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New markets and technological change for the traditional cereals in semiarid sub-Saharan Africa: the Malian case

Jeffrey D. Vitale [a], John H. Sanders [b,*]

[a] Department of Agricultural Economics, Texas A&M University, 2124 TAMU, College Station, TX 77843-2124, USA
[b] Department of Agricultural Economics, Purdue University, Krannert Bldg., Rm. 609, 403 W. State St., West Lafayette, IN 47907-2056, USA

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Abstract

During the last three decades in sub-Saharan Africa, development and research resources have concentrated on the higher-rainfall and irrigated regions, especially on export crops and the principal food crops grown there. There has been much less concern and investment in semiarid regions without irrigation. Another negative factor has been the lack of public policy concern with the profitability of the basic food crops. With good weather, prices collapse. With bad weather, governments and NGOs dispense food crops as food aid or at subsidized prices. This article documents the importance of the demand side to facilitate diffusion of new technologies for the basic food commodities of semiarid regions—the traditional cereals. With farm programming models aggregated into a sector model, the combination of technological change and demand shifts for sorghum are evaluated in one semiarid region where the traditional cereals are concentrated. It focuses on combining policies to increase the prices farmers receive after introduction of technologies that use higher input levels. It also compares benefits of a strategy that focuses on yield and demand increases for a traditional cereal of the semiarid region, sorghum, with two alternative strategies for the higher-rainfall zone.

JEL classification: Q12

Key words: Sorghum; Millet; Price collapse; Inventory credit; Fixed harvest income objective; Demand expansion; Sector model

1. Introduction

In a new century, after 20 years of structural adjustment, donors and national governments are reevaluating development strategies. The increasing nutritional problems in sub-Saharan Africa have renewed concerns about poverty programs. In agriculture, this translates into looking again at the potential of lower-rainfall regions and programs to increase the productivity of the basic food crops.

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

The lower-rainfall regions have historically been healthier, so population densities are generally greater than in the higher-rainfall rural zones (Vitale, 2001). The traditional food crops (sorghum, millet, cowpeas, pigeon peas) have been adapted over time to these harsh production conditions. They can be cultivated in areas where most other crops have erratic yield responses and frequent failure. Farmers have generations of experience in growing the traditional food crops, which are firmly entrenched in rural and urban food patterns.

Besides a concern with equity, there are efficiency reasons for putting more attention on the traditional crops of the semiarid regions. Although yield gains have been more rapid for export crops and crops in the higher-rainfall regions over the last 30 years, yields can be substantially increased in lower-rainfall regions with water harvesting and increased soil fertility (Sanders et al., 1996).

This article examines available technologies and potential markets for the traditional cereals of the semiarid region of one country, Mali. Farm and sector modeling are combined to estimate the effects of various demand-expansion policies and to compare them with two important alternatives. The conclusions present the implications for public policy.

2. Technology introduction into semiarid regions

Economists have been arguing during the last two decades that low-rainfall (semiarid) regions of sub-Saharan Africa have little potential for increasing cereal productivity and that greater returns could be obtained from investments in the more favored higher-rainfall (sub-humid) or irrigated areas, where production costs are lower and higher-valued crops could be produced. As a result, domestic agricultural policy in many countries, even those with large semiarid regions, has concentrated more heavily on diffusion of new technologies into the sub-humid zone and on extending the frontier there rather than on increasing productivity of the basic food crops in the semiarid zone.

In West Africa, and especially in the Sahelian countries,[1] where investments in improved public health reduced the prevalence of tropical diseases (McMillan et al., 1998), agricultural technology has advanced much more rapidly in the sub-humid than in the semiarid zones. Technological change in the Sahelian countries has been concentrated in the Sudano-Guinean zone (the sub-humid zone) on the principal crops, cotton and maize. Cotton and maize introduction in the southern areas of Mali and southwestern Burkina Faso provide some of the more successful stories of new technology diffusion in sub-Saharan Africa (Sanders et al., 1996). Also, striking advances have occurred in the irrigated areas in Mali, with substantial increases in rice productivity.

One principal catalyst for technology introduction in the sub-humid zone has been a strong market demand for cotton and, periodically, for maize. This allowed farmers to make money from the increased productivity of the new technologies. The introduction of demand-driven technology is also exemplified by the profitability and rapid growth of the niche crops, including green beans in Burkina Faso, flowers and pigeon peas in Kenya, and irrigated rice in Mali.

For these crops experiencing rapid technological change in the Sahel, price collapse has generally not been a problem. For cotton, parastatals have historically fixed the prices. Rice has benefitted from rapidly growing urban markets. The niche crops of fruits, grain legumes, other vegetables, and flowers have been exported, and have not yet experienced market saturation.

Niche crops benefit only a small part of the agricultural sector—and often overseas' rather than domestic consumers. In contrast, the basic food crops of a country (sorghum and millet for the Sahelian countries) are produced by most farmers and are basic in the diet of most of the population. Productivity gains there will have very large impacts on both consumers and producers.

For this study, the three principal agroecological zones of the Sahelian countries were classified as the sub-humid zone and two principal cropping zones in the semiarid region, the Sudanian and the Sahelo-Sudanian (Table 1; Fig. 1).

In the higher-rainfall region of the semiarid zone, the Sudanian zone, sorghum is the principal crop, except on sandy soils. On the sandy soils and in most of the Sahelo-Sudanian zone, millet is the principal crop because it has more tolerance of low rainfall and poor soil fertility than sorghum. Both crops are grown in both regions, and this combination utilizes the soil and water diversity and reduces risks.

Some have argued that the principal constraint in semiarid regions is labor. The evidence on the introduction of labor-replacing technologies does not support this in the Sahel. Rather, the principal technologies being introduced into the semiarid zone appear to indicate that the primary constraint is quality land (Table 1). The technologies introduced over the last two decades into the two semiarid zones have been

[1] The Sahel refers to the countries between the humid coastal countries and the Sahara. Included are Burkina Faso, Chad, Gambia, Mali, Mauritania, Niger, and Senegal. The word Sahel comes from the Arabic word for shore or border (Sen, 1982, p. 113). The island of Cape Verde was later added to this Sahel group. The Sahel is also an agroecological zone and too dry for crop production without irrigation. The main semiarid crop zones are the Sudanian and the Sahelo-Sudanian, the zones of predominant sorghum and millet production, respectively, in the Sahelian countries.

Table 1
Rainfall by region and technologies successfully introduced in the three principal agroecological regions of crop production in the semiarid tropics of West Africa

Zones	Rainfall expected 90% probability (mm)	Technologies	Responses to principal constraints	
			Water availability	Soil fertility
Sudano-Guinean	800–1,100	New cotton and maize cultivars with inorganic fertilizers and improved agronomic practices	Sufficient rainfall in most years in this zone	Inorganic fertilizers used in the combined technology package
Sudanian	600–800	Contour dikes and organic fertilizers, zaï[a]	Holds runoff	Organic fertilizers
		Improved early cereal and cowpea cultivars	Water earliness gives drought escape	Selected for low soil fertility conditions
Sahelo-Sudanian	350–600	Contour dikes and organic fertilizers, zaï[a]	Holds runoff	Organic fertilizers
		Early cereal and cowpea cultivars	Drought escape with earliness	Selected for low soil fertility conditions
		Supplementary irrigation[b]	Full water control	Rice heavily fertilized

[a]Zaï are hand-dug trenches.
[b]Only small areas of supplementary irrigation (<1 ha) provided by government to farmers. These are a type of income stabilization for dryland farmers.
Source: Adapted from Sanders et al. (1996, p. 149).

various labor-intensive, water-retention techniques (dikes and zaï, which are hand-dug trenches); organic fertilizers, often obtained by gathering manure with or without putting it in compost heaps; and early cultivars for drought escape (Table 1; Sanders et al., 1996). These technologies substitute in very labor-intensive ways for the lack of water and low soil fertility.

3. Potential technologies in the semiarid Sahel

There is a larger gap in potential yield increase in Mali for the principal crop of the semiarid region, sorghum, than for either of the predominant cereals of the irrigated and higher-rainfall regions, specifically rice and maize (Fig. 2). This gap indicates the potential for farm-level improvement with the technologies presently available on the experiment station.

Currently, the technology is available to close this gap for sorghum and millet through higher-purchased-input usage and new cultivars combined with improved management and cultivation practices, especially water-retention practices. Yet the diffusion has been much slower for the principal crops of the semiarid zone than for the higher-rainfall region. This same phenomenon occurred in the United States where hybrid sorghum and associated technologies were introduced about 20 years after hybrid maize. But once introduced, this technology combination diffused

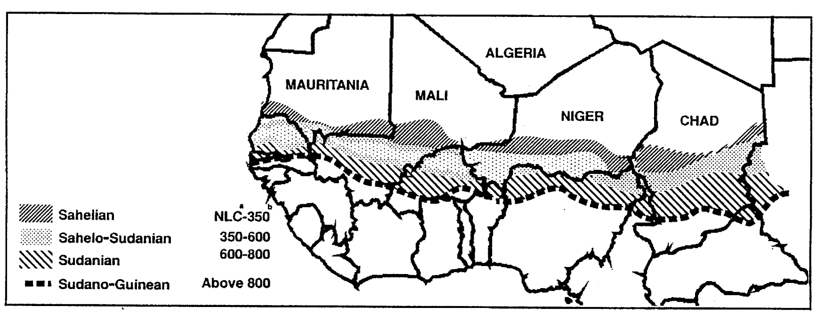

Fig. 1. Agroclimatic zones in semiarid West Africa (90% probability). *Source:* Gorse and Steeds, 1987, Appendix. *Note:* Below the dotted line is the higher rainfall zone of the Sudano-Guinean zone often not included in semiarid definition. In the Sahel this is the zone of cotton and maize as well as sorghum and millet.

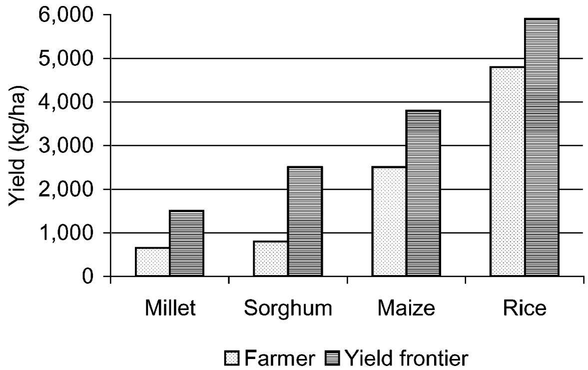

Fig. 2. Best-farmer and experiment-station yields of new and traditional cereals, Mali. *Source:* Vitale, 2001, p. 9.

more rapidly than that of maize. Within 15 years from the mid-1950s, sorghum yields in the United States were tripled (Miller and Kebede, 1987, p. 7; for the maize story, see Duvick, 1987, pp. 15–47).

Sorghum and millet take up about 80% of the production area in the semiarid regions of Mali (i.e., the Sudanian and Sudano-Sahelian zones; Vitale, 2001). Even in the sub-humid Sudano-Guinean zone of the Sahelian countries, sorghum and millet are grown on approximately one-half of the crop area in southern Mali (Vitale, 2001).

When more water and higher soil fertility are available, semiarid regions have a comparative advantage over higher-rainfall regions. Because of more sunlight and less disease, the highest crop yields in the world are obtained in semiarid and arid regions with irrigation. However, in many regions, as in much of Mali, irrigation is not technically or economically feasible. Nevertheless, there are a range of water-harvesting techniques that better utilize available rainfall (or other water sources) and thereby reduce risks and increase the returns to soil-fertility improvements (Shapiro and Sanders, 2002). With improved water availability and increased soil fertility, the returns to new cultivars are substantially improved. Breeders can then move away from the search for earliness (drought escape) and can concern themselves with yields under moderately improved conditions, resistance to disease and insects, and food/feed characteristics.

Developing countries can now make substantial yield gains in sorghum and millet and close some of the gap with maize and rice, as the United States did with sorghum in 1955–1970. In developed countries, sorghum has not disappeared from the crop mix in semiarid regions as incomes have increased. Instead, it competes with maize for animal feed.[2] One advantage of traditional cereals is that they are better adapted to the low-rainfall and poor soil-fertility conditions that dominate the semiarid agroecology. When more water is made available and soil fertility is increased, some of the area will shift out of these crops to higher-value activities, such as fruits and vegetables. However, most of the area will stay in these traditional staples, for which better conditions enable substantially increased yields.

4. Marketing improvements and profitability of traditional food crops

Various explanations for the slower diffusion process of new crop technologies into semiarid zones have been hypothesized, including higher risk levels and alternative employment opportunities. Our hypothesis is that the principal factor retarding the introduction of these new technologies is reduced profitability resulting from three price problems of the traditional food crops: (1) farmers are pressed to sell at the post-harvest price lows; (2) major between-year price collapses result from good weather and the failure to develop alternative markets for the basic food crops; and (3) the main poverty policy of many developing countries is the attempt to keep down prices of the primary food commodities, thereby limiting the upside potential for price increase.

Low prices have discouraged farmers from using more inputs. Unfortunately, food production has become more difficult because of continuing soil degradation and nutritional problems in the low-income work force. Higher levels of purchased inputs are required to substitute for the fertility loss of the disappearing fallow system. To pay for these inputs, improved marketing strategies and the evolution of new markets will be necessary. Changing public policy attitudes that recognize the need for farmers to make money and the development of alternative poverty

[2] Millet has not historically been an important feedcrop in the United States but has been the principal component of bird food. Recently, there have been efforts from the USDA in Georgia to introduce millet on the poor soils there as an animal feed.

Table 2
Current and expected millet prices in the four Sahelian countries, October 2002

Country	October 2002 millet price (FCFA/kg)	Expected price at millet harvest in 2002 (Nov.–Dec.) (FCFA/kg)	Expected peak during the hungry period[a], 2003 (July–Sept.) (FCFA/kg)
Niger	100	80	230
Senegal	250	100	300
Burkina Faso	140	75	220
Mali	168	90	225

[a]Note that the hungry period is the two months before the next harvest, in this case 2003.
Source: Field interviews, Abdoulaye and Sanders, Oct. 2002.

policies, rather than keeping food prices down, would also help.

Seasonal prices (item 1 above) vary. To demonstrate their extent, farmers in the Sahel were questioned about present prices and price expectations for millet in 2002–2003 (Table 2). The price roughly tripled 10 months after the harvest season. This is the hungry season, the period immediately before the harvest of the early maize.

For most Sahelian farmers in the semiarid zone, the cash requirement at harvest overrides the desire to put aside a stock of their basic commodities for their own subsistence or to maximize incomes (Vitale, 2001; Abdoulaye, 2002). They have to satisfy this cash requirement first and thus suffer income loss from the lower prices for their staples.

What influence does seasonal price variability have on profitability? To respond to that question, the latest data for the past crop year (2001–2002) were used. Rainfall was normal but later than average; it was the second year of below-normal conditions so prices were higher and more variable than with the good rainfall of the late 1990s. Yields for new technology were used for average and better farmers. For both types of farmers, profitability per hectare is very low if marketing is done at the post-harvest period. However, profits are substantially increased if farmers wait for the expected price recovery after 5 or even 10 months until the hungry season (Table 3).

The second price problem of the between-year price collapse resulting from good weather and price inelasticity of demand for the basic food staple will require the development of alternative markets and public policy to support infrastructure investment. This is the focus of the next two sections.

5. Developing new markets for the traditional cereals

Food consumption in the Sahelian countries is dominated by cereals, especially sorghum and millet

Table 3
Farm profitability and time of sale of sorghum with new technology (US$/ha), Mali

Farmer type	Marketed at harvest, 2002 (Nov.–Dec.)	Marketed at mid-point hungry period, 2003 (Mar.–Apr.)	Marketed during hungry period (July–Sept.)
Average[a,b]	3.13	69.27	135.41
Better[a,b]	20.31	99.33	178.35

[a]Farm profit (per hectare) was calculated using yields corresponding to modestly adverse rainfall years. This corresponds to yields of 729 kg/ha for average farmers and 871 kg/ha for better farmers. Household labor was valued at prevailing wage rate of 750 FCFA/day (∼1 US$/day using IMF 2001/2002 exchange rate of 744 FCFA = 1 US$). The assumed new technology uses an intermediate-season cultivar and inorganic fertilizer applications of 100 kg/ha for complex cereal compound (NPK:15–15–15) and 50 kg/ha for urea (NPK:46–0–0).

[b]Traditional yields would be about 500 kg/ha for either better or average farmers. Corresponding profits in the three columns in this table would be 17.77, 63.13, and 108.49 (US$/ha).

Source: Calculated by J. Vitale from the technical coefficients of Vitale (2001), using the above price variability for millet of Table 2. Note that millet and sorghum prices move together.

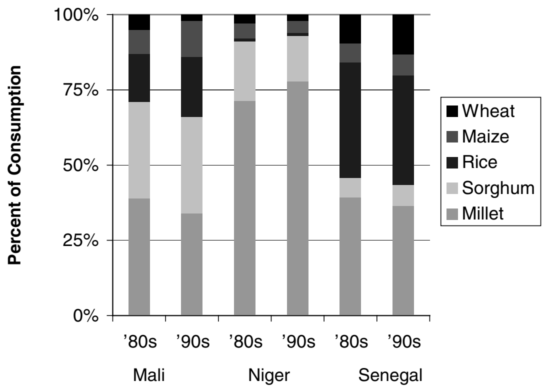

Fig. 3. National cereal consumption patterns in three Sahelian countries. *Source:* Adapted from Coulibaly, B., 1999, pp. 13–16.

(Fig. 3). A recent trend in the Sahelian countries is the shift in consumption to rice and away from traditional cereals. This is largely explained by urbanization associated with an increase in consumers' food-purchasing power as well as an increase in the opportunity cost of women's time; women are increasingly entering urban workplaces (Boughton and Reardon, 1997). Lower processing costs and reduced preparation time of rice make it an attractive alternative to sorghum and millet in urban areas, and consumers are willing to pay a premium for this convenience, as evidenced by the significantly higher price of rice compared to either sorghum or millet (Boughton and Reardon, 1997; Coulibaly, B., 1999; Dibley et al., 1995).

Even with this increasing demand for rice, traditional cereals continue to dominate national consumption patterns. Rural areas in these countries remain almost exclusively consumers of sorghum and millet as the basic food grains, comprising about 90% of the calories consumed (CPS, 1998). Senegal is an exception, with rice being an important staple in both urban and rural areas. In urban areas, while rice remains the main staple food for the main, early afternoon meal (particularly for urban workers unable to return home for lunch), the other two daily meals (breakfast and evening supper) are typically based on at least one of the traditional cereals (Reardon, 1993).

Historically, efforts to increase demand for the traditional cereals have been less successful than for maize and rice. One principal constraint is the low price elasticity of demand. With good-rainfall conditions and/or with rapid technological change, prices of traditional cereals collapse. Falling food prices from new technology provide benefits to consumers. But late- or non-adopters can be in a worse situation if prices decline more than the cost-saving effects of new production practices.

Why do prices collapse in good-rainfall years? People can eat only so much of their basic staple, and it is difficult to find new markets once the price has collapsed. Moderating these price collapses by developing new markets would encourage a more rapid introduction of new technologies.

A recent example of price collapse was the over 50% fall in cereal prices in Mali between 1998 and 2000 during 3 years of above-normal cereal production (Kebe et al., 2000). Farmers in the Sahelian region are aware of this type of price behavior and the importance of new marketing opportunities for their cereal surplus. They consider price collapse a principal factor discouraging new-technology introduction.[3] Government-supported programs to handle cereal surpluses through managing the supply side with price supports and storage schemes have had little success, as seen in Zimbabwe in the early 1980s and in Mali in the early 1970s (OMA, 1990).

With economic growth and the availability of new technologies, there needs to be a focus on new market opportunities for traditional cereals. Fortunately, there are emerging food and feed markets for traditional cereals. As noted above, one of the reasons for the increasing consumption of rice was the greater ease of processing and preparation as compared with the traditional cereals. Food scientists have been applying these same techniques to sorghum and millet.

There has been a rapid growth of processors and processed foods from sorghum and millet in the Sahelian countries, especially in Senegal but also in Mali (Ouendeba et al., 2002). Some of those small-scale food processors are even exporting to West Africans in Europe and the United States. As with rice, the new pre-processed millet products can be taken out of the package and boiled for rapid cooking. Other similar

[3] These observations are from field interviews with 19 farmers in the Segou region of Mali between 1996 and 1997 and 14 farmers in the Sikasso region of Mali in 2000. Similar issues of poor marketing channels in basic food items hinder technology advancement in other parts of sub-Saharan Africa.

products have been developed, including sorghum for parboiling with the consistency of rice. Sorghum and millet have also been used in other processed forms, such as baby-weaning formulas, cookies, and beer.

6. Growth of the poultry industry

Even bigger gains in the demand for cereals will come with shifting dietary patterns for meat, especially poultry. Urbanization and economic growth change the nature of food demand from basic staple food crops to a more diversified diet that includes more animal products, fruits, and vegetables (Pingali and Rosegrant, 1995). Increased protein consumption, especially of chicken and eggs, will require rapid increases in feed-grain consumption.

Experience in other countries has shown that innovations in production and consumption[4] technologies have enabled the poultry industry to lead the growth in fresh-meat production. Growth in poultry consumption has continued since the 1970s in the United States while the consumption of other fresh meats has leveled off or declined. Per capita chicken consumption passed beef in the early 1990s to become the principal meat consumed (USDA-ERS, various issues). This shift to rapid growth of poultry consumption has now occurred in middle- and lower-middle income countries, such as Spain, Brazil, and Honduras. In Honduras from 1980 to 1994, poultry consumption increased by 8.6% annually (Sanders and Lopez-Pereira, 1996).

Intensive poultry production with confined feeding has begun in several countries of sub-Saharan Africa, including Senegal. Incomes are 50% to 100% higher than in the other Sahelian countries (World Bank, 2003, pp. 234, 235). Customs and food-use patterns are similar, so it is likely that other countries will follow Senegal in these changing consumption patterns.[5]

[4] There also are substantial innovations on the consumption side, as illustrated by the rapid growth worldwide of chicken-specialty restaurants. The number of fast-food restaurants specializing in chicken has accelerated in sub-Saharan Africa, particularly in urban Kenya, Botswana, and Zimbabwe.

[5] One reviewer flagged the importance of other factors in determining consumption, such as infrastructure and market size. This phenomenon of shifts to poultry is observed in countries and regions of sub-Saharan Africa with more rapidly increasing economic growth, including Botswana, urban Zimbabwe, and Kenya. This type of comparative consumption analysis over time seems to be very useful for sub-Saharan Africa.

As incomes increase, developing countries have generally been unable to keep pace with the growth in feed-grain demand and have had to resort to imports. The potential to capture the demand increase for sorghum and millet in these emerging feed markets by producers in the Sahel will depend upon their ability to compete with imports and with other grain (e.g., maize) producers. As in Senegal currently, the preference of the feed-grain mixers will generally be for imported maize, which has a more guaranteed quality and availability than either of the traditional cereals. Sorghum and millet are good animal feeds, so farmers can benefit from locally produced cereals and reduced transportation costs, as compared to importing maize. However, institutional changes supporting farmers in producing a high-value, quality-controlled sorghum or millet that can be reliably delivered to a feed mixer will probably require formation of producer groups and even advance contracts.

Milling requirements are different for the various cereals due to differences in grain size and polycarp. Also, because the variability in grain size between farms and years is greater in sorghum and millet than in maize, some investments need to be made to adapt the machinery from milling only maize (B. R. Eddleman, 2001, personal communication).

New institutions at the regional level will be needed to facilitate, grade, and provide the required quality control of the new feed source and assure fulfillment of contracts at specified times. Producers' associations and cooperatives are increasingly common in the Sahelian countries but they need better and regular contacts with the processors to understand the quality requirements and to make advance contracts.

Facilitating these contracts and information exchanges is expected to be much easier than raising maize under semiarid conditions or paying the high transportation costs for imported feed grains.

7. Farm-level model

Most discussions of semiarid agriculture get stuck on the risk problem. Farmers' tradeoffs between expected income and income variability are difficult to measure, interpret, or confirm. Generally, there is difficulty in narrowing down the alternatives in a plausible way based upon field observations. The farm-model sector presented here includes farmers' expressed responses to risks. Farmers are first concerned with having a minimum cash flow at harvest and then sufficient grain for food.

Based on farm interviews by Sidibé (2000), Vitale (2001), and Abdoulaye (2002), a lexicographic utility function was developed in which the household firm first has a fixed-harvest-income objective,[6] then a food-subsistence objective. When these two constraints are satisfied, the firm maximizes profits.

Subsistence objectives are standard in modeling low-income agriculture. Even more important, according to our farmer interviews in the Sahel, is the fixed-income requirement. These minimum income goals or pressing cash requirements also have a long history in farm modeling. Most farm modeling has treated one or the other, subsistence or minimum income objectives. The two goals and their interaction are stressed by farmers and in our modeling.

The harvest-income objective can override or be more important than the subsistence-food objective. In low-rainfall years, farmers are often so pressed to attain their income goal that they will sell so much grain that they have to find ways later in the year to obtain sufficient food. They will expect to receive cash or food transfers later in the year from relatives, or they or their relatives can work more off-farm after the production season (Reardon, 1997). During Abdoulaye's (2002) farm interviews in Niger in the second year of bad weather, sacks of maize sent by relatives from the Ivory Coast were arriving in the village.

Among critical expenditures that have to be paid at harvest time, farmers mention taxes; school expenses; reimbursement of labor, including family labor (often in the form of gifts for the wives); payments for credit received during the growing season for pressing expenditures, such as medical costs; cash for younger family members to migrate; naming ceremonies; and weddings. These income objectives at harvest and the price premium farmers forego by selling at harvest are the basis of support for the recent development programs for inventory credit.

[6] In later refinements of this modeling with more field data, the harvest-income objective varies with the state of nature (Abdoulaye, 2002). Adjusting the harvest income goal is what we would expect farmers to do. In adverse years, they would pay their family members less, give fewer gifts to their wives as part of compensation, and even defer getting another wife. In very adverse years, they would not be able to pay for credit received.

A comparison of farmers' actual activities was made with model predictions for both our specification and a more conventional risk model (negative exponential utility function). The lexicographic explanation of farmer behavior worked as well or better than more conventional risk models (Sidibé, 2000; Vitale, 2001). The two objectives of harvest income and food consumption are apparently farmers' responses to a risky environment. Expected profits are reduced to assure these goals.

A further adjustment is used to avoid farmers' sacrificing too much profit to attain these goals. In the low-rainfall state (approximately 15% probability), shadow prices to reach the two principal constraints can become so high that the income and consumption targets need to be adjusted. Because farmers are expected to make these adjustments, it is also done here. This iterative adjustment process responding to shadow prices is explained in more detail in Vitale (2001). The different technologies evaluated not only increase profits (inorganic fertilizers) but also reduce risks (water harvesting with ridges and tied ridges).

The simplified model is laid out in the seven equations below.

Objective function:

$$\text{Max.} \sum_i \sum_j \sum_k \text{Prob}_k (P_{sik} Q_{sik} - c_{ij} X_{ij} - P_{sik} B_{sik}). \tag{1}$$

Lexicographic goal 1. Satisfy the harvest-income objective:

$$\sum_i \sum_k P_{hik} Q_{hik} \geq I_k. \tag{2}$$

Lexicographic goal 2. Satisfy the household food-subsistence objective:

$$\sum_i (Q_{cik} + B_{ik}) F_i \geq C_k. \tag{3}$$

These objectives are pursued subject to the following crop production accounting, supply identity, resource constraints, and resources available for food expenditures:

$$Q_{pik} = \sum_j Y_{ijk} X_{ij} \tag{4}$$

$$Q_{pik} = Q_{hik} + Q_{sik} + Q_{cik} \tag{5}$$

$$\sum_i \sum_j a_{ijl} X_{ij} \leq RES_l \quad (6)$$

$$P_{sik} B_{sik} \leq M^e_{kr}. \quad (7)$$

where X_{ij} is the decision variable for quantity of crop i planted using technology j; Y_{ij} is the yield of crop i planted using technology j; P_{hik} is the price of crop i during harvest period h in state k; P_{sik} is the price of crop i during the hungry season s in state k; Q_{hik} is the quantity of crop i sold at harvest in state k; Q_{cik} is the quantity of crop i consumed on-farm in state k; Q_{sik} is the quantity of crop i sold during the hungry period s in state k; Q_{pik} is the total quantity of crop i produced in state k; Prob_k is the probability that state i occurs; I_k is the farmer's harvest-income target; C_k is the household cereal-subsistence target; F_i is the percent contribution of crop i toward satisfying cereal subsistence target; c_{ij} is the unit production cost of crop i using technology j; B_{sik} is the quantity of crop i purchased in market in state k during the hungry season s; a_{ijl} is the demand of crop i planted using technology j for resource l; RES_l is the availability of resource l; and M^e_{kr} is the resources expected to be available for food in rainfall state k and in income state r.

In objective function (1), there are nine states of nature, varying with both total rainfall and variability within the year (Vitale, 2001, pp. 353, 356). This division was based on an evaluation of historical rainfall patterns. The model was solved for the best farmers (15%) and for average farmers (40%) (based on fieldwork from Kergna et al., 1998). The best farmers are expected to be leaders in innovation and average farmers are expected to follow. The below-average farmers (45%) do not have a combination of the resource base, the initiative, and/or knowledge to adopt the new technologies. Hence, only 55% of the farmers participate in the technological-change process in the sector model (Vitale, 2001, p. 241).

Because prices are lowest at harvest, farmers will sell only what they absolutely need to attain their harvest-income goal. The shadow price on this constraint is the rate of return to holding on to the crop and selling at the price recovery or the percentage return (gross) on inventory credit.[7]

[7] The return here on selling later needs to be adjusted for the costs of storage and the interest on capital. In the semiarid region, with the institutional support of doing storage on the village level, these storage costs are reduced.

In the subsistence-consumption equation, the shares (F_i) of each component are held constant. The cross-price elasticities between cereals are zero in this specification for attaining the subsistence goal. Equations (4)–(6) are standard for the production function, an identity for the three uses of farm output, and the resource constraints, respectively.

The resources available for food purchases (7) include the available cash for food purchases that the farmer has going into the crop season and what he expects to earn later in the year for food purchases and to obtain in remittances in cash (for food) and food from his relatives. Food purchases will be most important in adverse rainfall years, when the farmer is not going to be able to cover his subsistence requirements from his own production. The empirical estimate forM^e_{kr} here was for farmers' expenditures for food in adverse years, based upon savings and expected earnings during the off season. In normal and good rainy seasons, this income goal is expected to be higher but less pressing in driving the model results.

Once technologies are identified that satisfy farmers' behavioral requirements over all the relevant states of nature, a principal barrier to continuing diffusion is the price collapse resulting from the inelastic demand for a staple commodity. This collapse often is a result of good or even normal weather conditions and can be aggravated by the introduction of new technologies. The combined effect of technology introduction and good weather conditions on prices and consequently on adoption therefore requires the more aggregate perspective of the sector model.

8. Sector model

The farm models allow the evaluation of potential diffusion and profitability of new technology at the start of the introduction process. Over time, as more farmers adopt, prices decline. Price declines always benefit consumers. Innovative farmers benefit from technological change when the price decline is less than cost reduction from technological change. Unfortunately, price collapses, which slow down or stop the diffusion process, can result in even early innovators losing money, according to the farmers interviewed.

In developing countries, a substantial price collapse when good weather is combined with successful technology introduction has been frequently observed. In

Ethiopia, this price collapse occurred in maize in both 1996 and 2000 with both good weather and considerable success in introducing new technology. In 2000, the Ethiopian farm-level maize price decreased from 150 to 20–30 Birr/quintal (8.31 Birr/$ in 2001, according to IMF, 2002) and provoked a farmer and public policy crisis.

This price-collapse problem is handled with sector analysis. Prices are endogenous to the model when aggregate supply functions for the agricultural sector (derived from aggregating the farm-level programming results) are combined with aggregate demand for agricultural products. The sector model maximizes social welfare as the sum of consumer and producer surplus. It enables not only an estimation of the aggregate benefits of the technological change and demand changes but also estimation of gains to various beneficiaries.

The farm-level model includes nine states of nature. In the sector model, these are reduced to three. There are adverse years (15% probability),[8] normal years (61% probability), and good-weather years (24% probability). Model solutions always include all states of nature. However, the sensitivity analysis with the price variation is done for specific states of nature. Price collapses occur only in good-rainfall years but prices decrease slightly from the mean in normal-rainfall years.

For the supply function, farm programming models are developed for four different regions (the Sudano-Guinean, Sudanian, Sahelo-Sudanian, and Sahelian zones[9]) and two farm types (best and average farmers), and encapsulated in the sector model. Farmers not participating in the technological change process (45%) still provide their supply and respond to price changes; this is done with point estimates. Then estimates are made of the number of farmers in each category and the results multiplied by an expansion factor to give the supply side of the agricultural sector.

[8] A further modification was made. For the very adverse years (9% probability), the farmer expects food aid from donors and/or the government; hence, this very adverse condition is excluded from his planning process. This adjustment also reduces the tradeoff necessary in profits to obtain the harvest income and subsistence goals. Notice that in these very adverse years, the tradeoffs would be the largest. The problem of the realism of farmers sticking with these subsistence and income (at harvest) goals to even obtain them in very adverse years is then reduced.

[9] The Sahelian agroecological zone is not mentioned in Table 1 because this is a very marginal zone with negligible crop production. The rainfall levels are 200 to 350 mm/year at 90% probability.

The demand function is based upon summing the demand functions for farmers, urban consumers including 12 cities, and the processing industry. Perfect substitution between sorghum and millet is assumed. No substitution is allowed between the traditional and new cereals. Two-thirds of the average cereal consumption of 212 kg/adult is of the traditional cereals (Kebe et al., 2000; Coulibaly, B., 1999).

9. Data

On the supply side, technology components are obtained from field and experiment-station data and were repeatedly discussed with technical personnel in the region. The new technology options include higher levels of inorganic fertilizer, improved water-retention techniques, and new cultivars. Variations of all three technologies are already available and being utilized by the better farmers. These better farmers are using some inorganic fertilizer and improved cultivars. Both the best and average farmers employ ridging with animal traction for water retention. Further new cultivars are being produced currently on the experiment station. Better water-retention techniques are available. For technologies not yet on the farm experiment station, yields are discounted by 25% to account for the less-controlled conditions found on farms (Coulibaly, O., 1995; Vitale, 2001).

A moderate liquidity increase is necessary for purchasing more inorganic fertilizer. It can be generated from the sales of small ruminants, from remittances, or in a dynamic context from the profits of the previous year's savings resulting from the initial use of inorganic fertilizer. Because technologies are highly divisible, they can be used gradually; liquidity is not considered to be a critical constraint.

The inventory-credit programs provide the opportunity to obtain higher prices and increase liquidity. In the last 2 years, a number of agencies—including FAO, the World Bank, and the UNDP—have been employing inventory credit to enable farmers to achieve harvest-income goals by lending money at harvest and setting aside part of the harvest as collateral (Ouendeba et al., 2002). The farmers or the cooperative representing them can sell the crop later, after the cereal price has recovered, and repay the loan, interest, and storage costs.

Geographic Information Systems (GIS) are used to perform the aggregation required in "scaling-up" from the embedded farm models to the regional markets. The total cultivated area surrounding each of the primary markets included in the model is estimated using the Cropland Use Intensity data layer (FEWS, 1997). The number of farmers within the market basin of attraction is then calculated using household demographic data (Vitale, 2001).

How does the demand shift, and where do the values for this critical shift of demand come from? The pivotal point of 120 CFA/kg (exchange rate of 744 CFA/$ during 2001; IMF, 2002) is the initial estimate at which sorghum becomes too expensive for alternative food and feed uses and other commodities are substituted. Above this point, firms cannot make a profit on sorghum food processing or feed use. In October 2002, when millet prices were over 200 CFA/kg, many of the processors stayed out of the market.

Empirical estimates of the own-price elasticity of demand for sorghum/millet are −0.24 before the devaluation of 1994 and −0.63 after devaluation for urban Mali (estimates from two surveys in 1993 and 1996, respectively, in Coulibaly, B., 1999, pp. 50 and 51). A 1985–86 study of seven regional capitals in Mali found an own-price elasticity of −0.53 for sorghum/millet (Rogers and Lowdermilk, 1988 cited in Reardon, 1993, p. 8).

When the sorghum price increases, urban consumers reduce some of the quality components of their diet, which are higher priced, to make sure that they get sufficient sorghum/millet (Coulibaly, B., 1999). At very low prices with good weather, people can eat only so much sorghum/millet. Alternative markets for processed foods and feed use are just getting started; they are most developed in Senegal. In good-weather years with the increased supply of all the alternative cereals and minimal alternative markets, a price elasticity of demand of around zero (−0.05) seems to be most appropriate for the model (also used in Roth's sector model for Burkina Faso, 1986; Roth et al., 1991; Savadogo and Brandt, 1988; Vitale, 2001, p. 234).

As incomes increase and people shift their diets to higher-quality animal products, the income elasticity of demand for livestock products is expected to be around 1 (Johnston and Mellor, 1961). The derived demand with respect to income for livestock feed will shift out with income growth. Consumption changes across countries with economic growth indicate substantial increases first in food processing of the basic cereals and then with continued economic growth, a movement into feed use of the basic grains. The demand curve would become more elastic with the increased alternative use of feed (and decreased use of cereals as food with the dietary shift to higher quality). Also, there would be shifts outward from higher incomes, changes in tastes, and greater substitutability among products for feed. This was simplified to an increase of the price elasticity of demand (−0.9 used here).

In the short run, the main ongoing change is the increased processing of sorghum/millet for human food. It is necessary to evaluate how quickly this sector evolves and its contribution to these price elasticities. The short-run estimate at the lower level of the available empirical estimates was −0.25 and seems to be conservative. The long-run estimate was consistent with other countries but optimistic for the Sahelian countries because of continued low rates of economic growth experienced there.

10. Sector model: conceptualization of the combined shifts and results

With the shift in supply from technological change, price decreased substantially because of inelastic demand (Fig. 4). Consumers clearly benefit and producers lose if the area in E is greater than G. With the combination of shifting supply resulting from new technology and increasing demand caused by new processing, there is an increase of price from the initial equilibrium p_0 to p_2. With higher prices, producers unequivocally benefit; there are positive and negative effects for consumers. The change in producer surplus is $B+H_1+H_2+H_3+F+G$. Net consumer benefits will depend upon the relative size of the two effects; the reduction in consumer surplus from higher price plus the new areas below the demand curve resulting from the processor demand shift (I_1+I_2).

The distribution of benefits between consumers and producers is reversed when $p_2 < p_0$. In this case, technological change reduces the price faster than demand expansion can increase it (Fig. 5). There is an unequivocal gain for consumers and a potential loss for producers ($F + G+H-B$).

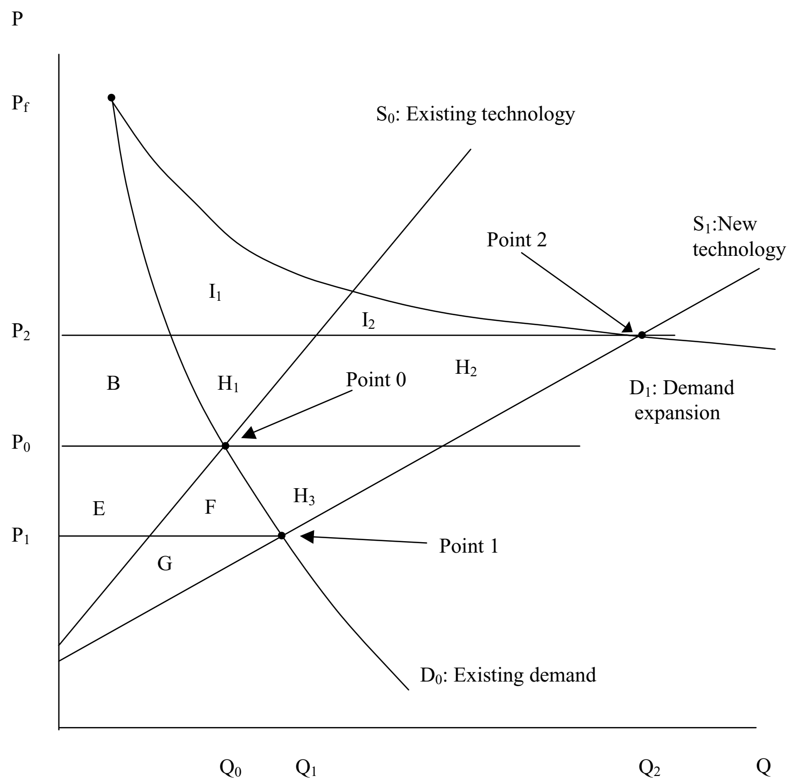

Fig. 4. Changes in consumer and producer surplus with technology introduction and demand-expansion policies ($p_0 < p_2$). *Source:* Vitale, 2001, p. 223.

There are three pairs of alternative cases of technological change and demand increase here: (1) with and without new technology but no demand change; (2) with new technology plus short-run demand expansion with and without increased liquidity; and (3) with new technology with long-run demand expansion, with and without liquidity increase.

Both good and average farmers shift into the new technology, and incomes fall on both types of farms with the lower cereal prices (Scenario B in Tables 4 and 5). The dynamics of the technology diffusion process are that the early and mid-period adopters make a profit before the price has fallen too much. As the price continues to fall, it is the late-adopters and nonadopters who absorb the losses.

In the short-run demand scenario (C in Tables 4 and 5) with the introduction of new processed foods using traditional cereals, consumer demand increases rapidly enough to eliminate the negative price-decline effect of new technology on farm incomes. Both the farm areas in new technologies and farm incomes increase. In the long run, the substantial expansion in demand depends on the increasing use of the traditional cereals as animal feed (Scenario D in Tables 4 and 5). From this demand increase, there is a further increase in adoption of new technology and increase in income.

Shadow prices for these demand-expansion scenarios indicate very high returns on additional investment in fertilizers and new cultivars. If farmers modestly increase their liquidity, adoption of new sorghum technology and farm income would increase further.

In the case of long-run demand expansion with liquidity increase, both types of farmers would shift to a more intensive technology package that contains higher fertilizer applications and a higher-yielding water-retention technique—tied ridging rather than ridging alone.

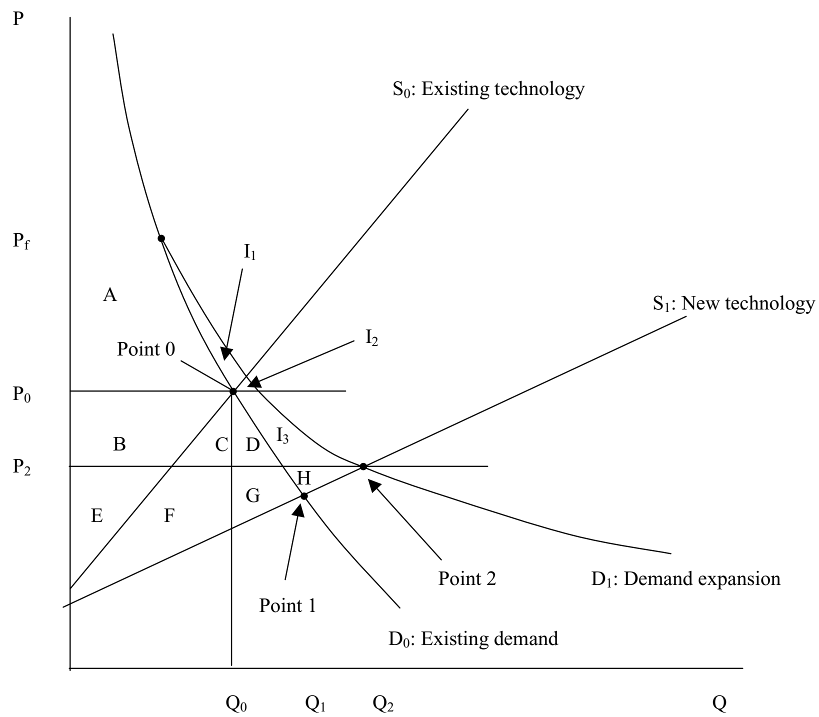

Fig. 5. Changes in consumer and producer surplus with technology introduction and demand-expansion policies ($p_0 > p_2$). *Source:* Vitale, 2001, p. 218.

Fig. 6 illustrates the various changes from technology introduction and demand expansion for the good state of nature.[10] This is the most important production period for demand expansion to have an effect. With only the introduction of new technology (no demand expansion), the price of sorghum decreases from 66 to 59 FCFA/kg and farm incomes decline (B in Tables 4 and 5). With the short-run demand expansion and technological change, prices increase to 90 FCFA/kg and farm incomes also climb (C and E in Tables 4 and 5). The extent of the increase in farm incomes depends on the increases in liquidity. Consumption of sorghum increase by 9% and 14% in the two liquidity cases (C and E in Fig. 6).

For the long-run demand expansion with rapid introduction of sorghum as animal feed, the sorghum price increases to 110 FCFA/kg in the limited liquidity case and to 102 FCFA/kg in the increase liquidity case (D and F in Fig. 6). Farm incomes increase further (D and F in Tables 4 and 5), and consumption of sorghum increases by 10% and 18% (D and F in Fig. 6).

For the Sudanian zone, the gains to society from a program to promote the introduction of new sorghum technology would be considerable.[11] With only new technology introduced (new sorghum cultivars and inorganic fertilizer) and no demand expansion, the producers lose substantially (US$2.7 million) and consumers gain, with a net welfare gain of US$4.2 million (Table 6). The short-run demand increase scenario increases net welfare gains by 56% to US$6.5 million. Producers now benefit because the price is increased. Similarly, the increased price causes a loss for consumers (B in Fig. 4). This price decline is not offset by the demand expansion ($I_1 + I_2$ in Fig. 4). If liquidity is moderately increased along with the short-run demand increase, the total effect on consumer welfare becomes positive. The demand expansion effect

[10] As noted earlier, all solutions include all three states of nature. This case is illustrated because the price decline is most pronounced in the good (adequate rainfall) state of nature. There is also a slight decline from the expected price in the normal state of nature.

[11] There will be some spill-over to the other two agroecological zones. These gains are also included in the modeling and reported in Table 6.

Table 4
Best farmers' technology adoption, crop portfolio, farm income, and constraints in response to new technology introduction in the Sudanian zone under different demand and liquidity scenarios

Description			Scenario*					
			A	B	C	D	E	F
Crop	**Technology**[a,b,c]	**Tech**	**Planted Area (ha)**					
Sorghum	Local-0-R	Exist.	0.0	0.0	0.0	0.0	0.0	0.0
Sorghum	Improved 50-R	Exist.	1.4	0.0	0.0	0.0	0.0	0.0
Sorghum	Improved-50-R	New	n/a	0.9	2.1	2.5	2.0	0.0
Sorghum	Improved-100-R	New	n/a	0.0	0.0	0.0	0.0	1.5
Sorghum	Improved-100-TR	New	n/a	0.0	0.0	0.0	0.5	1.0
Millet	Local-0-R	Exist.	11.0	11.7	11.7	11.3	11.5	11.5
Groundnut	Local-0-R	Exist.	0.0	0.0	1.0	1.0	0.3	0.0
Groundnut	Improved-100-R	Exist.	1.0	1.0	0.0	0.0	1.6	1.9
Cowpea	Improved-100-D	Exist.	0.7	0.5	0.3	0.2	0.5	0.6
Incomes								
(+) Market sales (US$)			1,210	1,175	1,319	1,476	1,452	1,748
(+) Harvest-income requirement (US$)			150	150	150	150	150	150
(+) Home consumption (US$)[d]			1,405	1,293	1,616	1,784	1,489	1,686
Total expected income (US$)			2,765	2,618	3,085	3,410	3,091	3,584
(−) Harvest-income efficiency loss (US$)			75	75	75	75	75	75
(−) Food-subsistence risk premium (US$)[e]			163	105	26	56	0	0
Shadow values								
Returns to purchased inputs (%)				590	298	371	<20	<20
Higher quality land (US$)				0	24	45	67	89

[a]Technology described by three items: seed variety type, quantity of cereal compound fertilizer (kg/ha), and soil-preparation technique.
[b]Improved refers to newly developed cultivars bred for conditions in the Sudanian zone that are set for release within the next 2 to 5 years.
[c]Two soil-preparation techniques, R and TR, refer to ridging and tied ridges.
[d]Home consumption valued at consumer market prices during the hungry period (August through October).
[e]Shadow price for the additional cost of obtaining the food-storage goal. It reflects both the transaction costs of finding and purchasing the required food and whatever risk premium farmers are prepared to pay due to the uncertainty of being able to find the food for their subsistence goals, hence their preference to produce it themselves.
*Definitions of the scenarios considered: T = 0 farmers' technology levels; T = 1 new technology; D = 0 existing demand in year 2000; D = SR short-run demand; D = LR long-run demand; L = 0 existing liquidity; L = 1 farmers increasing liquidity in response to higher returns.

A	B	C	D	E	F
T = 0	T = 1	T = 1	T = 1	T = 1	T = 1
D = 0	D = 0	D = SR	D = LR	D = SR	D = LR
L = 0	L = 0	L = 0	L = 0	L = 1	L = 1

Source: Vitale (2001, p. 263).

of the processing then increases consumer surplus by US$1.1 to 3.4 million (C and E scenarios in Table 6). Similar increased income and net welfare effects result from long-run demand expansion when confined poultry feeding increases rapidly.

11. Postscript on alternative technology-introduction strategies

Many articles have compared investments in marginal *versus* favored regions, with much of the emphasis for research resource allocation on the favored regions (Byerlee and Morris, 1993; Fan and Hazel, 2000; Fan et al., 2000; Renkow, 1993, 2000). Recently, a consensus has emerged that technology is presently available and profitable for semiarid regions (Sanders et al., 1996; Sanchez et al., 1997; World Bank, 2003, p. 68). Programming results here also support the potential benefits in terms of farm profitability and social welfare of technology introduction into semiarid regions.

There are many competing options for social investments so it is useful to compare the returns to these technologies for the semiarid zones with similar

Table 5
Average farmers' technology adoption, crop portfolio, farm income, and constraints in response to new technology introduction in the Sudanian zone for different demand and liquidity scenarios

Description			Scenario*					
			A	B	C	D	E	F
Crop	**Technology**[a,b,c]	**Tech**	**Planted Area (ha)**					
Sorghum	Local-0-R	Exist.	2.0	1.5	1.1	1.1	0.0	0.0
Sorghum	Improved-50-R	New	n/a	0.5	0.9	0.9	1.2	0.8
Sorghum	Improved-100-R	New	n/a	0.0	0.0	0.0	0.3	0.5
Sorghum	Improved-100-TR	New	n/a	0.0	0.0	0.0	0.5	.7
Millet	Local-0-R	Exist.	11.0	11.4	11.1	11.3	8.7	8.5
Groundnut	Local-0-R	Exist.	0.0	0.0	0.55	0.35	0.47	0.62
Groundnut	Improved-100-R	Exist.	.8	0.0	0.0	0.0	0.0	0.0
Cowpea	Improved-100-D	Exist.	0.8	0.0	0.3	0.2	0.5	0.6
Incomes								
(+) Market sales (US$)			135	158	237	276	341	394
(+) Harvest-income requirement (US$)			150	150	150	150	150	150
(+) Home consumption (US$)[d]			1,337	1,293	1,616	1,784	1,489	1,686
Total expected income (US$)			1,622	1,601	2,003	2,210	1,980	2,230
(−) Harvest-income efficiency loss (US$)			75	75	75	75	75	75
(−) Food-subsistence risk premium (US$)[e]			163	105	26	56	0	0
Shadow values								
Returns to purchased inputs (%)			58	189	227	294	<20	<20
Higher quality land (US$)				5	14	21	53	68

Notes: See Table 4.
Source: Vitale (2001).

technologies for the higher-rainfall zone. Introduction of sorghum technology in the semiarid zone is compared with programs to introduce new sorghum and maize technologies in the sub-humid zone. The main difference between sorghums for the two regions is the longer season length, hence higher yields for the higher-rainfall zone. Maize is not grown in the semiarid zone, except for small areas contiguous with the households, where human and animal waste products are deposited.

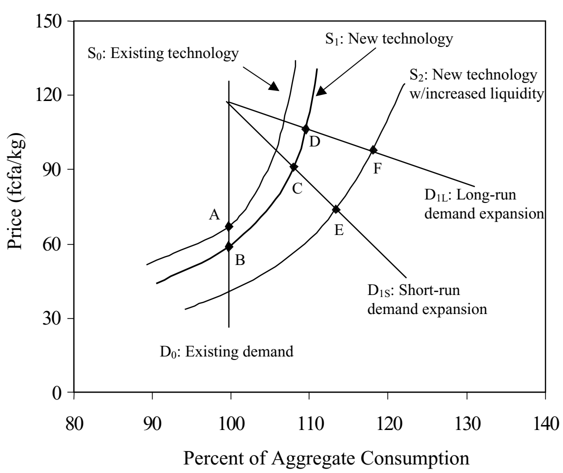

Fig. 6. Price and quantity responses to new sorghum technology introduction under the different demand scenarios. *Source:* Vitale, 2001, p. 261.

Using the short-run demand expansion with increased liquidity, new sorghum technology introduction concentrating on the semiarid Sudanian zone results in higher social returns than the alternative strategies of introducing sorghum or maize into the sub-humid zone (Table 7). This was also true for the long-run demand expansion scenario (Vitale, 2001, p. 289).

The Sudano-Guinean zone has higher rainfall and hence higher yields than the Sudanian zone. The Sudanian zone has greater numbers of farmers and areas of sorghum production. Even with conservative assumptions about diffusion and yield increase, the larger sorghum areas offset the climatic advantages of the sub-humid zone.

With increased water availability, inorganic fertilizers and new cultivars, sorghum yields can be

Table 6
Impacts of new technology introduction in the Sudanian zone on changes in social welfare for producers and consumers under demand-expansion and increased-liquidity scenarios (million US$)

Item	Scenario[a,b]				
	*B	C	D	E	F
Producer surplus[c]					
Sahelian	0.13	0.08	0.06	0.99	2.33
Sudanian	−1.03	4.71	8.64	7.67	17.51
Sudano-Guinean	−1.82	3.40	4.40	4.90	10.38
Total	−2.72	8.19	13.10	13.56	30.22
Consumer surplus					
Staple-oriented[d]	6.88	−3.58	−7.58	−2.58	−14.58
Demand expansion[e]	0	1.87	1.13	3.42	2.78
Total	6.88	−1.71	−6.45	0.84	−11.80
Social welfare	4.16	6.48	6.65	14.4	18.42

[a]The model scenarios are defined as follows:

*D = 0 existing demand in year 2000; D = SR short-run demand; D = LR long-run demand; L = 0 existing liquidity; L = 1 farmers' increasing liquidity in response to higher returns.

Definitions of the scenarios considered:

B	C	D	E	F
D = 0	D = SR	D = LR	D = SR	D = LR
L = 0	L = 0	L = 0	L = 1	L = 1

[b]Changes in consumer and producer surplus with respect to base conditions of existing technology, existing demand, and existing farmers' liquidity.

[c]Producer surplus includes surplus from all three farmer groups: better, average, and poor.

[d]Includes urban consumers from all agroecological zones. The economic surplus of farmers' home consumption of cereals is included in the producer surplus.

[e]Component of consumer surplus from the short- and long-run-demand expansion scenarios.

Source: Vitale (2001, p. 256).

Table 7
Impacts of alternative technology introduction policies on social welfare changes for consumers and producers under short-run demand expansion and farmers' increased liquidity scenarios (million US$)

Item	New sorghum technology in the Sudanian zone	New sorghum technology in the Sudano-Guinean zone	New maize technology in the Sudano-Guinean zone
Producer surplus[a]			
Sahelian	0.99	1.00	0.87
Sudanian	7.67	3.52	1.89
Sudano-Guinean	4.90	5.62	4.96
Total	13.56	10.14	7.72
Consumer surplus			
Staple-oriented[b]	−2.58	−3.01	−1.87
Demand expansion[c]	3.42	3.12	2.84
Total	0.84	0.11	0.97
Social welfare	14.44	10.25	8.69

[a]Producer surplus includes surplus from all three farmer groups that were described in the data section.

[b]Includes urban consumers from all of the agroecological zones; farmers' home consumption of cereals is not included in consumer surplus but rather in the producer surplus.

[c]Component of consumer surplus from the short- and long-run-demand expansion scenarios.

Source: Vitale (2001, p. 28).

substantially increased in the lower-rainfall region. This strategy of concentrating introduction efforts on sorghum technology for the Sudanian zones also has equity effects. Because farmers in the semiarid Sudanian zone have been largely left out of much previous intensification activity, incomes are lower than in the Sudano-Guinean zone.

12. Conclusions

With higher prices from either selling at different times during the season or from demand expansion into processing or feed in the better rainfall years, higher input purchases are profitable, according to budgeting and programming results. One currently popular strategy for increasing the profitability of intensification activities is to enable farmers to avoid selling at the post-harvest price low by providing inventory credit. This credit is now being promoted by different agencies in the Sahel. As a marketing strategy this is a temporary gain because, as more farmers do it, the seasonal price variation will disappear. Nevertheless, there appear to be big gains; the introduction process is already ongoing. The public sector can accelerate it with extension and encouragement to the financial sector.

A second step is to develop alternative markets for food and feed for the traditional cereals to moderate seasonal price collapses. This process of increased consumption of processed basic food crops and the shift from food grains to feed grains has occurred in the developed countries and is proceeding in the middle-income developing countries. The first part of increasing demand for processed foods, including the traditional cereals, is ongoing in the low-income developing countries.

Innovations for the processed food market of the traditional staples have two components: (1) higher-quality white sorghums and improved millets have been developed by breeders and are available in the Sahel; and (2) innovations in processing and preparation have been made for the traditional cereals by food scientists. A wide range of processed traditional cereal products with a convenience level similar to rice are becoming available in urban areas.

Currently, the number of processors and the quantities of the traditional cereals (sorghum and millet) that they purchase are increasing rapidly in the Sahelian countries. Governments can facilitate this process by establishing good regulatory and legal environments to encourage and protect both farmer cooperatives and the new emergent sector of food processors.

Larger gains in demand shifts will come from an expanding demand for feed grains. As incomes grow sufficiently (within the next 5 to 10 years) in these countries, there will be shifts in consumption from food grains to animal products and the potential for rapid growth of domestically produced feed grains. The new higher-quality white sorghums and improved millets developed for human consumers also have nutritional advantages for animal feed. Public policy to plan for and facilitate this process for the low-income countries could reduce feed-grain import requirements. Quality control and fulfilling contracts are new concepts among farmers and processors, so the public sector should not only encourage this evolution but also set up a regulatory and legal framework to encourage both sides to fulfill contracts.

In the long run with demand expansion and agricultural prices falling more gradually as technology continues to be introduced, not only consumers but also many innovating producers will benefit because for many production costs will fall more rapidly than prices. This gradual decline is a contrast with present price collapses from a combination of good weather and technological change. Storage programs designed to reduce price fluctuation within years could also be useful in moderating price fluctuations. To encourage the continued introduction of new technologies, many in the public sector need to become aware of the importance of farmers making money.

Clearly, the effects of demand expansion presented here are preliminary estimates because the projections for both future yields and diffusion will drive these results. Strategies should reflect both the costs and the benefits of alternatives. Nevertheless, our preliminary comparison of the strategy of introducing new sorghum technology into the semiarid zone indicates higher social returns than the focus on either sorghum or maize for the sub-humid zone. In public policy, it is important to identify missed opportunities as well as build upon previous successes.

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References

Abdoulaye, T., "Farm Level Analysis of Agricultural Technology Change: Inorganic Use on Dryland in Western Niger," unpublished Ph.D. thesis, (Purdue University, Department of Agricultural Economics: West Lafayette, IN, 2002).

Abdoulaye, T., and J. H. Sanders, "Economics of Fertilizer Use in Semiarid African Agriculture: The Niger Experience," mimeo, (Purdue University, Department of Agricultural Economics: West Lafayette, IN, 2002), pp. 43.

Boughton, D., and T. Reardon, "Will Promotion of Coarse Grain Processing Turn the Tide for Traditional Cereals in the Sahel?" *Recent Empirical Evidence from Mali. Food Policy* 22, no. 4 (1997), 307–316.

Byerlee, D., and M. Morris, "Research for Marginal Environments. Are We Underinvested?," *Food Policy* no. 4 (1993), 381–393.

Coulibaly, B., "Effects of Devaluation on Food Consumption Patterns in Urban Bamako," Unpublished M.S. thesis, (Purdue University, Department of Agricultural Economics: West Lafayette, IN, 1999).

Coulibaly, O., "Devaluation, New Technologies, and Agricultural Policies in the Sudanian and Sudano-Guinean Zones of Mali," Unpublished Ph.D. dissertation, (Purdue University, Department of Agricultural Economics: West Lafayette, IN, 1995).

CPS, *Recueil des Principales Statistiques du Secteur Rural Malien* (Ministry of Rural Development and Water: Bamako, Mali, 1998).

Dibley, D., D. Boughton, and T. Reardon, "Processing and Preparation Costs for Rice and Coarse Grains in Mali: Subjecting an Ipse Dixit to Empirical Scrutiny," *Food Policy* 20, no. 1 (1995), 41–50.

Duvick, D. D., "Genetic Contributions to Yield Gains of U.S. Hybrid Maize 1930–1980," In W. R. Fehr (ed.), *Genetic Contributions to Yield Gains in Five Major Crop Plants*. Crop Science Society of America Special Publication No. 7, (American Society of Agronomy: Madison, WI, 1987), pp. 15–47.

Eddleman, B. R., *Personal Communication* (2001).

Fan, S., and P. Hazell, "Should Developing Countries Invest More in Less Favored Areas? An Empirical Analysis of Rural India," *Economic and Political Weekly* (2000), 1455–1463.

Fan, S., P. Hazell, and T. Haque, "Targeting Public Investments by Agroecological Zone to Achieve Growth and Poverty Alleviation Goals in Rural India," *Food Policy* 25 (2000), 411–428.

FEWS (Famine Early Warning System), Various Price, Production, Rainfall, and GIS Data Posted on the USAID-FEWS website, (1997).

Gorse, J. E., and D. R. Steeds, *Desertification in the Sudanian and Sahelian Zones of West Africa*, Technical Paper 61 (World Bank: Washington, DC, 1987).

IMF (International Monetary Fund), *International Financial Statistics*, Washington, DC, (2002).

Johnston, B. F., and J. W. Mellor, "The Role of Agriculture in Economic Development," *American Economic Review* 51, no. 4 (1961), 566–593.

Kebe, D., M. Fofany, and P. Traore, "Impact de la Baisse des Prix des Cereales Seches Sur les Revenus des Producteurs," Institut Economie Rurale internal report, Aug (2000).

Kergna, A., A. Yapi, S. Debrah, A. Sadie, and O. Sanogo, "An Analysis of the Economic Impact of Sorghum and Millet Research in Mali," *ICRISAT/IER Joint Impact Assessment of Agricultural Research*, Bamako, Mali, (1998).

McMillan, D., J. Sanders, D. Koenig, K. Akwabi-Ameyaw, and T. Painter, "New Land Is Not Enough: Agricultural Performance of New Lands Settlement in West Africa," *World Development* 26, no. 2 (1998), 187–211.

Miller, F. R., and Y. Kebede, "Genetic Contributions to Yield Gains in Sorghum, 1950–1980," in W. R. Fehr (Ed.), *Genetic Contributions to Yield Gains in Five Major Crop Plants*. Special Publication No. 71–14, (Crop Science Society of America, American Society of Agronomy: Madison, WI, 1987).

OMA, *Le Reflet: Bulletin Mensuel du Marche Agricole* (Observatoire du Marche Agricole: Bamako, Mali, 1990).

Ouendeba, B., T. Abdoulaye, and J. H. Sanders, "Food Staples in West Africa Production and Marketing. A Concept Note," Mimeo, (ICRISAT and Purdue University: Niamey, Niger and West Lafayette, IN, 2002).

Pingali, P., and M. Rosegrant, "Agricultural Commercialization and Diversification: Processes and Policies," *Food Policy* 20, no. 3 (1995), 171–185.

Reardon, T., "Cereal Demand in the Sahel and Potential Impacts of Regional Cereals Protection," *World Development* 25 (1993), 17–35.

Reardon, T., "Using Evidence of Household Income Diversification to Inform Study of the Rural Nonfarm Labor Market in Africa," *World Development* 25, no. 5 (1997), 735–747.

Renkow, M., "Differential Technology Adoption and Income Distribution in Pakistan: Implications for Research Resource Allocation," *American Journal of Agricultural Economics* 75, no. 1 (1993), 33–43.

Renkow, M., "Poverty, Productivity and Production Environment: A Review of the Evidence," *Food Policy* 25 (2000), 463–478.

Roth, M., "Economic Evaluation of Agricultural Policy in Burkina Faso: A Sectoral Modelling Approach," Unpublished Ph.D., dissertation (Purdue University, Department of Agricultural Economics: West Lafayette, IN, 1986).

Roth, M. J., P. C. Abbott, and P. V. Preckel, "Evaluating Agricultural Price Policy under Dual Market Regimes and Institutional Constraints," *Journal of Development Economics* 34 (1991), 179–197.

Sanchez, P. A., K. D. Shepherd, M. J. Soule, F. M. Place, R. J. Buresh, A.-M. N. Izac, A. U. Mokwunye, F. R. Kwesiga, C. G. Ndiritu, and P. L. Woomer, "Soil Fertility Replenishment in Africa: An Investment in Natural Resource Capita," In R. J. Buresh,

P. A. Sanchez, F. Calhoun (Eds.), *Replenishing Soil Fertility in Africa*. SSSA Special Publication No. 51 (Soil Science Society of America: Madison, WI, 1997), pp. 1–46.

Sanders, J. H., and M. Lopez-Pereira, "Sorghum in Central America: Technological Change on the Hillsides and the Plains," Mimeo for INTSORMIL (Purdue University, Department of Agricultural Economics: West Lafayette, IN, 1996).

Sanders, J. H., S. Ramaswamy, and B. I. Shapiro, *The Economics of Agricultural Technology in Semiarid Sub-Saharan Africa* (Johns Hopkins University Press: Baltimore, 1996).

Savadogo, K., and J. A. Brandt, "Household Food Demand in Burkina Faso: Implications for Food Policy," *Agricultural Economics* 2 (1988), 345–364.

Sen, A. K., *Poverty and Famines, An Essay on Entitlement and Deprivation* (Clarendon Press: Oxford, UK, 1982).

Sidibé, M., "A Farm Household Analysis of Technological Change and Structural Adjustment Policies in the Peanut Basin of Senegal," Unpublished Ph.D. dissertation (Purdue University, Department of Agricultural Economics: West Lafayette, IN, 2000).

Shapiro, B., and J. H. Sanders, "Natural Resource Technologies for Semiarid Regions of Sub-Saharan Africa," In C. B. Barrett, F. Place, A. A. Aboud (Eds.), *Natural Resources Management in African Agriculture: Understanding and Improving Current Practices* (CABI Publishing: New York, 2002), pp. 261–274.

USDA-ERS (United States Department of Agriculture-Economic Research Service). Various issues. Livestock, Dairy and Poultry Outlook, Washington, DC.

Vitale, J. D., "Economic Impacts of New Sorghum and Millet Technologies in Mali," Unpublished Ph.D. dissertation (Purdue University, Department of Agricultural Economics: West Lafayette, IN, 2001).

World Bank, "Sustainable Development in a Dynamic World, Transforming Institutions, Growth, and the Quality of Life," *World Development Report* 2003 Washington, DC (2003).