of income.

- $\overline{L}$ is total household labor force.

- p_f^b, p_{nf}, p_l are prices paid (food and non-food consumption items) or received (livestock and other activities) by the households. Transactions costs, and notably transportation costs, should be taken into account in the determination of these prices.

- y_k is income by source *k*, including the value of production for home consumption valued at its opportunity cost.

3 Estimation results on land allocation

The data we use come from a survey administered in 2000 in four administrative regions of Northeast Burkina Faso: Gorgadji, Dori, Gorom, and Bani (see Drabo, Dutilly-Diane, Grell, and McCarthy, 2001). The survey instrument consisted in village-level questionnaires applied to 48 villages, institutional questionnaires applied to 200 natural resource management organizations found in these villages, household questionnaires applied to 401 randomly selected households in these villages, and six market questionnaires covering the regions surveyed.

In this analysis, we are particularly interested in two aspects of the context in which the household's income strategy is determined: a) The importance of community cooperation in influencing livestock productivity, and b) the role of technological innovations in NRM on crop production, both of which in turn affect individual production decisions and the income levels achieved. The links that we establish are first the impact of the introduction of contour stone bunds on yield, and second the role of yield on food market participation decisions, land allocation, other production decisions, and income. We, therefore, start by preliminary analyses of community cooperation and agricultural yields, and then proceed to estimate the production and consumption decisions in this section, and the household income and income sources in the next section.

3.1 Indices of cooperative behavior at the village level

Whether a community is cooperating or not in managing its common grazing lands is not directly observed, but more general cooperation in the village manifests itself through a number of observable activities practiced by community members, notably the density of organizations in the village and the extent of villagers' participation to the activities of these organizations. McCarthy and Dutilly-Diane (2002) give a detailed description of these village organizations and their activities. Following their steps, we construct indices to measure the community's cooperative capacity in the management of its natural resources using a principal components approach. Table 1 reports the loadings of the variables that enter in the first two factors.

Table 1. Definition of indices of cooperative capacity

(Variable loadings on the first two factors in principal components analysis)

Variables	Formal cooperation capacity	Effective cooperation capacity
NRM membership (percent of households)	0.355	0.087
Number of non-NRM organizations per household	0.300	-0.291
Number of NRM organizations per household	0.241	-0.065
Non-NRM membership (percent of households)	0.168	-0.175
Average number of meetings of NRM organizations	0.032	0.071
Average participation rate in meeting	0.028	0.091
Total number of rules of NRM organizations	-0.013	0.101
Total number of activities of NRM organizations	0.058	0.207
Average number of days for activities per member	0.087	0.223
Average participation rate in activities	0.132	0.422

The first factor, that we call "Formal Cooperation Capacity", characterizes the number and coverage of organizations in existence in the village. We distinguish the organizations with an explicit, albeit not necessarily exclusive, natural resource management (NRM) mandate (land allocation committee, farmers' and herders' associations, forest and water management committees, etc.) from the other organizations (social groups for mutual insurance, cultural activities, credit, etc.). For each of the two categories, we retain the number of organizations per household and their membership coverage.

The second factor, that we call "Effective Cooperation Capacity", characterizes the level of activity of these organizations and the effective participation of their members. This includes the average number of meetings they hold per year and the participation rate in these meetings. It also measures the number of rules that regulate the relationship between agriculture and livestock breeding, such as dates of entry and exit of animals in cultivated areas, and prohibition or limits on tree cutting, slash-and-burn, hay cutting, use of common pasture by sick animals, and use of water points by livestock. Finally, we count all activities undertaken by these associations in direct relation with natural resource management. These activities are regrouped under four types: erosion control, reforestation or agro-forestry, maintenance of fences between crop and pasture zones, and water-point maintenance. The three most important variables in the second factor are the percentage of members that contribute workdays to these activities, the average number of days allocated by members to each type of activity, and the number of activities undertaken.

We will see later in the analysis that these two indicators of cooperative behavior capture very different aspects of collective action. In many ways, the number of organizations and their membership, in Burkina Faso, largely originate in donor interventions that require the constitution of ad-hoc organizations to implement a project. Burkina Faso is indeed one of the favorite countries for bilateral and NGO projects, and community activities are frequently dominated by demands imposed by these projects. Many village organizations that were created in the context of particular projects remain formally in existence long after the project has lost its momentum or disappeared. Presence of a large number of such organizations in a village typically reflects the rapid succession of programs and projects that each had to create a new organization to satisfy donor requirements. By contrast, the indicators that reflect the level of participation in and the number of activities of organizations characterize effective cooperation among villagers that expectedly will influence productivity in the use of common pastures.

3.2 NRM technology and potential yield equations

We now analyze the capacity of the water harvesting and soil conservation technology consisting in the construction of contour stone bunds in enhancing grain (millet and sorghum) yields. This traditional technology was introduced in Burkina Faso by the Mossi in the early 20th century. It regained interest in the 1970s and 1980s in response to droughts, particularly in the Central Plateau and Yatenga (Marchal, 1986). Impacts on yields have been measured between 40% (Critchley, Reij, and Seznec, 1992; Warren and Rajasekaran, 1993) and 100% depending on the region, the rainfall in the year of the study, and the spacing of stone bunds (Lamachère and Serpantie, 1991; Zougmoré et al., 1992). Because of its extraordinary simplicity and effectiveness, this NRM technology has spread rapidly over a significant area of the country.

The choice of which field is protected by stone bunds is endogenous, partly the decision of the field owner himself, partly the result of the political process in allocating project benefits, and partly related to the physical characteristics of the field and its location in the village. In addition, stone bunds create strong externalities as collection of water runoffs and protection from soil erosion go beyond the field that the stone bunds actually surround. We, therefore, measure not the yield effect of having stone bunds in any one particular field, but of presence of a stone bunds construction project in the village. In our sample, 31 of the 48 villages have had such a project, and 67% of the sample households live in these villages. Because presence of a stone bunds construction project in a village is expectedly endogenous, we instrumentalize this variable with village characteristics and verify the statistical validity of the instruments by performing an overidentification (OID) test.

Yields are in part determined by the agricultural practices chosen by the household. To abstract from these endogenous choices, and measure the yield potential of the land, we regress individual yields on village and regional characteristics only. The region surveyed can be divided into three geographical units according to their rainfall: the North (Oudalan) is the driest region with on average 400 mm per year, the North of the Seno receives 450 mm per year, and the South of the Seno 550 mm. Average millet yields in these regions were in the year of the survey 254, 416, and 385 kg/ha, respectively. Soil quality was recorded by classifying villages by dominant soil type in three categories: sandy soil (Seeno) that is particularly appropriate for millet, clay soil (Bolaare), and poor degraded soil (Kollade). Average millet yields on these three soil types were 357, 330, and 332 kg/ha respectively.

The results reported in Table 2 show that yields improve with rainfall, and were lowest on clay soils. The fact that clay soils gave lower yields than poor degraded soils was due to an unusually high rainfall in the year of the survey, leading to water excess that clay soils could not absorb. As expected, stone bunds have the highest productivity impact in low rainfall areas. When rainfall is excessively abundant, stone bunds retain too much water, depressing yields. In the low rainfall area, the stone bunds project increased yield by 158 kg/ha of grains, which represents a 41 percent increase over the average yield of 385 kg/ha in the area.

Table 2. Impact of stone bunds on yields - Robust IV
(Dependent variable: household level millet/sorghum yield in kg/ha)

	Average value of variable	Coefficient	t-ratio
Rainfall (base is high rainfall) and NRM technology			
Medium rainfall	0.235	-73.3	-0.4
Low rainfall	0.422	-483.1	-3.8
Stone bunds in village[1]	0.666	-355.3	-3.3
Stone bunds * medium rainfall[1]	0.198	172.1	0.8
Stone bunds * low rainfall[1]	0.241	513.6	2.4
Dominant soil type in the village (base: clay soil)			
Sandy soil	0.329	68.8	1.8
Poor degraded soil	0.406	79.8	2.5
Constant term		582.1	7.7
Average value of yields (kg/ha)	336.9		
Number of observations	374		
Second stage F(7,363): *p* -value			0.000
Joint significance of instruments F(3,363): *p* -value			.000, .000, .000
Chi[2] (OID test): *p* -value			0.75

All explanatory variables are dummy variables.
[1]Instrumented variables: Stone bunds in village, stone bunds*medium rainfall, stone bunds*low rainfall.
Instruments are village variables: number of ethnic groups, number of quarters, dummy variables for the presence of four external development projects.

3.3 Participation in the cereal market

Estimation of the market participation equation (12) is reported in Table 3. As in all following equations, the independent variables are classified into categories that correspond to the variables in the household model as follows:

- Prices and transactions costs (p_f^b, p_l, p_{nf}). We do observe prices but, in cross-section analysis, prices reflect in part regional variations correlated with the households' behavior rather than determinants of their behavior. We note in particular that livestock prices are lowest in the regions that have the most livestock production and hence where markets are swamped by supply, while grain prices are highest in villages where food production is low and most households are buyers. To avoid this endogeneity problem, we do not use observed prices as determinants of behavior and only keep a measure of transactions costs represented by regional effects and distance to the nearest local town where most purchases take place.

- Shifters in consumption (z_u, T). We regroup in that category the shifters in preferences and the exogenous transfers as they always appear together in the model. The only pure shifter of preferences that turns out to be useful in the empirical analysis is the number of dependents. Exogenous transfers are measured by a dummy taking the value of one if the household received cash from a migrant who is not a household member.

- Shifters in production (z_f, z_l). Two shifters are clearly identified with crop production. This is the potential yield and affiliation of the household to a traditionally agriculturalist ethnic group. Among other shifters, land availability in the village as a whole could benefit either crop production or livestock, although we will see that more land always favors the livestock sector. The cooperation indices constructed in the previous section characterize village members' capacity to manage externalities and public goods, for any activity (management of common pastures, soil erosion on agricultural land, provision of clean water, etc.) and in any village land (pasture or cultivated land). There is, therefore, no *a priori* reason to attribute the cooperation indices to any one activity. Management of externalities and coordination are, however, more important for livestock grazed on common lands than for agricultural production, and this is confirmed by empirical results. The human capital shifters (whether any household member over 12 years old has been educated in a public school or has received training in local language literacy) can be important for all activities. The household's labor force (number of men and women 16 to 60 years old) is not only a factor of production for all activities, but also a shifter in preferences as it contributes to the demand for food.

For this and the following estimations that have yield as an explanatory variable, we use IV estimators. Instruments for yield are chosen among the variables of soil quality, rainfall, presence of a program of stone bunds construction used in the estimation of potential yields above, as well as the share of land in millet. The choice of instruments varies according to each equation in order to satisfy the two conditions that insure their validity: i) the first stage equation is well explained (combined F-statistic for coefficients of instruments indicate joint significativity) and ii) the over-identification (OID) test does not reject the validity of the instruments.

Because the cooperation variables may be endogenous, a Hausman test of exogeneity of the cooperation variables is performed and results reported in the corresponding tables.

In the survey, we observe 13.1% of households participating to the cereal market. Compared to self-sufficient households, buyers cultivate less land (4.2 vs. 5.2 ha), have a number of animals that is not statistically different (11.2 vs. 8.9), and a higher incidence of public education (19% vs. 9%).

With a small percentage of households not participating in the market, estimation of the determinants of participation to the cereal market (Table 3) is difficult, and few parameters are statistically significant. Yet, we see a strong effect of yield in reducing use of the market to acquire cereals. Indirectly, we can get an order of magnitude of the effect of a stone bunds construction program. A gain of 158 kg/ha in yield, which would result from such a program in a low rainfall area, would induce a decline of 4.7 percentage points in market participation. This represents a 36% increase in food self-sufficiency, from 13.1% to 17.8% of the households. Public education also reduces participation to the cereal market. As we shall see later, this is because education helps increase crop production for food buyers.

Table 3. Participation in the cereal market - IV Probit

(Dependent variable = 1 if buyer)

Variables	Average value of variable	Marginal effect 100*dF/dx	z-ratio[1]
Price and transactions costs			
Distance to the market (km)	17.8	-0.10	-0.9
Shifters in consumption			
Number of dependents	4.47	0.06	0.1
Transfers +	0.12	-3.34	-0.8
Shifters in crop production			
Yield (kg/ha) - instrumented[2]	337.5	-0.03	-2.1
Agriculturalist ethnic group +	0.45	-0.35	-0.1
Shifters in production			
Formal cooperation	0.22	-1.07	-0.1
Effective cooperation	0.66	-6.87	-1.0
Land availability (ha per household)	36.1	-0.14	-2.6
Age household head (ln)	3.88	3.91	1.0
Public education +	0.10	-11.99	-2.2
Literacy +	0.08	2.74	0.6
Shifters in production and consumption			
Number of adults in the household	4.53	-0.06	-0.1
Oudalan+	0.42	13.99	3.3
Average value of endogenous variable (%)	86.9		
Number of observations	373		
Second-stage Chi^2 (13): *p* -value			0.000
Joint significance of instruments F(2,358): *p* -value			0.000
Chi^2 (OID test): *p* -value			0.21
Hausman exogeneity test for fomal cooperation: *p* -value			0.37
Hausman exogeneity test for effective cooperation: *p* -value			0.72

[1] z-ratio for the corresponding underlying parameter.

[2] Instruments for yield are percentage of village land in poor degraded soil and average yield in the district.

+ Indicates dummy variable.

3.4 Land allocated to crop production by market participation regime

We now turn to the estimation of the land allocated to crop production. As noted in the household model, and reflected in equations (13), the decisions taken by households that are net buyers of food and households that are food self-sufficient respond to different signals. For household buying food, the opportunity cost of food production is well defined by its effective market price while, for self-sufficient households, food production responds in part to the households' demand for food.

With an endogenous choice of market participation, the estimation of two separate land allocation functions on separate sub-samples could suffer from selectivity bias. We thus estimate a switching regression model to correct for potential selectivity bias. The selection equation is a reduced form equation of market participation (with land quality, rainfall, and program of stone bunds construction rather than predicted yield). In neither case, however, was there any significant selectivity bias (t-statistics of the coefficient on the Mills ratios were 1.4 for buyers and 0.7 for self sufficient). We thus report estimations without these corrections.

Table 4. Land allocated to crop production - Robust IV

(Dependent variable: logarithm of land in ha)

	Food buyers			Food self-sufficient		
Variables	Average	Coefficient	t-stat	Average	Coefficient	t-stat
Price and transactions costs						
Distance to market (kms)	17.6	0.011	2.6			
Shifters in consumption						
Number of dependents				4.5	-0.05	-1.5
Transfers +				0.13	-0.83	-2.7
Shifters in crop production						
Yield (ln) - instrumented[1]	5.6	0.70	2.0	6.0	-1.09	-2.4
Agriculturalist ethnic group +	0.45	0.17	1.8	0.52	-0.14	-0.4
Shifters in production						
Formal cooperation	0.23	0.29	0.9	0.23	1.54	1.5
Effective cooperation	0.66	-0.36	-1.4	0.73	-1.13	-1.6
Land availability (ha per household)	35.8	-0.002	-1.5	35.9	-0.004	-0.9
Age of household head (ln)	3.9	0.20	1.3	3.8	0.80	2.7
Public education +	0.09	0.47	2.8	0.21	0.17	0.7
Literacy +	0.08	0.06	0.4	–	–	–
Shifters in production and consumption						
Number of men 16-60 years old	2.4	0.13	3.2	4.4	0.26	4.3
Number of women 16-60 years old	2.2	0.13	3.2	–	–	–
Oudalan+	0.46	0.47	2.4			
Constant term		-4.40	-2.0		4.63	1.5
Average land allocated to crop (ha)	4.28			5.25		
Number of observations	313			48		
Second stage F statistic : *p* -value			0.000			0.000
Joint significance of instruments F statistic : *p* -value			0.02			0.08
Hansen J-statistic (OID test): *p* -value			0.58			0.38
Hausman exogeneity test for fomal cooperation: *p* -value			0.11			0.50
Hausman exogeneity test for effective cooperation: *p* -value			0.36			0.29

[1] Instruments for yield in the buyers of food equation are percentages of land of different quality in the village.
Instruments for yield in the self-sufficient in food equation are stone bunds in the village, low rainfall, and their product.
– Indicates that public education stands for "public education or literacy", and that men stands for men and women 16–60 years old.
+ Indicates dummy variable.

Table 4 reports estimation results for the area of cultivated land by each household. The most interesting result is the expected opposite signs of an increase in yields on the area devoted to food crop by buyers and self-sufficient households. Food buyers respond to higher productivity in food crop production by cultivating more land. By contrast, self-sufficient households cultivate less land when yield increases. For them, the coefficient of –1.09 is not significantly different from –1. A unit elasticity indicates constant production and hence also constant consumption. Technological change thus allows self-sufficient households to reduce area while maintaining production and consumption constant. Following model predictions, the saving in labor afforded by technological change in food production should be used to increase labor participation in other activities, a behavioral response we will analyze later.

Buyers of food, who are integrated in the market, also respond to changes in transactions costs in accessing the market, increasing their cultivated area by a small but significant 0.1 ha for every additional 10 kms of distance to the markets. In accordance with non-separability in the household model, the land area of self-sufficient households responds to their demand shifters while that of buyers does not. We verified separability of the buyers' model by introducing the two shifters of consumption, and found neither to be significant. Other variables affecting positively the number of hectares in food production are the household's labor force, both female and male, and, for buyers, public education and membership in a traditional agriculturalist ethnic group.

4 Impact of technological change in agriculture and cooperation in NRM on households' income strategies

We have established the roles of technological change in agriculture and cooperation in NRM on market participation decisions, and shown how, depending on market participation, technological change affects land allocated to crops. We can now turn to analyzing the way in which technological change and cooperation affect households' total income and the income strategies they pursue. This will allow to understand how heterogeneity in household conditions, determining in particular their market participation strategies, may imply that changes in technology and improvement in cooperation have differential impacts on their income levels and livelihood strategies.

In equations (14), crop incomes are measured as the value of production with prices equal to the opportunity costs (market price for buyers and shadow prices for self-sufficient). This is consistent with the theory of household behavior. In empirical work, however, this raises the problem of the non-observability of shadow prices. As an alternative, we computed incomes using average purchase prices at the village level. These incomes are thus better thought of as aggregates of activity levels, rather than effective monetary values.

4.1 Total income

Table 5 reports estimation of the income equations (14) for food buyers and self-sufficient households. Results show that an increase in yield potential has a strong effect on the total income of both categories of households. An increase of 34 kg/ha in yield (equal to 10 percent of average yield) would produce an increase in income of CFAF 30,000 for buyers and 51,000 for self-sufficient, which represent 6 and 10% of their average incomes, respectively. Under low rainfall conditions, the village-level contour stone bunds construction program would induce an increase in income of CFAF 142,000 for buyers and 237,000 for self-sufficient, or 28 and 45% of their average incomes, respectively. Effective cooperation benefits food buyers, expectedly because they have the capacity to take advantage of more productive pastures. The small number of observations of food self-sufficient households makes estimations of their behavior difficult, a weakness that we particular encounter in this and the following estimations on income by source.

Table 5. Total income - Robust IV

(Dependent variable: total annual income in 1000 CFAF)

	Food buyers		Food self-sufficient	
Variables	Coefficient	t-stat	Coefficient	t-stat
Price and transactions costs				
Distance to market (kms)	2.0	0.8		
Shifters in consumption				
Number of dependents			-16.4	-0.5
Transfers +			163.3	0.6
Shifters in crop production				
Yield (kg/ha) - instrumented[1]	0.9	1.7	1.5	2.5
Agriculturalist ethnic group +	-29.6	-0.7	-42.6	-0.4
Shifters in production				
Formal cooperation	-1.3	0.0	-795.8	-1.4
Effective cooperation	224.1	2.0	522.5	1.2
Land availability (ha per household)	0.7	1.0	1.2	0.6
Age household head (ln)	-43.3	-0.6	-25.2	-0.1
Public education +	140.7	2.1	127.6	0.6
Literacy +	26.5	0.3	–	–
Shifters in production and consumption				
Number of men 16-60 years old	59.6	2.6	183.1	3.2
Number of women 16-60 years old	57.6	2.7	42.5	0.5
Oudalan+	343.5	4.5		
Constant term	-238.2	-0.7	-788.8	-1.3
Average value of income (1000 CFAF)	512.5		532.6	
Number of observations	325		48	
Second stage F statistic : *p* -value		0.000		0.000
Joint significance of instruments F statistic : *p* -value		0.07		0.09
Hansen J-statistic (OID test): *p* -value		0.21		0.81
Hausman exogeneity test for fomal cooperation: *p* -value		0.61		0.48
Hausman exogeneity test for effective cooperation: *p* -value		0.91		0.93

[1] Instruments are percentages of land by soil types in the food buyers equation, and rainfall and percentage of village land with clay soil for the self-sufficient equation.

– Indicates that public education stands for "public education or literacy".

+ Indicates a dummy variable.

Exchange rate in August 2000: 1000 CFAF = 1.34 US$.

4.2 Sources of income

Finally, we analyze households' income strategies in response to the relative potential profitability of the different activities, as determined by their own particular asset endowments and operational context. We estimated income equations by activity (crop, livestock, non-farm activities, and migration) as function of the same variables as those in the total income equations above. In Tables 6 and 7, we report partial results from estimations of these equations for the samples of buyers and self-sufficient households, respectively. Estimations of these income equations do not show many significant coefficients, particularly for the non-agricultural and migration incomes, as few households participate to these activities and they represent smaller shares of total income. Reported results focus on the marginal income effects of yields (in turn affected by stone bunds projects), abundance of community land per household, the community's ability to cooperate, and the household's human capital assets.[2]

In applying the Hausman exogeneity test to the cooperation variables in all sources of income equations, we find that exogeneity cannot be rejected except for effective cooperation in the crop income equation of food buyer households (see Tables 6 and 7). In this case, we instrument this cooperation variable with a village-level variable (the percentage of rules made in collaboration with the chief and a village organization). Instruments for yield and effective cooperation in the crop equation satisfies the OID test.

For food buyers, the fact that an increase in yield induces not only an increase in crop income but also a decline in livestock income, and an increase in migration income, indicates a re-allocation of resources (labor) away from livestock towards agriculture and migration. These households thus take advantage of technological change to engage in food production for import substitution. They also increase participation to seasonal migration. This is because migration is in effect quite seasonal (during the dry season) and thus compatible with agricultural activities, while tending to livestock is a full time activity throughout the year that is incompatible with seasonal migration. This is also confirmed by the result that households from agriculturalist ethnic groups have much higher migration income than others.

Results for food self-sufficient households are quite sharply contrasted. For them, higher yields in agriculture do not change their income from crops, and resources freed by more efficient agricultural technology are devoted to livestock production. Complementarity of migration with agriculture and its substitutability with livestock activity is also seen here as these households decrease seasonal migration as they increase their commitment to livestock. As observed by Reardon (1994) and Reardon and Taylor (1996), higher agricultural production reduces migration. Our results qualify this response as we find that it is conditional on food market participation, only applying to households who do not depend on the food market to acquire at least part of their food.

Overall land availability at the community level is favorable to livestock income for food buyers, and by substitution not to off-farm activity and agriculture. Results also show the differential role of the capacity to organize and cooperate in the communities by categories of households in terms of market participation. What we called effective cooperation has a positive impact on livestock income for all categories of households, and by substitution a negative effect on non-agricultural activities (self-sufficient) and on crop income (buyers). By contrast, formal cooperation has a negative effect on livestock for the self-sufficient, and a positive effect on agricultural income (buyers). These results converge to an interpretation of effective cooperation, which measures the level of community members' activity and participation in different types of local organizations, as a true indicator of the community's capacity to cooperate and coordinate, making livestock production more profitable. By contrast, formal cooperation, which measures the existence of organizations rather than their level of activity reflects a type of social makeup, often induced by the large number of foreign projects that have come to the region, that does not support the collective action necessary for livestock and fosters instead individual activities in agriculture, non-agriculture, and migration. Overall, effective cooperation has a strong positive aggregate effect on the income of buyers, while formal cooperation never influences households' total income.

Finally, we note that education favors non-farm activities and crop income (self-sufficient). It has an important effect on overall income for buyers, equal to around 25% of average income.

[2] Note that the marginal effects on the different sources of income do not add up to the total because of the partial participation of households to migration and non-agricultural activities.

Table 6. Income by source, food buyer households - Robust IV, partial results

(Dependent variables: income by source)

	Marginal effect on income (1000 CFAF)			
	Crop	Livestock	Non-farm[1]	Migration[1]
Shifters in crop production				
Yield (10 kg/ha) - instrumented[2]	3.1**	-2.9*	-0.2	8.0*
Agriculturalist ethnic group +	34.9**	-73.7**	-6.7	117.9**
Shifters in livestock production				
Land availability (10 ha per household)	-6.2*	15.2*	-19.3**	2.3
Formal cooperation	78.5*	-10.6	77.2	-37.2
Effective cooperation	-228.0*	194.8**	-22.4	7.6
Education				
Public education or literacy	84.4**	-0.3	84.0**	-24.7
Average value of income (1000 CFAF)	156.3	235.2	43.2	75.8
Second stage F statistic : *p* -value	0.00	0.00	0.00	0.00
Joint significance of instruments F statistic : *p* -value	0.00, 0.00	0.00	0.00	0.00
OID test: *p* -value	0.16	0.28	0.76	0.93
Hausman exogeneity test for fomal cooperation: *p* -value	0.19	0.71	0.19	0.14
Hausman exogeneity test for effective cooperation: *p* -value	0.03	0.95	0.99	0.19

Estimation with robust IV for crop and livestock income, and with IV Tobit for non-farm and migration income. In addition to the reported variables, explanatory variables include distance to market, age of household head, number of men and women 16-60 years old, and an Oudalan dummy.

Number of observations: 325 food buyers.

* (**) Indicates coefficient significant at more than 90% (95%).

[1] Marginal effect among participants to the activity.

[2] Instruments for yield are chosen among land quality variables, average yield in the district, stone bunds in the village, and rainfall variables.

[3]For crop income, exogeneity of formal cooperation is rejected. In the crop income equation, both yield and effective cooperation are consequently instrumented. Instrument for formal cooperation is the % of rules made in collaboration with chief and organization.

Table 7. Income by source, food self-sufficient households - Robust IV, partial results

(Dependent variables: income by source)

	Marginal effect on income (1000 CFAF)			
	Crop	Livestock	Non-farm[1]	Migration[1]
Shifters in crop production				
Yield (10 kg/ha) - instrumented[2]	0.6	4.5*	5.5	-14.2**
Agriculturalist ethnic group +	11.2	-50.8	-110.1	-2.4
Shifters in livestock production				
Land availability (10 ha per household)	1.0	8.8	-21.1	38.4
Formal cooperation	59.1	-533*	917	403
Effective cooperation	-123.1	647**	-891**	-165
Education				
Public education or literacy	-0.1	-37.0	275**	188
Average value of income (1000 CFAF)	254.3	185.3	61.9	30.2
Second stage F statistic : *p* -value	0.00	0.04	0.03	0.00
Joint significance of instruments F statistic : *p* -value	0.02	0.00	0.00	0.04
OID test: *p* -value	0.98	0.31	0.90	0.80
Hausman exogeneity test for fomal cooperation: *p* -value	0.73	0.84	0.33	0.14
Hausman exogeneity test for effective cooperation: *p* -value	0.65	0.21	0.19	0.15

Estimation with robust IV for crop and livestock income, and with IV Tobit for non-farm and migration income. In addition to the reported variables, explanatory variables include distance to market, age of household head, number of men and women 16-60 years old, and an Oudalan dummy.

Number of observations: 48 food self-sufficient.

* (**) Indicates coefficient significant at more than 90% (95%).

– Indicates that public education stands for "public education or literacy".

[1] Marginal effect among participants to the activity.

[2] Instruments for yield are chosen among land quality variables, average yield in the district, stone bunds in the village, and rainfall variables.

5 Conclusion

Farm households in Burkina Faso's Sahelian zone have a comparative advantage in livestock production as a cash crop and, at the same time, need to produce their food consumption largely through home production due to very high transactions costs on food markets. Food production can be increased through improved NRM, in particular water harvesting and soil conservation using the remarkably simple and effective traditional practice of contour stone bunding. When food markets fail, the theory of household behavior predicts that technological change in food production can be effective in promoting households' cash crop economy (de Janvry, Fafchamps, and Sadoulet, 1991). Benefits from this cross-activity effect depend on the nature of households' food market integration strategy (buyers or self-sufficient), stressing the importance of considering heterogeneity in predicting differentiated effects across households of a given policy intervention.

Empirical results from survey data indeed show that yield increases in food crops help food buyers import substitute in food consumption, increasing their area planted in and their income derived from crops, reducing livestock production, and increasing seasonal migration which is more compatible with seasonal agriculture than with the yearlong livestock activity. Self-sufficient households, by contrast, can take advantage of higher yields to free resources from food production and allocate these to expanding their livestock economy, thus capitalizing on the region's comparative advantage. As they increase their commitment to livestock, which is a year-round activity, they reduce their participation in seasonal migration.

Greater effectiveness in cooperation in the management of CPR helps increase income derived from livestock for all categories of households. However, not all forms of cooperation are effective. When cooperation is only formal, individual activities are pursued (crops, non-agricultural employment, and seasonal migration) as opposed to livestock activities that rely on common property resources, taking farm households away from regional comparative advantages.

Technological change in NRM to raise yields in food production is thus important in helping reduce poverty among Sahelian households, one of the poorest regions in the world. Higher productivity in agriculture helps more households opt out of the food market and achieve food self-sufficiency. Greater efficiency in food production for home consumption in turn helps them free resources from agriculture that they can devote to developing their livestock economy. More effective cooperation in the management of community resources makes their livestock economy more productive. Combining improved NRM in agriculture with institutional innovations in CPR management is thus an effective formula in reducing poverty in that region.

References

Critchley, W., C. Reij, and A. Seznec. 1992. "Water Harvesting for Plant Production." In Case Studies and Conclusions for Sub-Saharan Africa, Volume II, World Bank Technical Paper No. 157.

de Janvry, Alain, Marcel Fafchamps, and Elisabeth Sadoulet. 1991. "Peasant Household Behavior with Missing Markets: Some Paradoxes Explained." Economic Journal 101(409): 1400-17.

Drabo, Boureima, Céline Dutilly-Diane, Hermann Grell, and Nancy McCarthy. 2001. "Institutions, action collective et utilisation des ressources pastorales dans le Sahel Burkinabé". CAPRI, IFPRI: Washington D.C.

Kessler, J.J., and C. Geerling. 1994. "Profil Environmental du Burkina Faso". Wageningen Agricultural University, the Netherlands.

Key, Nigel, Elisabeth Sadoulet, and Alain de Janvry. 2000. "Transactions Costs and Agricultural Household Supply Response". American Journal of Agricultural Economics, 82(2): 245-59.

Lamachère, J.M., and G. Serpantie. 1991. "Valorisation agricole des eaux de ruissellement et lutte contre l'érosion sur champs cultivés en mil en zone soudano-sahélienne, Burkina Faso, province du Yatenga, région de Bidi." In Utilisation rationnelle de l'eau des petits bassins versants en zone aride, pp. 165-178. Ed. AUPELF-UREF, John Libbey Eurotext: Paris.

Marchal, J.Y. 1986. "Vingt ans de lutte antiérosive au Nord du Burkina Faso". Cahiers de l'ORSTOM, Série Pédologie, XXII(2): 173-180.

McCarthy, Nancy, and Céline Dutilly-Diane. 2002. "Collective Action and Natural Resources Management: An Application to Northeastern Burkina Faso." IFPRI's Working Paper: Washington D.C.

Ouédraogo, Hubert, and Camilla Toulmin. 2002. "Tenure Rights and Sustainable Development in West Africa: A Regional Overview." Paper given at the DFID Workshop on Land Tenure, Poverty, and Sustainable Development in Sub-Saharan Africa, Sunningdale, Berkshire, U.K.

Reardon, Thomas. 1994. "La diversification des revenues au Sahel et ses liens éventuels avec la gestion des resources naturelles par les agriculteurs". In Promotion de systèmes agricoles durables dans les pays d'Afrique soudano-sahélienne. Actes de colloques. FAO : Rome.

Reardon, Thomas, and J. Edward Taylor. 1996. "Agroclimatic Shock, Income Inequality, and Poverty: Evidence from Burkina Faso". World Development 24(5): 901-914.

Warren, D.M., and B. Rajasekan. 1993. "Putting Local Knowledge to Good Use." International Agricultural Development 13 (4): 8-10.

Zougmoré R., S. Guillobez, N.F. Kambou and G. Son. 2000. "Runoff and Sorghum Performance as Affected by the Spacing of Stone Lines in the Semiarid Sahelian Zone". Soil and Tillage Research, Vol. 56 (3-4), pp. 175-183.