

Economic and Environmental Impact of Improved Sorghum and Millet Technology in Mali¹

Bobby R. Eddleman², Alpha O. Kergna³, Jeffrey Vitale⁴, Bruce A. McCarl⁵, C. Chen⁶, and Paul Dyke⁷

ABSTRACT

To provide improved methods to assess the impact of introduction and use of technology, a suite of integrated interactive models was created for use in developing countries. The Agricultural Sector Model (ASM) was used to estimate the economic consequences of adopting a new sorghum production system derived from joint U.S. and Malian research under the INTSORMIL CRSP and ICRISAT. It assumed an adoption rate of between 20 and 30% among regions of Mali. Demand is based on estimates of population growth in the year 2015 (World Food Summit target date) for the various regions of Mali. The annual total national welfare associated with adoption of the technology was estimated to be FCFA 635 billion per year in the year 2015. The EPIC model was run with 20-year simulations. The model predicts a reduction in erosion using the new production system ranging 1-3% in the Segou region; 30-43% in Kayes. The reduction is attributed to faster development of canopy cover exhibited with the new system. This is due both to the improved germplasm and the increased use of fertilizer. These results suggest the economic benefits of the new production package are accompanied by positive environmental consequences through reduction in soil erosion.

INTRODUCTION

One of the challenges confronting policy makers in developing countries is satisfying their country's food demand goals set by the World Food Summit for the year 2015. In the West African Sahel (WAS), high population growth is expected to pose a major concern. With fast growing populations and recent stagnation in production, the 2015 food targets in the WAS will remain somewhat Spartan in nature. Here, the food target goals will focus on assuring subsistence levels of basic food items to its citizens. To keep pace with the growth in population, food production will need to grow at about an annual rate of 3 percent throughout much of the WAS.

Author Contact: Bobby R. Eddleman, Email: b-eddleman@tamu.edu

¹Paper presented to the SANREM Research Scientific Synthesis Conference, November 28-30, 2001, Athens, GA

²Texas A&M University, ³Institut d' Economie Rurale, Mali, ⁴Texas A&M University, ⁵Texas A&M University, ⁶Texas A&M University, ⁷Texas A&M University

In the past, it would have been much easier for to meet the increased food demand through

area expansion using traditional technology. But today, with the supply of quality lands exhausted throughout much of the Sahel, area expansion amounts to marginal land clearing. Yields decline as farmers push onto the marginal lands, and over time the removal of land cover results in accelerated land degradation. If prudent land management practices are not followed, the process of continued land expansion poses a serious threat to the environment, as well as to societies food security (Scherr and Yadav 2001).

The rising land costs in the Sahelian areas has prompted interest in the semi-humid frontier areas of the WAS. These regions are free of the soil moisture constraints that limit production in the Sahel, and generally the supply of quality land is not as much of an issue in the semi-humid tropics as it is in the Sahel. The push onto the sub-humid frontier has been made possible through investments in public health and infrastructure, which have allowed farming communities to increase dramatically over the past two decades (McMillan et al. 1998). Being more responsive to intensification, these higher productive areas have experienced a significant amount of new technology introduction. The primary crops that typically have been intensified have been cotton and maize, cash crops that have attracted support from private and semi-private sources (e.g. CMDT). However, staple food crop production has received substantial co-benefits in this region. Sorghum and millet productivity is enhanced from the higher levels of input usage that is generally available from the more developed input supply channels, and in the low lying "bas-fonds" areas, there are substantial opportunities for production in rice, Irish potatoes, and vegetable gardening.

Even with an emphasis on the higher productive frontier, the drier Sahelian areas should not be ignored (Vitale 2001). Although area expansion is no longer a viable option in the Sahel, new technology offers an alternative to increase production through raising yields on lands already cultivated. Research stations throughout the West African Sahel have demonstrated the ability of new technology to raise land productivity to heights far above traditional technology (Matlon 1990). Moreover, new technology is likely to mitigate resource degradation since farmers would allocate more of their resources to the higher quality fields, and would turn their attention from the marginal lands.

Another consideration for policy makers is to determine which commodity, or portfolio of commodities, to focus technology introduction on. In the WAS, there are four cereals that can be used to meet basic food requirements: sorghum, millet, rice, and maize. Rice and maize perform well in the semi-humid areas and have a greater response to intensification under improved growing conditions than do sorghum and millet. Recent shifts in consumption patterns have tilted towards rice and maize as opposed to sorghum and millet (Reardon 1993). Alternatively, the traditional cereals (sorghum and millet) require much less demanding growing conditions, and outperform rice and maize in the harsher Sahelian agro-ecological zones. As a result, sorghum and millet are produced over a much larger area than are rice and maize, hence allowing for smaller productivity gains to achieve the same aggregate effect as rice and maize. Moreover, sorghum and millet have a long and established consumption pattern that is not expected to experience further declines over time, particularly so in the rural areas.

This paper considers the role that new technology would play in achieving the World Food Summit 2015 target demands for the staple crops. Technology introduction in both the drier Sahelian areas, as well as the in the semi-humid frontier, are considered. To do this, a sector model was constructed to estimate the societal impacts from new cereal technology introduction, and to determine the extent to which they can empower societies ability to reach the World Food Summit 2015 targets. The sector model approach allows for a comparison

between the impacts from both the Sahelian and semi-humid production zones, as well as the potential for cross commodity comparisons.

This paper begins with a brief description of Mali, the country that was chosen for a case study. Next, the sector model is presented in a descriptive format where its basic functions are explained. A data section follows this, where model parameters such as yields, future food demands, and adoption rates are detailed. Then a description of the four new technology introduction scenarios is presented, followed by the sector model's results. The paper concludes with suggested policies, as well as implications for future research.

BACKGROUND

Mali was chosen as a case study since conditions in Mali are for the most part typical of other countries in the WAS. In Mali's Sahelian region, the major challenges to agriculture include high population growth rates that average about 2.5 percent throughout the region, recent stagnation in food production from poor food policies and dwindling land supply, as well as increasing concerns over its natural resource base and accelerating resource degradation. However, Mali also has opened substantial areas in its semi-humid frontier areas located in the Sikasso region, which has become one of the more successful stories in agricultural development in West Africa (Sanders et al. 1996). Here, cotton yields have increased nearly four-fold since the early 1960's, and maize yields have experienced productivity gains nearly as large.

Mali has three main agro-ecological zones: Sahelo-Sudanian, Sudanian, and Sudano-Guinean¹ (Figure 1). In terms of production area, over 45 percent of Mali's land area is in the driest zone, the Sahelo-Sudanian, while the high potential Sudano-Guinean zone contains only 22 percent of the production area. The remaining 33 percent is in the Sudanian zone (Vitale 2001). Most of the staple food production takes place in the drier Sahelo-Sudanian zone and Sudanian zone. Total cereal production in these two zones (excluding rice) is over twice as large as cereal production in the Sudano-Guinean zone (RSSP 1998; FEWS 1997; Vitale 2001). However, maize production is primarily limited to the wetter Sudano-Guinean zone, where over seventy percent of Mali's maize is produced.

Although staple food production is dominant in the drier two zones, the high potential Sudano-Guinean zone produces the largest value given its propensity for cash cropping. The total value of crops produced in 1996 was estimated to be about \$ 205 million in the Sudano-Guinean zone (Vitale 2001). This is about one-third more than the value produced in the Sahelian zone, even though total production area in the Sahelian zone is over twice as large as the Sudano-Guinean

zone. The Sudanian zone produced about \$ 169 million in crops in 1996, about 15 percent less than the Sudano-Guinean even though the Sudanian zone has a 10 percent larger production area.

[1] Average annual rainfall in the zones are as follows: Sahelian zone (350-600 mm), Sudanian zone (600-800 mm), and Sudano-Guinean (800-1,100 mm).

METHODOLOGIES

An agricultural sector model (ASM) for Mali was constructed and used to estimate impacts

from new sorghum and millet technology (McCarl et al., 1980). A primary feature of ASM is its ability to estimate how prices would change if new technology were introduced. It does this by simulating market outcomes in each of the major cities. The aggregate supply from the surrounding farm population enters each market, and consumers make their purchases depending upon the prevailing price. The ASM determines the price in each market in a manner that is believed to be consistent with how free, competitive markets function. In equilibrium, market prices are such that throughout the country, all producers have maximized their profits, and consumer's preferences are best satisfied given their income.

Two types of consumers are included in the model. Subsistence level farmers are presumed to retain sufficient food for family consumption to meet specified minimum caloric needs, along with tastes and preferences before products are marketed. Market-based consumers in the cities maximize their utility of preferences, subject to budget constraints. Producers maximize their profit given a production technology and prices; therefore, the supply function depends on prices and technology.

Aggregation of each consumer demand function and each producer supply function results in market demand and supply functions. As explained, in competitive markets, social welfare is maximized when all markets are in equilibrium. That is, maximum welfare will occur at the intersection of the market demand and supply functions. In addition, ASM also includes resource constraints that limit the regional supply of land, labor, and other factor inputs.

DATA

New Technology and Yields

The Mali ASM has a total of five sorghum production systems. The existing sorghum technology is a mix of traditional and improved production practices. Traditional practices include the use of local varieties, ridge tillage, and some manure to increase soil fertility. Improved practices include manure applications, ridge tillage to improve water retention, as well as improved varieties and inorganic fertilizers. The more intensive production scenario includes a more complete adoption of the improved production practices and varieties, and the adoption of two new varieties N^oTenimissa and Seguetana Cinzana.

Sorghum and millet yields for local and improved varieties for the Sudanian Zone and the Sudano-Guinean Zone are from Coulibaly (1995). These yield data were collected from different sources in Mali within the sorghum and millet breeding program. On-station, researcher managed trials and researcher managed on-farm trials and farming systems data were collected. On-station yields were reduced 25% and researcher managed on-farm yields were reduced 15% to account for better conditions on station for conducting experiments and better management (plowing, weeding, and harvesting on a timely basis) of researcher managed on-farm trials than farmers fields. Technology improvements were appraised in the Mali ASM by setting up different crop yields and cost of production versions of the model to provide simulation with and without the sorghum and pearl millet improvement technologies in Mali agriculture. The Mali ASM, upon solution, generates a wide range of information including estimates of regional and national agricultural commodity prices and quantities, input use, land use and crop mixes, and consumer and producer economic surpluses.

A biophysical model, EPIC, was used to estimate yields for the intervening period between 1997 and 2015. EPIC estimates soil erosion and tracks soil nutrient flows over time. Yields using traditional technology were found to have the largest yield decline, roughly .8 percent per

year, and in general future yield estimates were consistent with a similar study in Mali (Dalton 1996). Significant reductions in yield declines were found when more intensive farming practices were employed.

Food Demand

The 2015 World Food Summit demand targets were forecasted based upon population growth projections, rural to urban migration, and assumptions on likely changes in consumer's income and food preferences. Projected food demands were done for both rural and urban households and were based on current per capita consumption patterns. The projections show about a 30 percent increase in rural demand, and a much larger increase in urban food demand of about 55 percent for sorghum and millet. Urban food demand increased significantly more due to higher future incomes, population growth, and rural to urban migration.

Adoption Rates

Given the scarcity of data on the adoption rates for the new sorghum technology, adoption figures were obtained from expert opinion and field experience. The adoption rates serve in the model as upper limits on the maximum number of farmers that could adopt; technologies are only adopted in the model provided that they are profitable (i.e. increase social welfare). Existing adoption rates of new sorghum and millet technology are estimated to be between 15 and 20 percent (Kergna 1998). Complete (maximum) adoption is given by a 50 percent adoption rate for the new technologies.

RESULTS AND DISCUSSIONS

Scenarios

In conducting the impact assessment, the Mali ASM was run under 1997 demand and supply conditions that reflected current levels of technology in crop and livestock production in each region. This was defined as the *Baseline* simulation. The current adoption rates were used to allow the systems to enter the base model simulation. In this manner, the economic impacts from fully adopting existing technologies can be separated from the expected potential benefits from new technology introduction. In the *Present* scenario, the new sorghum technologies are introduced into the model, and are allowed to compete with the local varieties being produced with the ridge tillage only. The *Year 2015* scenario considers future growth in demand that reflect projected population growth in both rural and urban areas. This is done with both existing and new technology. Finally, the *Maize* scenario considers an alternative new technology strategy, the introduction of new maize technology.

Baseline

The ASM model solution was compared to observed 1997 data to determine how well it corresponded to actual conditions in the Mali agricultural sector. Market prices and total production for the base model solution are close to the observed data for 1997, as shown in Table 1. For example, the prices of pearl millet and sorghum under the current adoption base model solution are within 2% of the observed prices in 1997. Production quantities for these two commodities were within 4% of observed levels. Prices and production quantities for the other commodities, in the base model solution are generally within 1% to 10% of observed values. Thus the base ASM solution corresponds fairly closely to current production quantities and prices for most major agricultural commodities in Mali.

Table 1 Sector Model Results: Commodity Prices, Production, and Consumer Demand

Item	Observed	Year 1997 Demand		Year 2015 Demand		
		Existing Technology	New Sorghum Technology	Existing Technology	New Sorghum Technology	New Maize Technology
Price (fcfa/kg)						
Millet	77	79	32	127	76	121
Sorghum	77	77	53	147	76	136
Maize	69	69	62	101	61	48
Production (000 ton)						
Millet	738	766	903	843	1,003	875
Sorghum	540	556	674	611	806	632
Maize	290	274	277	280	296	383
Total	1,568	1,596	1,854	1,734	2,105	1,890
Urban Demand (000 ton)						
Millet	-	227	364	279	352	294
Sorghum	-	356	474	445	552	463
Maize	-	87	90	94	135	193
Total		670	928	818	1,039	950

Present

Under existing demand conditions, the introduction of new technology results in dramatic price declines. The model predicts a complete adoption of the new sorghum and millet technologies up to the maximum adoption rates discussed above. As a result of the increased use of technology, sorghum prices would fall by about 59 percent as compared with current adoption, and millet prices would fall by about 31 percent (Table 1). Sorghum and millet production would increase by 137 and 118 thousand tons, respectively, corresponding to increases of 18 and 21 percent. Prices of maize would decline as production would be slightly increased.

With home consumption demands fixed near subsistence levels, the technology induced supply response for sorghum, millet, and maize would be absorbed by regional demand from consumers in the towns and urban areas. Clearly, for such large supply increases the demand for sorghum and millet is inadequate to maintain prices, as under existing demand sorghum and millet are primarily limited to staple foods with correspondingly low income and price demand elasticity. This explains the precipitous fall in food prices that accompanies technology introduction under existing demand conditions.

The national welfare components for the four scenarios are listed in Table 2. Consumers'

surplus represents the Mali domestic consumers' surplus, and includes the home consumption value of the food produced and consumed on farms. Producers' surplus is the returns to land and labor resources of farmers. Farmers and their families benefit from both increases in returns to land and labor resources, as well as reductions in home consumption expenditures. Foreign surplus refers Mali's trade surplus, which is largely from cotton exports. Total social welfare is the summation of consumers' surplus, foreign surplus, and producers' surplus.

The analysis indicates that when current sorghum and pearl millet technologies are fully adopted under current 1997 demand conditions, consumers are the primary beneficiaries (Table 2). Urban consumers gain 19.6 billion fcfa² annually from the full adoption of the new technologies. This gain is distributed among the regions according to consuming population, with the largest share accruing to the capital city of Bamako. In contrast, producers experience a 45.7 billion fcfa annual reduction in the returns to their labor and land resources. However, much of this loss is offset by the 31.86 billion fcfa annual reduction in the home consumption expenditure that was included in the consumer surplus. Thus, the net loss to producers (i.e. rural households) is 13.84 billion fcfa.

Total social welfare in Mali increased 6.03 billion fcfa annually with full adoption of current sorghum and millet technologies under current 1997 demand conditions. These results indicate that current technologies when fully adopted and new cultivars being introduced may be expected to increase consumers' and national economic welfare, but reduce the economic welfare of farmers and their families in the aggregate.

² Since the fcfa devaluation in 1994, the average exchange rate has been around 500 fcfa = 1\$.

Table 2 Sector Model Results: Welfare Measures

Item	Year 1997 Demand		Year 2015 Demand		
	Existing Technology	New Sorghum Technology	Existing Technology	New Sorghum Technology	New Maize Technology

Consumer Surplus^a (million fcfa)	764,457	816,026	852,047	1,051,502	956,144
		(+51,569)	(+87,590)	(+287,045)	(+191,687)
Producer Surplus^b (million fcfa)	151,331	105,629	203,458	220,035	211,873
		(-45,702)	(+52,127)	(+68,704)	(+60,542)
Foreign Surplus^c (million fcfa)	6,818	7,006	6,576	5,596	6,336
		(+188)	(-242)	(-1,223)	(-482)
Social Welfare (million fcfa)	796,243	802,278	1,062,081	1,277,132	1,174,353
		(6,035)	(265,838)	(480,889)	(378,110)

^{a,b,c} Numbers in parentheses are the change in corresponding surplus relative to the existing technology case under 1997 demand conditions.

Year 2015

The current adoption base model solution is compared with the simulation reflecting existing and new technology introduction under projected 2015 demand conditions. Table 1 shows the results from the introduction of new sorghum and millet technology given the adoption rates discussed above. The model results indicate that with the new technology, the 2015 World Food Summit demand targets would be adequately achieved as indicated by the slight decline³ in food prices. Sorghum and millet prices would fall slightly by 1 and 3 fcfa/kg, respectively, corresponding to declines of less than 3 percent.

To meet the projected 2015 demand targets, sorghum and millet production would need to increase by 250 and 237 thousand tons, respectively, or about 44 percent for sorghum and 30 percent for millet (Table 1). Home consumption for each of the cereal grains would increase about 31 percent by the 2015 target date, reaching a combined 1.135 million tons for sorghum, millet, and maize.

³ If future food targets were not being adequately met, prices would rise significantly since food scarcity in the markets would bid up food prices.

A very different outcome emerges if new technology introduction was to stop, and technology was to remain fixed at existing levels out to the year 2015. All of the staple food prices would rise significantly, with sorghum experiencing the largest price increase. Sorghum prices would rise from 77 fcfa/kg to 147 fcfa/kg, corresponding to a 90 percent price increase. Millet prices would rise from 79 to 127 fcfa/kg, and maize prices would increase 69 to 101 fcfa/kg.

Producers have only limited ability to reallocate resources from non-staple food crop production such as peanuts and cowpeas, and the continued use of traditional technology results in yield declines from soil degradation as discussed above. As a result, aggregate staple food production would only increase modestly from 1997 levels under current technology conditions. Millet production would increase by about 10 percent from 766 to 843 thousand tons; sorghum by about 9 percent from 556 to 611 thousand tons; and maize by about 2 percent from 274 to 280 thousand tons.

With higher food prices, consumer's purchasing power is reduced, and urban demand falls to levels that are not much higher than 1997 demand levels. Urban demand for sorghum and millet would fall by 20 and 22 percent, respectively, if new technology were not introduced. This is likely to leave many consumers short of food subsistence needs, and suggests that satisfying the world food summit food targets⁴ would be jeopardized by failing to introduce new technology.

The analysis indicates that when sorghum and millet technologies are introduced under the 2015 World Food Summit target demand, both domestic consumers and producers are beneficiaries. Consumers, including farmer's home consumption, gain 287 billion fcfa, of which 160 billion of this can be attributed to home consumption expenditures by farmers and their families. Producers' returns to land and labor are increased by 68 billion fcfa, resulting in a net welfare gain of 228 billion fcfa when combined with savings in home consumption expenditures. In contrast, foreign surplus declines as cotton exports are reduced by 1.2 billion as the increased food demand reallocates resources towards food production and slightly away

from cotton production.

Total social welfare in Mali is increased by 481 billion fcfa under the 2015 demand growth scenario. These results emphasize the importance of assumptions about demand growth when economic impacts of new technologies are assessed in developing economies where agriculture is a dominant source of gross domestic product and employment.

If new sorghum technology were not introduced, then gains in consumer and producer surplus would be significantly lower. Consumer and producer surplus would only increase by 88 and 52 billion fcfa, respectively. Total social welfare would increase by only 266 billion fcfa, only about 56 percent of what social welfare would be if new technology were introduced.

⁴The model used demand curves with fixed price elasticity. When high prices are encountered, aggregate demand falls appreciably, and quite likely below some consumer's subsistence level. An alternative would be to put a food subsistence constraint in for the urban households as was done for the rural households. See Vitale 2001.

Maize Scenario

The introduction of new maize technology would be much less effective in meeting the 2015 food targets. Although maize demand in the year 2015 would be adequately met, as indicated by the future maize price decline, sorghum and millet prices would increase substantially compared to their prices under the new sorghum technology alternative. Maize prices would fall from 61 to 48 fcfa/kg, but sorghum and millet prices would increase from about 76 fcfa/kg to 136 and 121 kg/ha, respectively. For sorghum and millet, there would be little change from the existing technology case.

While the percent increase in maize production is roughly the same as those for sorghum and millet, the larger production base for sorghum and millet explain why the aggregate benefits from new sorghum and millet technology are greater than maize. For instance, maize production would increase by about 40 percent, but this would correspond to an aggregate increase of only 109 thousand tons. Conversely, for sorghum a 44 percent increase would correspond to a 250 thousand ton increase, and for millet a 30 percent increase would correspond to a 237 thousand ton increase.

This aggregate effect also explains why the total social welfare change for the introduction of new maize technology is substantially lower than for new sorghum technology introduction. Total social welfare would increase by 378 billion fcfa, 20 percent lower than the increase in social welfare that would be generated if new technology were introduced in sorghum.

CONCLUSION

This paper demonstrated using ASM that new sorghum technology introduction has the potential to increase food production to levels sufficiently above those set by the 2015 World Food Summit targets. One clear message is that it will be necessary to improve cereal market infrastructure to jumpstart the process of technology introduction. Under present demand conditions, prices fall faster and advance more quickly than do the reductions in production cost brought forth by new technology. Benefits from intensification accrue only to consumers

and only the very early adopters, and this threatens the process of new technology introduction towards the wider farming population. Thus, finding emerging markets for sorghum and millet will be important to promote the use of technology in the short to medium run.

While this paper presents optimism regarding new technology's potential to meet the 2015 food targets, it also presents an equal amount of pessimism if new technology introduction fails to materialize. Under existing technology, 2015 food targets would only be met with high food prices and the likely need for food aid. Such would be the case if the societies in the WAS were remiss in this intervening time before 2015, and entered the age of increased food demand using traditional technology. By then, continued land clearing of marginal lands is likely to result in significant environmental degradation. Efforts to intensify will be much less effective after the fact, will result in much larger societal costs in the long run, and will jeopardize future food security.

This means that the time to act would need to be now as far as establishing not only improved markets, but also in better developing input supply mechanisms. Although this paper did not focus on inputs, failure to keep production costs low as the process of technology diffusion process accelerates is vital. Kinks in the supply chains will result farmers bidding up input prices that would have similar effects to the fall in cereal prices that were documented in this paper. The new technologies will require that the seed manufacturing industry be ramped up, and assuring that rural vendors will have adequate access to inorganic fertilizer distributors to maintain inventory.

When new technology introduction was limited to maize, the 2015 food targets were only satisfied with high prices. Alternatively, new sorghum technology was found to provide higher societal impacts than new maize technology, and to result in a greater potential to increase food supply. The main advantage to sorghum would be from the larger production area since it is less demanding of soil nutrients and soil moisture. So, while the focus of development has often been on the semi-humid frontier, the drier sorghum and millet areas should not be overlooked when future food production is being considered.

This paper thus suggests that investments in sorghum and millet production should be maintained over the foreseeable future, and that sorghum and millet can be an integral part of strategies to assure that societies in WAS are able to satisfy the 2015 targets. In the sub-humid zones, sorghum and millet can maintain an important role in cotton and maize rotations, and here new varieties can be further refined to take advantage of a longer growing season. In the drier Sahelian areas, new technology gains in sorghum and millet might not be as impressive as with rice or maize, but the vast production areas are able to compensate for the more modest productivity gains.

The next modeling phase of this research will include a more detailed look into resource degradation, and how yields are likely to decline should traditional farm practices be pushed further out onto the frontier. A next generation erosion model, SWAN, will be used to better track the flow of soil carbon matter. This will bring into the analysis the importance of sequestering more carbon into the soils of the WAS, both for greenhouse gas mitigation as well as for more sustainable food production. In addition, the impacts from new technology introduction in sorghum and millet will be compared to those from rice and maize.

REFERENCES

Coulibaly, O.N., 1995. Devaluation, New Technologies, and Agricultural Policies in the Sudanian and Sudano-Guinean Zones of Mali. Ph.D. Thesis, Purdue University, West Lafayette, IN.

Dalton, T.J., 1996. Soil Degradation and Technical Change in Southern Mali. Ph.D. Thesis, Purdue University, West Lafayette, IN.

Famine Early Warning System (FEWS), 1997. Price, production, rainfall, and GIS data posted on the USAID-FEWS website. 1997.

Kergna, A., Yapi, A., Debrah, S., Sidibe, A., and Sanogo, O., 1998. An Analysis of the Economic Impacts of Sorghum and Pearl Millet Research in Mali. ICRISAT/IER Joint Impact Assessment of Agricultural Research.

Matlon, P.J., 1990. Improving Productivity in Sorghum and Pearl Millet in Semi-Arid Africa, *Food Research Institute Studies*, Vol. XXII, No. 1.

McCarl, B. Kline, D. and Spreen, T., 1980. Price Endogenous Mathematical Programming As a Tool for Sector Analysis. *Amer. J. Agr. Econ.* Vol. 62: 88-102.

McMillian, D., Sanders, J., Koenig, D., Akwabi-Ameyaw, K. and Painter, T., 1998. New Lands is Not Enough: Agricultural Performance of New Lands Settlement in West Africa. *World Development*. Vol. 26(2):187-211.

Reardon, T., 1993. Cereals Demand in the Sahel and Potential Impacts of Regional Cereals Protection. *World Development*. Vol. 21(1):17-35.

RSSP, 1998. Recueil des Principales Statistiques du Secteur Rural Malien. Bamako, Mali: Ministry of Rural Development and Water.

Sanders, J.H., Ramaswamy, S. and Shapiro, B.I., 1996. *The Economics of Agricultural Technology in Semi-Arid Sub-Saharan Africa*. Johns Hopkins Press, Baltimore, MD.

Scherr, S. and Yadav, S., 2001. Land Degradation in the Developing World: Issues and Policy Options for 2020. In: *The Unfinished Agenda: Perspectives on Overcoming Hunger, Poverty, and Environmental Degradation*. IFPRI, Washington, D.C.

Vitale, J.D., 2001. The Economic Impacts of New Sorghum and Millet Technologies in Mali. Ph.D. Thesis, Purdue University, West Lafayette, IN.