The Economics of Stress and Technology Development in the Sahel and the "Cerrados" of Brazil[1]

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ABSTRACT

After the successes of the Green Revolution in the better agroecological environments, increasing agricultural production in less favorable environments is the next logical objective. Many plant breeders have become involved in searching for abiotic stress tolerances. However, most crop systems in these environments will require higher chemical inputs, and in semi-arid regions, better water retention to attain sustainable yield increases even with the development of tolerance to toxic levels of aluminum saturation or to drought. Plant breeding will need to complement these agronomic improvements, and research planning needs to anticipate moderate increases in input levels by farmers.

Programs to introduce new crop technologies in two semi-arid zones in the Sahel and in the acidic soils of the Brazilian "cerrados" are reviewed. In two Sahelian regions, there was little agronomic improvement and a failure to achieve yield increases. In the higher-rainfall, acidic soils of the Brazilian "cerrados," rapid progress has been made with the combination of agronomic and breeding innovations. Some implications are drawn for the Sahel and for other regions of acidic soils, such as the "llanos."

INTRODUCTION

During the last two decades, plant breeders have been remarkably successful in overcoming biotic stresses by incorporating resistances to diseases, insects, and plant parasites into new cultivars. More recently, emphasis on breeding for tolerance to abiotic stresses, such as drought and nutrient deficiencies (or toxicities, such as aluminum), has increased. Agronomists, after observing the low use of purchased inputs by most farmers in developing countries and after viewing the riskiness of agriculture plagued by abiotic stresses, have been searching for low-cost chemical fertilizer substitutes.

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[1] "Cerrados" is a Portuguese term for a vegetation type associated with acidic savannas in Brazil; it refers to much of the Central Plateau of Brazil. We are grateful for the critical comments and suggestions of James Ahlrichs, Charles Rhykerd, and David Sammons.

New technology research has important economic elements. Technologies have to function in the farmers' environment and to be profitable. Moreover, agricultural development is a systems problem. Changing one element of the system will often affect and be affected by several other elements. Hence, technology introduction and research planning need to be concerned with the interactions in the agricultural system.

WHICH STRESSES?

The principal and obvious stress problem of semi-arid regions is apparent from their description: the lack of water. Total quantities are low and irregular. Moreover, in the lower-rainfall regions, variability is higher. Approximately 36% of the soils of the tropics have low fertility, but this problem is much less important in the semi-arid tropics with only 16% having this initial problem (Table 1; Sanchez and Logan, 1992, pp. 37, 38). Almost two-thirds of the tropical soils do not have soil-fertility problems, with the semi-arid soils having substantially more potential than other tropical soils when there is water. Unfortunately, this measurement of nutrient deficiencies does not include nitrogen. The primary production problem in semi-arid soils is having sufficient water at the critical periods of plant growth. However, when there are both deficiencies of water and soil fertility, then low water availability makes the use of soil-fertility amendments risky.

Clearly, in the sub-humid tropics of the Brazilian "cerrados," the dominant problems are Al toxicity and P-fixation associated with acidic soils (Table 1). But also in the sub-humid tropics, a lack of soil nutrients occurs on 55% of the area (Sanchez and Logan, 1992, p. 35). Surprisingly, problems associated with acidity affect a larger land area in the semi-arid zone than do soil-fertility problems. In Africa, nutrient deficiencies head the list of production problems and are found on 20% of the arable land (Sanchez and Logan, 1992, p. 41).

Even where soil fertility is not initially constraining, the introduction of increased available water and higher plant densities mines the available nutrients. Hence, soil fertility quickly becomes constrained and soil nutrient amendments are warranted. Moreover, increasing man/land pressure in many regions has been breaking down the traditional fallow-system method of managing land fertility. When soil fertility declines without replacement, soil degradation and crop movement into marginal soil areas occurs (Broekhuyse and Allen, 1988; Ramaswamy and Sanders, 1992). In much of semi-arid Sub-Saharan Africa, both limited available water and deficient soil nutrients are the major constraints; these interrelated problems will be considered in the next three sections for the predominant agro-climatic zones involving crops for semi-arid West Africa, the Sudanian and Sahelo-Sudanian zones.

The Brazilian acidity/excess-aluminum case will also be considered. Table 2 summarizes the soil stress factors in the three regions and the alternative approaches to respond to these problems: (a) higher levels of input, and (b) selecting for tolerances and developing improved cultivars.

Table 1. Main chemical soil constraints in two principal agroecological regions of the tropics.

	Semiarid tropics		Subhumid tropics (acid savannas)	
	Million ha	%	Million ha	%
Low-nutrient reserves[a]	166	16	287	55
Aluminum toxicity[b]	132	13	261	50
Acidity with Al toxicity[c]	298	29	264	50
High P fixation by Fe oxides[d]	94	9	166	32
Low CEC[e]	63	6	19	4
Total area	1,012[f]		525[f]	

[a]Less than "10% weatherable minerals in the sand-and-silt fraction. This constraint identifies highly weathered soils with limited capacity to suppy P, K, C, Mg, and S" (Sanchez, 1992, p.37).
[b]More than 60% Al saturation in the top 50 cm.
[c]Surface Ph of less than 5.5 but less than 60% Al saturation.
[d]Iron oxide/clay ratios greater than 0.2
[e]Less than 4 emol$_c$/kg of effective cation exchange capacity.
[f] Does not sum as several minor categories of problems were omitted and there are overlaps with some soils having more than one of the chemical problems.

Source: Sanchez and Logan, 1992, p. 38.

Table 2. Stress factors considered, sites, and alternative approaches.

			Alternative strategies	
Region	Country	Stress factors	Breeding	Agronomy
Sudanian Zone	Burkina Faso	Water availability Soil fertility	Drought tolerance	Water-retention techniques Ferilizers Series of other practices and techniques[a]
Sahelo-Sudanian Zone	Niger	Water availability Soil Fertility	[Same as above]	[Same as above]
"Cerrados"	Brazil	Soil acidity Al saturation Fixation of P	Tolerance to Al	Lime Fertilization

[a]See Nagy et al., 1988.

AGRICULTURAL TECHNOLOGY DEVELOPMENT IN THE SAHEL

Since the prolonged Sahelian drought of 1968-1973, substantial resources have been invested in developing new agricultural technologies in both national and international agricultural research systems. These research-development programs were evolved from the "Green Revolution" successes in South Asia during the late 1960s and early 1970s. Unfortunately, until recently Sahelian agriculture had stagnated or declined (Sanders et al., 1993). Finally, in the 1990s, technology development has impacted maize and cowpeas production, but not sorghum and millet. The introduction of new maize and cowpea technologies has been most successful in the transitional zone to the semi-humid, Sudano-Guinean region. However, large-scale diffusion of maize and cowpeas new cultivars into the semi-arid zones has occurred (Sanders, 1993, pp. 6-14). In contrast with the Sudano-Guinean zone where new cultivars of cotton and maize have been associated with increasing levels of chemical fertilizer, little increase in fertilizer use has been documented in the drier Sudanian and Sahel-Sudanian zones. Nevertheless, the primary lesson of these differential success rates so far is that for new cultivars to be successfully introduced and to have a large impact on subsequent yields, they have to be combined with chemical inputs, especially fertilizers.[2]

In semi-arid developing countries, minimal chemical-input levels are used for food crops because farmers are unable to take high levels of risk. Soil improvements, especially those that require cash purchases, increase farmers' risk everywhere, especially in regions of irregular water availability. Moreover, governments in developing countries often have foreign-exchange shortages, and imported chemicals receive low priority. Governments instead promote the use of local rock phosphate, manure, cereal/legume rotations, and other "substitutes" for commercially processed fertilizer.

Observing these conditions, research organizations often attempt the development of new cultivars, which would not require farmers to purchase increased inputs or governments to spend foreign exchange. Breeding solutions receive emphasis for addressing all constraints. Drought and aluminum tolerance have been added to the disease and insect problems that breeders address.

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[2] These should not be surprising results. U.S. sorghum yields increased from 1.2 m.t./ha in 1950 to 3.8 m.t./ha in 1980, an impressive growth performance. It was estimated that 34 to 39% of the yield increase came from genetic improvements. Hence, two-thirds of the yield increases resulted from other agronomical improvements including higher chemical inputs and improved water use (Miller and Kebede, 1984, pp. 6, 11).

Similarly, agronomic research has resulted in better manure-handling methods, improved use of crop residue, local rock phosphates, intercropping, and nitrogen fixation. Research and development programs have promoted variations of these concepts since the early 1970s in the Sahel. Unfortunately, practices based on these concepts have not spread, either because they do not work on farmers' fields or they are not profitable (Nagy et al., 1988; Sanders, 1989). After nearly two decades of experimentation and promotion of low-input alternatives, it is time to recognize that at extremely low input levels, there probably are no substitutes for chemical fertilizer.

The development of successful agricultural systems has always been associated with purchased inputs. Other "substitute" activities for fertilizer requiring high labor or management inputs, such as residue incorporation, different rotations, and more manure, were never cheap solutions. Rather, the cost calculations[3] failed to put monetary values on farmers' time or on farmers' learning costs to manage sophisticated production practices. Low-cost alternatives need to be differentiated from alternatives in which the cost accounting is incomplete. These alternatives need to be considered as complements rather than substitutes for chemical fertilizers (Sanders, 1989).

Moreover, an overreliance on breeding solutions to overcome all these constraints does not seem to be appropriate. Tolerance to adverse soil conditions and to drought can be usefully incorporated into improved cultivars. Unfortunately, for breeders, tolerance to stress is often associated with low yields. Moreover, present agricultural development programs should not wait for the development of these new cultivars when there are known agronomic techniques currently available to increase yields. The next two sections consider the introduction of new crop technologies into the two principal agro-ecological zones of semi-arid West Africa.

STRESS AND NEW TECHNOLOGIES FOR THE SUDANIAN REGION OF BURKINA FASO

At the 90% probability level, rainfall is between the 600 to 800 mm levels for this zone (Fig. 1). In the recent extended drought period, 1968 to the present, rainfall has been 100 — 150 mm below these levels.[4] Soils in the Sudanian region are low in principal nutrients and frequently subject to

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[3] On the benefit side, the multi-year or residual effects of chemical P, lime, and the rock phosphate make the economic analysis more complicated. However, more comprehensive analysis over time has further documented the advantages of chemical P over rock phosphate (Jomini, 1990).

[4] The standard isohyets are based on rainfall data collected from the '30s to 1960.

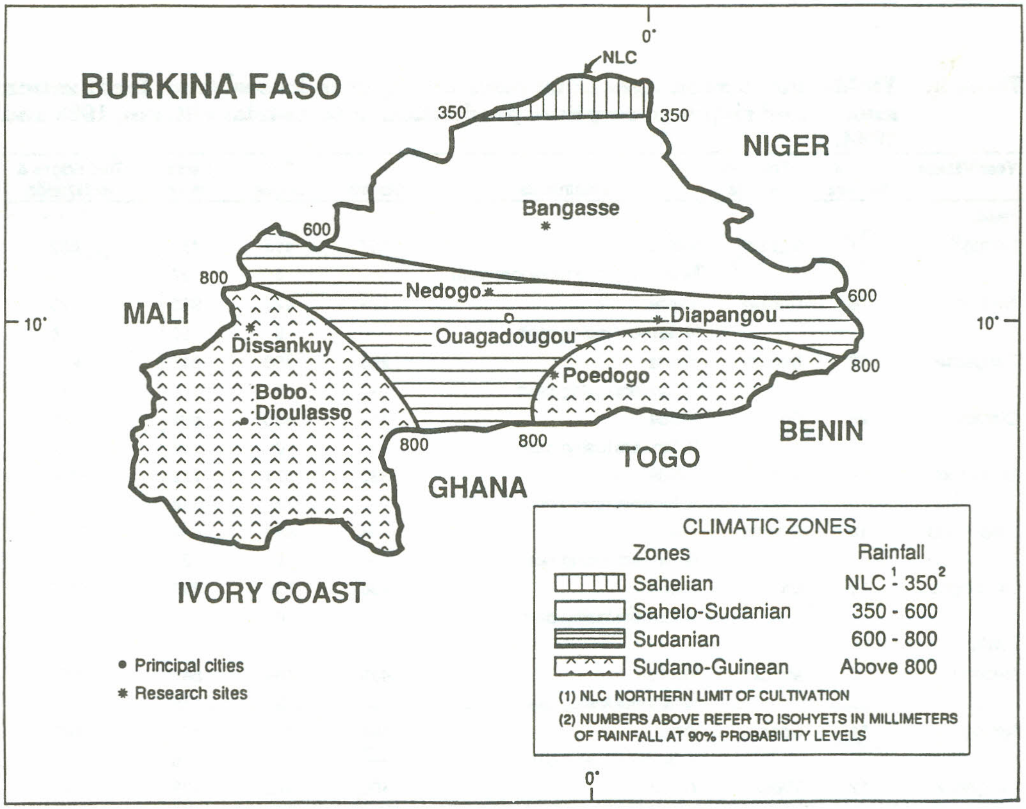

Fig. 1. Climatic zones of Burkina Faso, research sites, and principal cities.

crusting (Matlon, 1987, 1990). Crusting results in high runoff rates, further aggravating the water-availability problem.

Farm-level experiments have demonstrated the impacts on sorghum yields from agronomic techniques to overcome the two principal constraints of water availability and soil fertility. Individually, one water-retention device (tied ridging) and moderate chemical fertilization substantially increased yields. Moreover, the combination of the two inputs not only further increased yields but also reduced the riskiness of the fertilization (Table 3). Thus, agronomic techniques exist that function at the farm level and can substantially increase sorghum yields. Developmental strategies need to take advantage of agronomic practices already available to the Sahel. A similar technology has made a large impact on sorghum yields in the Texas high plains where tied ridges are known as furrow dikes (Krishna et al., 1987).

One basic requirement for new technology introduction is that agriculture be profitable. This is illustrated with farm-programming results from the impact of changing relative prices on the farm-level use of tied ridges and

Table 3. Yields and percentages of farmers taking cash losses* from fertilization and/or tied ridges in sorghum production in farm-trial villages, 1983 and 1984.

Year/Village	No. of farmers	Traction Source	Treatments	Control	Tied ridges	Fertilization	Tied ridges & fertilization
1984:							
Nedogo	11	Manual	Yields	157	416	431	652
			% farmers who have lost cash	—	0	27	9
Nedogo	18	Donkey	Yields	173	425	355	733
			% farmers losing cash	—	0	50	0
Bangasse	12	Manual	Yields	293	456	616	944
			% farmers losing cash	—	0	8	17
Dissankuy	25	Ox	Yields	447	588	681	855
			% farmers losing cash	—	0	28	0
Diapangou	19	Manual	Yields	335	571	729	1006
			% farmers losing cash	—	0	26	0
Diapangou	19	Donkey	Yields	498	688	849	1133
			% farmers losing cash	—	0	21	0
Diapangou	19	Ox	Yields	466	704	839	1177
			% farmers losing cash	—	0	5	0
1983:							
Nedogo	3	Manual	Yields	430	484	547	851
			% farmers losing cash	—	0	56	0
Nedogo	11	Donkey	Yields	444	644	604	962
			% farmers losing cash	—	0	58	42
Bangasse	12	Manual	Yields	406	493	705	690
			% farmers losing cash	—	0	21	17
Diapangou	24	Manual	Yields	363	441	719	753
			% farmers losing cash	—	0	8	8
Diapangou	25	Donkey	Yields	481	552	837	871
			% farmers losing cash	—	0	12	16
Diapangou	25	Ox	Yields	526	578	857	991
			% farmers losing cash	—	0	20	12

*Cash expenditures were only for chemical fertilizer. The only additional input for tied ridges was a substantial increase in the use of family labor. Note also that expenditures were paid by the project so that farmers did not actually lose these expenditures on chemical fertilizer.

Source: Sanders et al., 1990, p. 10.

fertilization (Fig. 2). These model results are also consistent with the farm-level shifts to more intensive technologies presently being observed in the Sahel (Vierich and Stoop, 1990).

These two principal sources of stress, inadequate water and low soil fertility, can be resolved with agronomic improvements. The combined technologies are profitable and reduce risk. Making agriculture more profitable would accelerate the adoption process as would increasing man/land pressure (Ramaswamy and Sanders, 1992). Once these higher levels of water and soil nutrients are introduced into the system, the potential for breeding

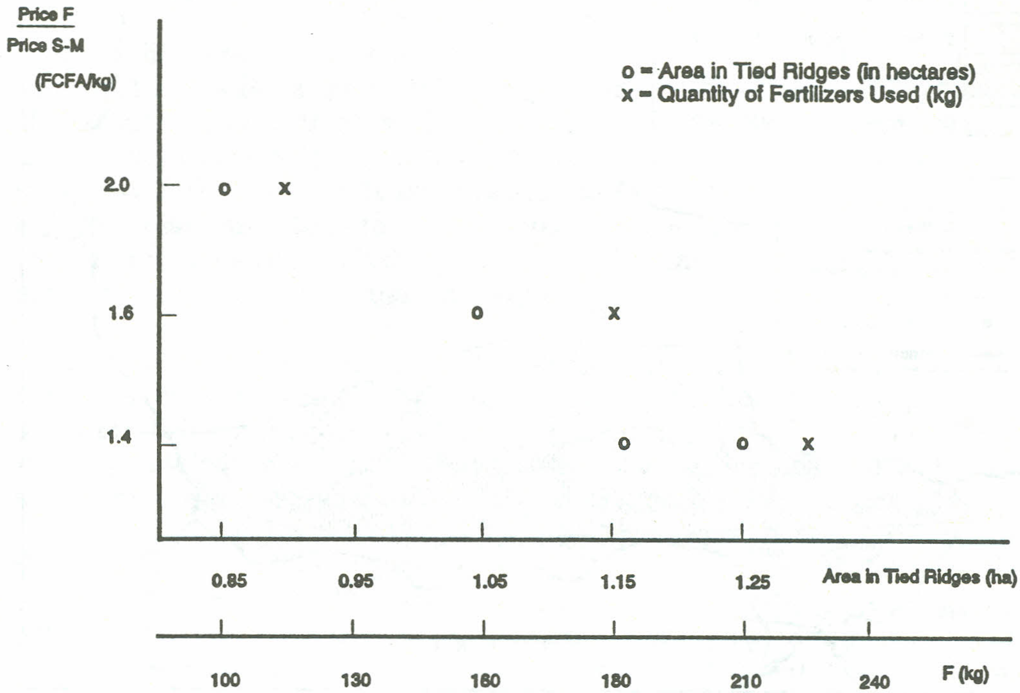

Fig. 2. Effects of improved economic environment on use of intensive technologies.

Note: The weighted price of fertilizer (Price F) is constant, with Urea at $0.26/kg and compound fertilizer at $0.36/kg (1988 prices) The average price of sorghum/millet (Price S-M) was $0.16/kg and increased to $0.20/kg and $0.24/kg, respectively. The prices of other crops were increased proportionally. Tied ridges and fertilizers were used as complementary inputs on the higher-quality sorghum land. On the compound area (or maize land) only tied ridges were used. Animal traction was used to make the ridges. The exchange rate in 1990 was 273 FCFA/US$.

improvements is substantially increased. Moreover, the search for low-cost supplementary techniques to improve soil fertility in addition to chemical fertilizer will also become more feasible. It is important to distinguish between present development with available technologies and future research.

STRESS AND NEW TECHNOLOGIES IN THE SAHELO-SUDANIAN ZONE OF NIGER

Most of the agricultural production and population in Niger is in the lower-rainfall region (350 to 600 mm of rainfall at 90% probability) (Fig. 3).

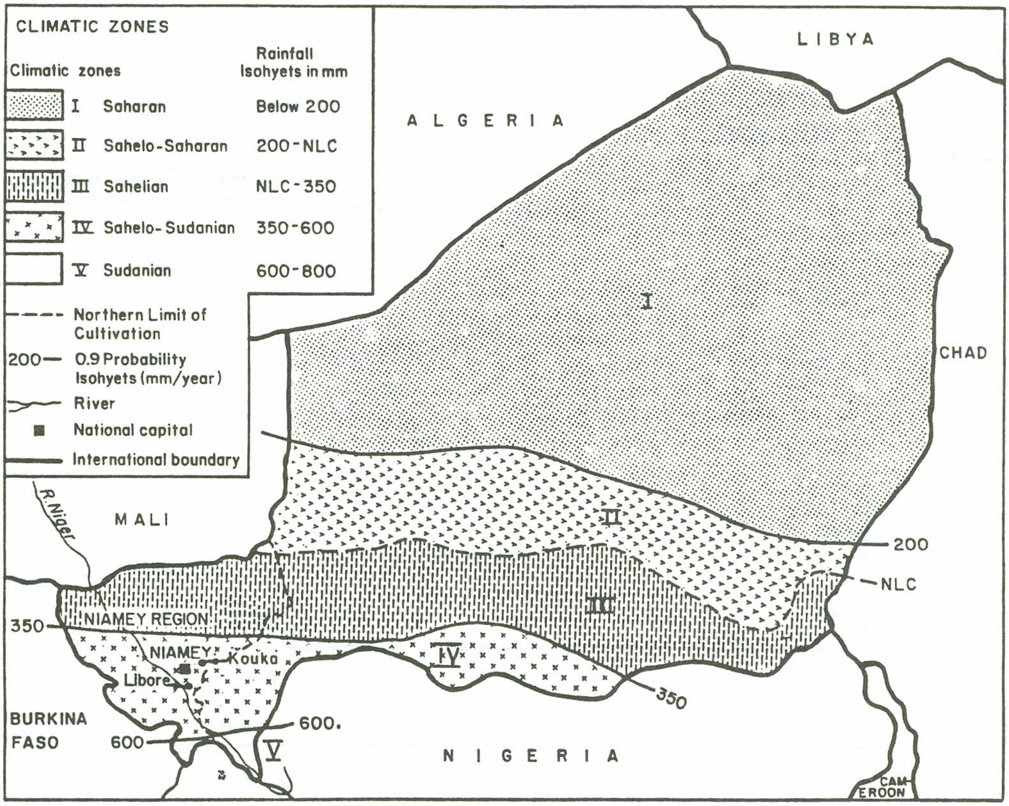

Fig. 3. Location of the Niamey Department in Niger, West Africa showing the agroclimatic zones based on the 90% probability rainfall (mm) isohyets.

Source: Adapted from Gorse, J.E. and Steeds, D.R. 1987.

Sandy-dune soils have low initial fertility. As in the Sudanian zone, the two principal constraints are water availability and soil fertility. Crusting of the sandier soils is often not a problem, but rapid infiltration of the rainfall below the plant roots frequently occurs. Fertilization and higher densities have been shown to increase water-use efficiency in these sandy-dune soils evidently by retaining more water, making it available to the plants (ICRISAT, 1987, 1988).

There has been substantial introduction of early maturity millet and cowpea cultivars in these agricultural systems but minimal introduction of chemical fertilizer. Without soil amendments, the higher-density agronomic systems with new cultivars are not sustainable. They will mine the meager soil-nutrient supply, which then forces farmers to move into other regions. As population increases, this migration becomes increasingly difficult. Hence, potential changes in policy and technology development were made to determine what could be done to influence farmers to use chemical fertilizer in two different regions of the Sahelo-Sudanian zone (Shapiro, 1990; Shapiro et al., 1993).

In the higher-rainfall zone (mean rainfall of 570 mm), either an input subsidy, the modificiation of fertilizer recommendations, or the introduction of a late maturity cultivar would all lead to fertilizer adoption, according to model results (Table 4). The model results above are also consistent with the fairly rapid diffusion of P fertilization on millet among farmers in one Sahelo-Sudanian village-testing site used by IFDC and ICRISAT (Mokwunye and Hammond, 1992, pp. 131, 132). Ultimately, these farmers will have to apply the other major nutrients.

Millet and cowpea cultivar technology development over the last decade have been oriented to short-cycle cultivars as rainfall has been one standard deviation below the long-term normal since the 1968-1973 drought. However, climatologists point out that Sub-Saharan Africa has had long-term weather cycles before, so that this low-rainfall period may only be a temporary phenomenon (Dennet et al., 1985; also see various Nicholson references they cite). The breeding emphasis on short-cycle cultivars can impede the use of higher-input levels (water retention and fertilizer) as these cultivars will not have sufficient time to take advantage of higher-input use in better and even normal rainfall years. Moreover, short-season cultivar yields can also be reduced by exposure to insect attacks, such as the headgirdler ("*raghuva*") in Niger, Senegal, and the Gambia, or be adversely affected by disease/insect complexes aggravated by late rainfall. Hence, introducing improved late maturity cultivars would encourage fertilizer use and enable farmers to continue their portfolio strategy of producing a mixture of cultivars to reduce climatic risk.

Table 4. Effects of various policy instruments on adoption of fertilizer in Libore, Niamey Region, Niger.

Policy or Program	Fertilizer use (ha)	Millet/Cowpea Income (US$)	Total Seasonal Income (US$)	Change in Crop Income (%)	Change in Total Income (%)	C.V. of total income
Current practices	N/A	446	812	—	—	.40
Improved short-season cultivars		578	921	+30	+13	.39
Input subsidy (10%)	1.2	602	922	+35	+14	.41
Credit program (10,000 FCFA at 0% interest)	0	576	942	+29	+16	.39
Phosphorus only	2.1	628	948	+41	+17	.44
Long-cycle millet variety	1.5	624	944	+40	+16	.42

Exchange rate: 298 FCFA/US$.
Source: Shapiro, 1990, p. 98

Table 5. Effects of various policy instruments on the adoption of fertilizer in Kouka, Niamey Region, Niger.

Policy or Program	Fertilizer use (ha)	Millet/Cowpea Income (US$)	Livestock Income (US$)	Total Income (US$)	Change in crop income %	Change in total income %	C.V. of total income
Current practices	N/A	301	186	503	—	—	.63
Improved cultivars	0	409	177	601	+36	+20	.50
Price support (50 FCFA)	0	430	177	622	+43	+24	.57
Credit program (10,000 FCFA at 0% interest)	0	409	197	621	+36	+23	.50
Input subsidy (50%)	0	409	230	653	+36	+30	.54
Adaptive livestock choices	0	409	230	653	+36	+30	.54

Exchange rate: 299 FCFA/US$.

Source: Shapiro, 1990, p. 127.

In the lower-rainfall region (mean rainfall of 430 mm), none of the above policy and technology changes resulted in fertilizer being adopted, according to model results (Table 5). Thus, there are some regions in the Sahelo-Sudanian zone where it will continue to be very difficult to introduce higher-purchased input levels and without fertilization, these improved systems will not be sustainable. Hence, for these regions, alternative strategies, such as agro-forestry and increased livestock production, appear to be more appropriate technology-development strategies. Crop-technology development is not an efficient instrument for increasing farmer incomes in all regions, especially those regions with very low availability of initial resources. There will be some difficult population adjustments, as in Niger where substantial settlement in these more adverse regions of the Sahelo-Sudanian zone has occurred. Nevertheless, difficult decisions about research resource allocation will often have to be made since there funds and researchers are finite. The Sahelo-Sudanian zone is not all unproductive sands but the regions for increasing crop productivity must be carefully selected and fertilization practices must be used to overcome low-fertility problems and rapid infiltration of rainfall.

AGRICULTURAL DEVELOPMENT IN THE "CERRADOS"

The savanna or sub-humid region of Brazil is an enormous area of 180 million ha of which about 5.4 of the 50 million with crop-production potential were being cultivated by the early 1980s (Goedert, 1983; pp. 405, 406; Fig. 4). Rainfall is generally sufficient, with mean rainfall of 1,000 to 1,800 mm and a dry season of three to five months. Nevertheless, drought periods can

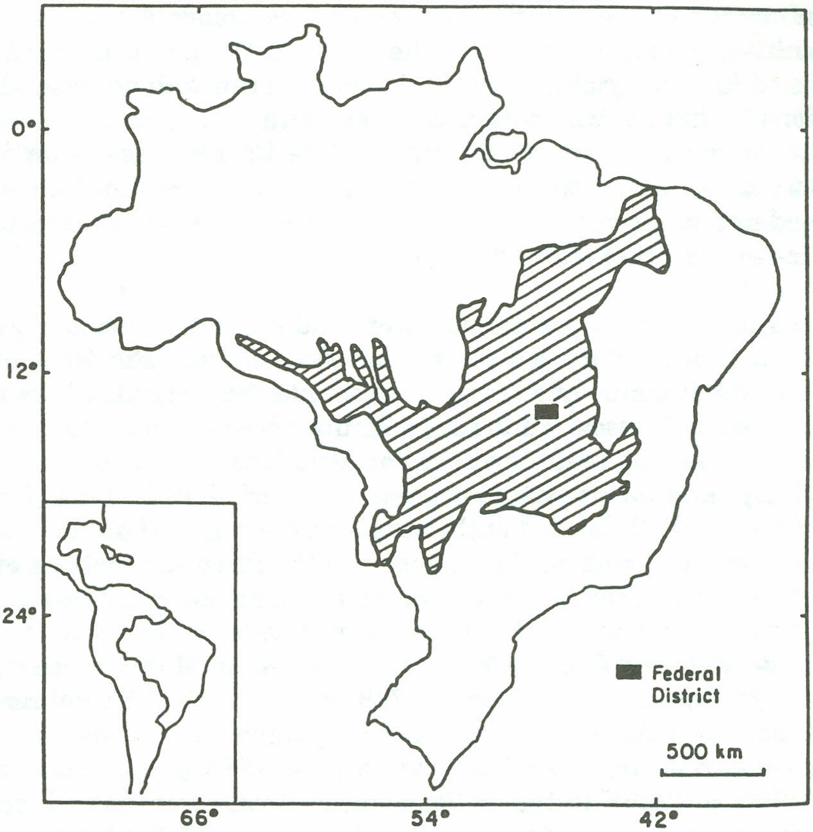

Fig. 4. Distribution of Cerrado (shaded area) in Brazil. Inset of South America shows Brazil.

Source Goedert, 1983, p. 406.

be a problem due to irregular rainfall, low soil-water retention, and acidic soil conditions leading to poor root growth and fixation of P (Goedert, 1983, p. 407). The Al saturation of the cation-exchange capacity is generally above 50%, considered toxic for most plants. On the positive side, the soils are deep and well-drained with gentle slopes and good micro-aggregate stability; hence, there are many factors favoring intensive mechanization (Goedert, 1983, pp. 408, 409).

Little settlement occurred in this region of Brazil before movement of the capital to Brasilia in the late 1950s. Since then there have been two principal waves of settlement. The first is associated with the expanded area in pastures. Large farmers contracted sharecroppers to clear the savanna brush and to establish pastures, frequently *Brachiaria* (Goedert, 1983, p. 40). For one to two years until pastures were established, the sharecroppers could cultivate upland rice. Both the rice and the pastures used minimal inputs and had low yields. Both had some tolerance to adverse aluminum conditions.[5] This system was associated with the opening up of outside markets in southern Brazil for rice and cattle resulting from improved transportation. This settlement pattern in the "cerrados" substantially increased national rice production, enabling Brazilian consumers to include more rice in their diets (Mandell, 1971).

The main success story of intensive or yield-increasing technology was the adaptation of a mechanized production system from Rio Grande do Sul, Parana, and São Paulo of wheat/soybeans into the "cerrados." For example, in the two Mato Grossos, while rice, peanuts, cassava, and cotton production all declined, the crop area in wheat and soybeans increased at 22 and 19%, respectively, annual growth rates over the period 1977-1984 (Homem de Melo, 1985, p. 84). This shift of the southern mechanized production system into the "cerrados" enabled the extension of the Brazilian soybean explosion. During the 1970s, Brazilian soybean production grew at a 22% annual rate, slowing down from the 35% annual growth rate of the 1967-1976 period (Homem de Melo, 1985, p. 83; Vieira et al., 1988). In Mato Grosso do Sul, the area in soybeans increased from 15,288 ha in 1970 to 1.83 million in 1983 (Bonato and Dall' Agnol, 1985, p. 1251.) A number of new soybean cultivars were developed in the 1960s (Homem de Melo, 1985, p. 80; Bonato and Dall' Agnol, 1985, p. 1255). In the 1970s, some cultivars were introduced, which had been adapted to the "cerrados" region, such as UFV-1 and in the late 1970s some EMBRAPA cultivars. Soybeans are very sensitive to high Al saturation; hence, the transfer of this system was successful only with substantial increases in the application of lime and phosphorus and the adaptation of soybean cultivars to these conditions (Bonato and Dall' Agnol, pp. 1251, 1255).

From the beginning, wheat was much less successful than soybeans in adapting to the region. The growth rates in wheat acreage reflected a very low initial base. Wheat production has gradually declined in the region after this boom period, especially in the 1990s with the elimination of government subsidies.

Adaptive research on maize has allowed the introduction of maize in rotation with soybeans. Initially, maize was introduced mainly in the more fertile areas of the Central West region, outside of the "cerrados." Substan-

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[5] Also, the standard burning before planting the rice would tend to reduce soil acidity, thereby lessening the aluminum problem.

tial maize breeding activity took place as well as introduction of higher levels of lime and chemical fertilizers. In Goias, maize yields doubled from the early 1970s (1.5 m.t./ha) to 1991 (3.1 m.t./ha) (FIBGE, various years). Recently, a new maize cultivar (BR-210), more adapted to Al toxicity and more efficient in phosphorus use, was released and has had a rapid diffusion. The first seeds of BR-201 were sold in 1988. In 1991, 20% of the maize seed sold in Goias and 18% in Mato Grosso do Sul were of this new cultivar (SPSB/EMBRAPA, 1992). In 1992, 13.8% of the maize seed sold in Brazil was of this cultivar. This also demonstrates its adaptation to better soils. BR-201 and other new cultivars to be released soon show not only a good performance in acid soils but also a good development in soils with better characteristics (Magnavaca and Bahia, 1993). This allows these improved maize cultivars to be sown in the corrected acid soils in a way that makes this correction economically possible. One of the difficulties of the correction of acid soils is that this correction is more effective in the superficial portion. The toxicity problems remain in the deeper portions. Cultivars more tolerant to Al toxicity make possible the exploration of this deeper portion by the roots (mainly to extract water) but the plants need to be more efficient to use the fertilizer placed in the arable portion and transform it into production.

Some private companies attempted unsuccessfully to introduce sorghum without soil improvements. Sorghum's drought tolerance did not help with the Al toxicity problem and this program was a failure. In contrast, sorghum later was introduced as a catch crop following soybeans, taking advantage of the improved soil fertility and reduced Al saturation. Following these two developments in the Goias "cerrados," the sorghum area increased to 15,000 ha in 1977, fell to 135 ha in 1981, and then increased to 12,360 ha in 1988 (FIBGE, various years).

The principal research promoting rapid crop expansion in the region has been the applied work on neutralizing aluminum and increasing P availability. Moreover, lime was available in the region. The Brazilians recognized that their rock phosphate dissolved very slowly over several years; hence, they used superphosphate on crops and left the rock phosphate for pasture improvement. The Brazilian government also provided input subsidies on fertilizer, lime, and bank interest on machinery purchases. The consequences were very rapid introduction of soybeans with higher purchased-input use, and later maize.

Soybeans and maize were impressive success stories in which breeding played an important role. Soil research and substantial increases of purchased inputs appeared to be critical factors in these successes (Table 6). The Brazilian case demonstrated that with research applied principally on

Table 6. Research programs, institutions and release of technologies for the "Cerrado."

Programs	Beginning	Institutions[a]	First release[b]
Research on "cerrado" soils	Mid-'50s	IAC	Beginning of '70s[c]
		IBEC-IRI	
		IPEACO	
Soybean breeding for "cerrado"	Mid-'60s	UFV	Early '70s[c]
		IAC	
Maize breeding for "cerrado"	End of '70s	CNPMS/EMBRAPA	1987

[a]IAC: Instituto Agronomico de Campinas - Campinas/SP.
IBEC-IRI: International Research Institute - Matao/SP.
IPEACO: Instituto de Pesquisa Agropecuaria de Centro Oeste-Sete Lagoas/MG, with a network of agricultural experiment stations in the "cerrado".
UFV: Universidade Federal de Vicosa - Vicosa/MG.
CNPMS/EMBRAPA: Centro Nacional de Pesquisa de Milho e Sorgo/Empresa Nacional de Pesquisa Agropecuaria - Sete Lagoas/MG.

[b]Approximate

[c]This release was followed by a large-scale government program to subsidize inputs, especially fertilizer and lime and interest on machinery.

soils, many interrelated problems of acid soils could be resolved. Infrastructure investment was important in the initial extensive settlement before the research systems were able to adapt and apply various technological alternatives to the "cerrados" soil problems.

The strategies for rice/pasture research have been very different from those for soybeans and maize. For the former activities, extensive breeding of cultivars for tolerance to adverse soil conditions has occurred with some success. One problem with this strategy is that crop and cultivar selections for adverse soil stress conditions frequently result in cultivars with less ability to respond to higher-input levels. If higher-input levels become feasible economically, not only will the tolerance to adverse conditions be less important but also there will be many other alternative crops and cultivars with a much steeper response curve to these higher inputs (Fig. 5). New soybean and maize cultivars could be rapidly introduced since lime and fertilizer use became profitable activities and the responsiveness of the new cultivars to these inputs increased. The government performed an active role in promoting new cropping systems and higher purchased-input levels.

RESEARCH POLICY IMPLICATIONS

In general, the semi-arid region of the Sahel has not been successful in introducing higher input levels. Since the drought of 1968-1973, researchers in national and international institutions have concentrated on breeding solutions and searched for substitutes for imported fertilizers.

In the Brazilian "cerrados," an initial period of low input, extensive rice/pasture systems occurred. Then with a strong applied research base in soils and dispersion of some adapted cultivars, new production systems were introduced. Lime and fertilizers were needed at moderate levels[6] for these systems to be introduced. There was substantial public investment in research and roads infrastructure. Moreover, the government subsidized farmers' input costs and soybean exports.

The Brazilian "cerrados" case may also be instructive for the Colombian "llanos." Before the investments in transportation, Central West Brazilian agriculture was mainly in cattle production. In these extensive settlements,

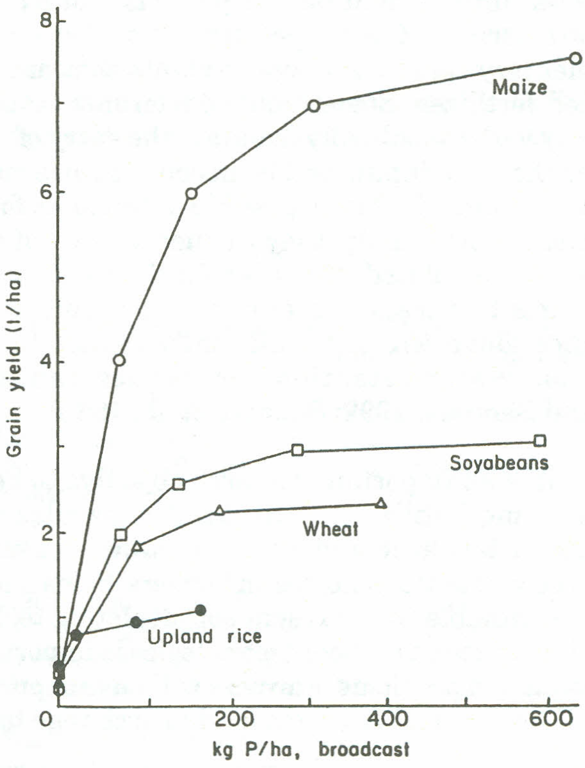

Fig. 5. Typical crop responses to phosphate fertilizer on virgin cerrado clay soils (Goedert, 1983, p. 414).

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[6] Two to three tons of lime per ha every three years and 40 to 60 kg per ha of P_2O_5 annually were typical levels adopted by farmers. Earlier extension recommendations were often higher for both. One important advantage of the "cerrados" was the proximity to large lime deposits.

cattle just graze natural and later improved pastures. The cattle require minimal inputs and are a high-value product so long-distance, expensive transportation can be paid for or the cattle can be walked out in an even earlier stage of infrastructure development. With the roads came the expansion of the upland-rice industry. Lime deposits were found in the Central West and adaptive research had been undertaken on soils and later on plants. Both the crop and the lime are lower-value products and inputs as compared with cattle and superphosphate; hence, the reduction in transportation costs was a critical component of the Brazilian success story and unless these costs are similarly reduced in the "llanos," new cultivars alone will have little effect. If transportation is poor or lime has to be transported from outside the region, then new crop activities may not be profitable even with the existence of new acid-tolerant cultivars.

Semi-arid, Sub-Saharan Africa will not be able to increase crop yields without substantial imports and farmer purchases of fertilizers. Chemical inputs are a characteristic of developed agricultural systems. Breeding can have a complementary role in developing plants that are more efficient in using the applied fertilizer. Some drought tolerance or some tolerance to aluminum toxicity will undoubtedly facilitate the entry of new technologies. However, higher chemical inputs will be needed to raise yields and to make the new systems sustainable. Many possible substitutes for chemical fertilizer are available. Unfortunately, they frequently are not economical when all costs are correctly calculated. Moreover, for the crusting soils of the Sahel, agronomic measures to increase water retention should also be introduced. Drought tolerance alone will not sufficiently reduce the risks of higher chemical inputs. Water-retention techniques can accomplish this (Ramaswamy and Sanders, 1992; Sanders et al., 1993).

For the Sahel, it is an important research objective to keep searching for cultivar tolerances and fertilizer substitutes. Meanwhile for some regions of the Sahel, chemical fertilizer and water-retention techniques have been demonstrated to be viable technologies on farmers' fields and to be profitable. They are more sustainable than present soil-depleting techniques. Further adaptation and introduction of these technologies is important to resolve the present crop-production problems. Farmers will have to purchase inputs and governments will have to utilize scarce foreign exchange to import chemical fertilizers.

Research in acid soils has already made lower levels of input use possible. Lime can be applied, with its primary purpose to neutralize aluminum and to supply calcium and magnesium rather than to increase pH (Sanchez and Salinas, 1981, pp. 335, 353). Fertilizer banding, pelleting of seeds with chemicals, and other application methods all seek to reduce input requirements. The use of inputs and the choice of crops will be substantially affected by economic factors (Helyar, 1991, pp. 370, 371). Nevertheless, policies to reduce input expenditures or to make their use more efficient are very different from attempting to eliminate inputs, especially when the actual levels of such inputs are minimal as in much of Sub-Saharan Africa.

In responding to stress, the first research requirement is to identify the relevant stress. This is no easy task because some assumptions have to be made about future input use. Breeder selection of new materials has often been done at high-input levels. Even for stress selection, other inputs besides the particular stress factor were often kept at high levels so that differences between cultivars could be more easily identified. In contrast, farming-systems proponents and others have frequently argued that selection should occur at the same low input levels used by farmers. The results here appear to indicate that in planning for the five to ten year research agenda, breeders need to collaborate with soil scientists and to assume that moderate increases in purchased-input levels and water availability for semi-arid regions will continue to occur. Governments will need to facilitate this process by insuring that agriculture remains a profitable activity.

REFERENCES

Bonato, E.R. and A. Dall' Agnol. 1985. Soybean in Brazil-Production and Research p 1248-1256. In Shibles, Richard (Ed.) World Soybean Research Conference III: Proceedings. Westview Press, Boulder, CO.

Broekhuyse, J.Th. and Andrea M. Allen. 1988. Farming Systems Research on the Northern Mossi Plateau. Human Organization 47(4):330-342.

Dennett, M.D., J. Elston and J.A. Rodgers. 1985. A Reappraisal of Rainfall Trends in the Sahel. J. of Climatology 5:353-361.

FIBGE (Fundacão Instituto Brasileiro de Geografia e Estatistica). Various years. Anuairo Estatistico do Brasil, Brazilian Foundation of Geography Statistics, Rio de Janeiro, RJ, Brazil.

Glantz, Michael H. 1987. Drought and Economic Development in Sub-Saharan Africa. In Glantz, Michael (Ed.) Drought and Hunger in Africa: Denying Famine a Future. Cambridge University Press, New York, NY, Pp 37-82.

Goedert, W.J. 1983. Management of the Cerrado Soils of Brazil: A Review. J. of Soil Science 34:405-428.

Helyar, K.R. 1991. The Management of Acid Soils. In Wright, R.J., et al. (Eds.) Plant-Soil Interactions at Low Ph. Kluwer Academic Publishers, The Netherlands, Pp 365-382.

Homem de Melo, Fernando. 1985. Distributive Implications of the Growth in Soybean Production in Brazil p 78-86. In Shibles, Richard (Ed.) World Soybean Research Conference III: Proceedings. Westview Press, Boulder, CO.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. ICRISAT Sahelian Centre Annual Report, Niamey, Niger.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. ICRISAT Sahelian Centre Annual Report, Niamey, Niger.

Jomini, P.A., 1990. "The Economic Viability of Phosphorus Fertilizer in Southwestern Niger: A Dynamic Approach Incorporating Agronomic Principles," unpublished Ph.D. dissertation. West Lafayette, IN: Purdue University, Dept. of Agricultural Economics.

Krishna, J.H., G.F. Arkin, J.R. Williams and J.R. Mulkey. 1987. Simulating Furrow-Dike Impacts on Runoff and Sorghum Yields. Transactions of the ASAE (American Society of Agricultural Engineering) 30(1):143-147.

Mandell, Paul I. 1971. The Rise of the Modern Brazilian Rice Industry: Demand Expansion in a Dynamic Economy. Food Research Institute Studies 10(2):161-219.

Matlon, P. 1990. Improving Productivity in Sorghum and Pearl Millet in Semi-Arid Africa. Food Research Institute Studies 22(1):1-43.

Matlon, P. 1987. The West African Semi-Arid Tropics. In Mellor, J.W., C.L. Delgado and M.J. Blackie (Eds.) Accelerating Food Production in Sub-Saharan Africa. Johns Hopkins University Press, Baltimore, MD, Pp 59-77.

Miller, Frederick R. and Yilma Kebede. 1984. Genetic Contributions to Yield Gains in Sorghum, 1950 to 1980. In Fehr, W.R. (ed.) Genetic Contributions to Yield Gains of Five Major Crop Plants, CSSA Special Publication No. 7, Crop Science Society of America, Inc., and American Society of Agronomy, Inc., Madison, WI, Pp 1-14.

Mokwunye, A. Uzo and L.L. Hammond. 1992. Myths and Science of Fertilizer Use in the Tropics,. In Lal, R., and P.A. Sanchez (Eds.) Myths and Science of Soils of the Tropics, SSSA Special Publication No. 29, Soil Science Society of America, Inc., and American Society of Agronomy, Inc., Madison, WI, Pp 121-134.

Nagy, Joseph G., John H. Sanders and Herbert W. Ohm. 1988. Cereal Technology Interventions for the West African Semi-Arid Tropics. Agricultural Economics 2:179-208.

Ramaswamy, S. and J.H. Sanders. 1992. Population Pressure, Land Degradation, and Sustainable Agricultural Technologies in the Sahel. Agricultural Systems 40(4):361-378.

SPSB/EMBRAPA (Serviço de Produçãs de Sementes Basicas/Empresa Brasileira de Pesquisa Agropecuaria). 1992. Programa de Milho Hibrido BR-201. Relatorio Operacional, 1991, unpublished mimeo. Public Seed Organization of EMBRAPA, Campinas, São Paulo, Brazil.

Sanchez, Pedro A. and Terry J. Logan. 1992. Myths and Science About the Chemistry and Fertility of Soils in the Tropics. In Lal, R., and P.A. Sanchez (Eds.) Myths and Science of Soils of the Tropics, SSSA Special Publication No. 29, Soil Science Society of America, Inc., and American Society of Agronomy, Inc., Madison, WI, Pp 35-46.

Sanchez, Pedro A., and Jose G. Salinas. 1981. Low Input Technology for Managing Oxisols and Ultisols in Tropical America. Advances in Agronomy 34:279-406.

Sanders, John H. 1989. Agricultural Research and New Technology Introduction in Burkina Faso and Niger. Agricultural Systems 30:139-154.

Sanders, John H. 1993. Economic Impact of the Commodity Research Networks of SAFGRAD. In Sanders, John H., Taye Bezuneh, and Alan C. Schroeder, Impact Assessment of the SAFGRAD Commodity Networks, USAID/AFR AND OAU/STRC-SAFGRAD, Washington, DC.

Sanders, John H., Joseph G. Nagy and Sunder Ramaswamy. 1990. Developing New Agricultural Technologies for the Sahelian Countries: The Burkina Faso Case. Economic Development and Cultural Change 39(1):1-22.

Sanders, John H., Sunder Ramaswamy and Barry I. Shapiro. 1993. The Economics of Agricultural Technology in Semi-Arid Sub-Saharan Africa, manuscript. Purdue University, West Lafayette, IN.

Shapiro, B.I. 1990. New Technology Adoption in Two Agricultural Systems of the Niamey Region of Niger. PhD diss. Purdue Univ., West Lafayette, IN.

Shapiro, B.I., J.H. Sanders, K.C. Reddy and T.G. Baker. 1993. Evaluating and Adapting New Technologies in a High-Risk Agricultural System – Niger. Agricultural Systems 42(1-2):153-171.

Sivakumar, M.V.K. 1988. Predicting Rainy Season Potential From the Onset of Rains in Southern Sahelian and Sudanian Climatic Zones of West Africa. Agricultural and Forest Meteorology 42:295-305.

Sivakumar, M.V.K., A Manu, S.M. Virmani and E.T. Kanemasu. 1992. Relation Between Climate and Soil Productivity in the Tropics. In Lal, R., and P.A. Sanchez (Eds.) Myths and Science of Soils of the Tropics, SSSA Special Publication No. 29, Soil Science Society of America, Inc., and American Society of Agronomy, Inc., Madison, WI, Pp 91-119.

Vieira, Arnaldo P., John H. Sanders and Mohamed K. Habash. 1988. Regional Decentralization of New Agricultural Technologies: Soybean Diffusion in the United States and Brazil. Quarterly J. of International Agriculture 27(2):150-162.

Vierich, H.I.D. and W.A. Stoop. 1990. Changes in West African Savanna Agriculture in Response to Growing Population and Continuing Low Rainfall. Agriculture, Ecosystems and Environment 31:115-312.