

PN-ABD-463  
6273



United States  
Department of  
Agriculture

Economic  
Research  
Service

Agricultural  
Economic  
Report  
Number 612

# Technology and Agricultural Productivity in the Sahel

Thomas S. Jayne  
John C. Day  
Harold E. Dregne

---

## **It's Easy To Order Another Copy!**

**Just dial 1-800-999-6779. Toll free.**

Ask for *Technology and Agricultural Productivity in the Sahel (AER-612)*.

The cost is \$5.50 per copy. For non-U.S. addresses, add 25 percent (includes Canada). Charge your purchase to your VISA or MasterCard, or we can bill you. Or send a check or purchase order (made payable to ERS-NASS) to:

ERS-NASS  
P.O. Box 1608  
Rockville, MD 20849-1608.

We'll fill your order by first-class mail.

---

**Technology and Agricultural Productivity in the Sahel.** By Thomas S. Jayne, John C. Day, and Harold E. Dregne. Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture. Agricultural Economic Report No. 612.

## **Abstract**

Increased agricultural productivity in the Sahel will require widespread diffusion of improved soil- and water-management practices that stimulate growth in a sustainable way. Techniques such as tied-ridges, animal traction, and fertilization can improve productivity but may not be viable unless used together. Improved soil and water management is required to produce a more fertile agronomic environment receptive to new high-yielding crop varieties needed to greatly expand productivity. However, environmental conditions, farmers' resources, inability to make complementary investments that would make such practices profitable, marketing channels, and institutional/policy arrangements constrain adoption of these techniques. Adoption rates can improve if new farming practices enhance soil and water conditions at modest cost, reduce the risk of food and capital loss during poor weather years, and relieve seasonal labor constraints. However, tandem improvements are necessary in input and product markets, rural institutions, and policies to stimulate adoption by creating opportunities and incentives at the farm level.

**Keywords:** Technological change, soil and water resources management, agricultural productivity, Sahel, dryland agriculture

## **Acknowledgments**

The authors are grateful to John H. Sanders, Purdue University; John Staatz, Michigan State University; and Art Dommen, Economic Research Service, for their valuable reviews, comments, and suggestions. The research leading to this report is supported by the U.S. Agency for International Development, Science and Technology Bureau, Technology of Soil Moisture Management Project under USDA-PASA No. BST-4021-P-AG-1080-00.

# Contents

	Page
<b>Summary</b> .....	iii
<b>Introduction</b> .....	1
<b>Characteristics of the Sahel</b> .....	1
Physical Characteristics .....	1
Soils .....	1
Climate .....	3
Demography .....	4
<b>Agricultural Productivity in the Sahel</b> .....	6
Factors Affecting Agricultural Productivity .....	6
The Potential for Irrigation .....	7
Dryland Agriculture .....	8
<b>Technology and Agricultural Productivity in the Sahel</b> .....	9
A Sahelian Green Revolution? .....	9
Improved Soil- and Water-Management Technologies .....	10
<b>Constraints to Technology Diffusion in the Sahel</b> .....	11
The Physical Environment .....	11
Farmers' Goals and Technology Adoption Criteria .....	12
The Marketing System .....	15
Economic Policies .....	15
<b>Conditions Necessary for Technology Diffusion</b> .....	17
Characteristics of Improved Technologies .....	17
Institutional and Policy Conditions .....	18
<b>Conclusions</b> .....	21
<b>References</b> .....	22

## Summary

Much of the Sahel is locked in a vicious cycle of increased cultivation and falling land fertility. Rapid population growth, a breakdown in traditional fallow lengths, slow technological advance, weak access to inputs, and local institutions and policies worsen this cycle. Traditional low-resource agriculture in the Sahel, based on labor-intensive cropping systems using few purchased inputs, probably cannot stimulate food production fast enough to meet the needs of a burgeoning population. While significant gains in agricultural productivity in the Sahel are possible, they will require widespread diffusion of improved soil- and water-management practices that stimulate growth in a sustainable way. This report examines factors that have slowed adoption of technology in the Sahel and identifies conditions necessary to increase use of those techniques.

Soil- and water-management techniques, including tied ridges, animal traction, dikes and bunds, and organic and chemical fertilization, can enhance the agronomic environment for crop production. However, climate and soil conditions, farm resources, technology adoption criteria, input and product market systems, and public and private institutional arrangements and policies impede widespread adoption of these techniques.

Improved soil and water management in the Sahel depends on modifying existing techniques to fit the particular conditions of the region. New techniques must stabilize farm returns or reduce the potential for loss because most subsistence farmers are averse to risk. New techniques must reduce seasonal labor demands or shift labor requirements from peak to slack periods because of critical labor shortages during the crop production cycle. New technologies must also be inexpensive because of credit constraints and limits on cultivating higher valued crops in many dryland areas.

Widespread use of otherwise viable technologies depends on institutional and policy conditions. These include a system of land rights that encourages farmers to invest in land-conserving practices, a more efficient rural financial system to disburse credit, and a means to improve demand for local coarse grains. Technology adoption also depends on marketing channels that influence the availability of, and incentives to use, these techniques. Greater consideration must also be given to macroeconomic policies that can stimulate the development of a sustainable agricultural system.

Improved soil and water technologies may conserve the resource base, increase and stabilize crop production, and be adopted given local resources. None of these practices will ensure a harvest in a low-rainfall year, but they could reduce the magnitude of loss.

An important benefit of improved soil- and water-management practices is the increased scope provided for successful introduction of new high-yielding crops. Dramatic gains in productivity in the Sahel require improved seed varieties, which in turn require significant improvements in soil and water conditions at the farm level. Improved resource management can promote productive and sustainable agricultural systems compatible with the intensification of land use that inevitably accompanies rapid population growth.

# Technology and Agricultural Productivity in the Sahel

Thomas S. Jayne\*  
John C. Day  
Harold E. Dregne

## Introduction

Sub-Saharan Africa is the only region in the world where population growth rates have outpaced food production growth rates over the past two decades. Even by African standards, the Sahel region of West Africa has registered particularly poor agricultural performance because of periodic droughts, questionable economic policies, and limited progress in developing farm-level technologies appropriate for the region.

Development efforts for the Sahel need to give greater attention to technical innovations compatible with evolving environmental and social conditions. The harsh climate and unpredictable weather create especially difficult problems for both farmers and policymakers.

Significant gains in agricultural productivity in the Sahel, while possible, will require greater diffusion of improved soil- and water-management practices. Widespread adoption of such practices is difficult because so much depends on the characteristics of the specific technologies involved, farmers' resources and goals, the socioeconomic institutions in place, and governmental policies. This report focuses on factors that have slowed technology transfer in the region and identifies conditions necessary for transfer to occur more rapidly.

## Characteristics of the Sahel

If agricultural productivity in the Sahel is to improve, new technologies and related farm management practices must be suited to the conditions in the region. This section describes major physical, climatic, and demographic features of the region.

---

\* The authors are visiting assistant professor, Department of Agricultural Economics, Michigan State University and visiting lecturer, University of Zimbabwe; Economist, Economic Research Service, U.S. Department of Agriculture; Professor Emeritus of Soil Science, Texas Tech University.

## Physical Characteristics

The Sahel region comprises the eight semiarid West African countries grouped along the 14th parallel: Senegal, The Gambia, Mauritania, Mali, Burkina Faso, Niger, Chad, and Cape Verde (fig. 1). The islands of Cape Verde are excluded from our discussion because of their distinct demographic and environmental character.

The Sahel encompasses over 2 million square miles, about two-thirds the size of the continental United States. Bounded by the Sahara Desert to the north and by the more humid coastal countries to the south, the Sahel's climate does not differ dramatically from surrounding countries. For example, the climate in the Sudan and northern Nigeria is similar to parts of the Sahel. Technology concepts discussed in this report can also apply to those areas.

Less than 4 percent of the Sahel's land is cultivated, and 30 percent of the land is too dry for agriculture (table 1). More extensive farming is restrained by the region's soils, water resources, terrain, vegetation, climate, and demographics.

## Soils

Sahelian soils vary north to south: mobile sand dunes and gravelly pans in the hyperarid Sahara to the north, deep sandy soils in the central semiarid zones, and medium-textured soils in the low hills of the subhumid regions to the south (21).<sup>1</sup> The physical and chemical properties of these soils restrain much of the Sahel's crop production.

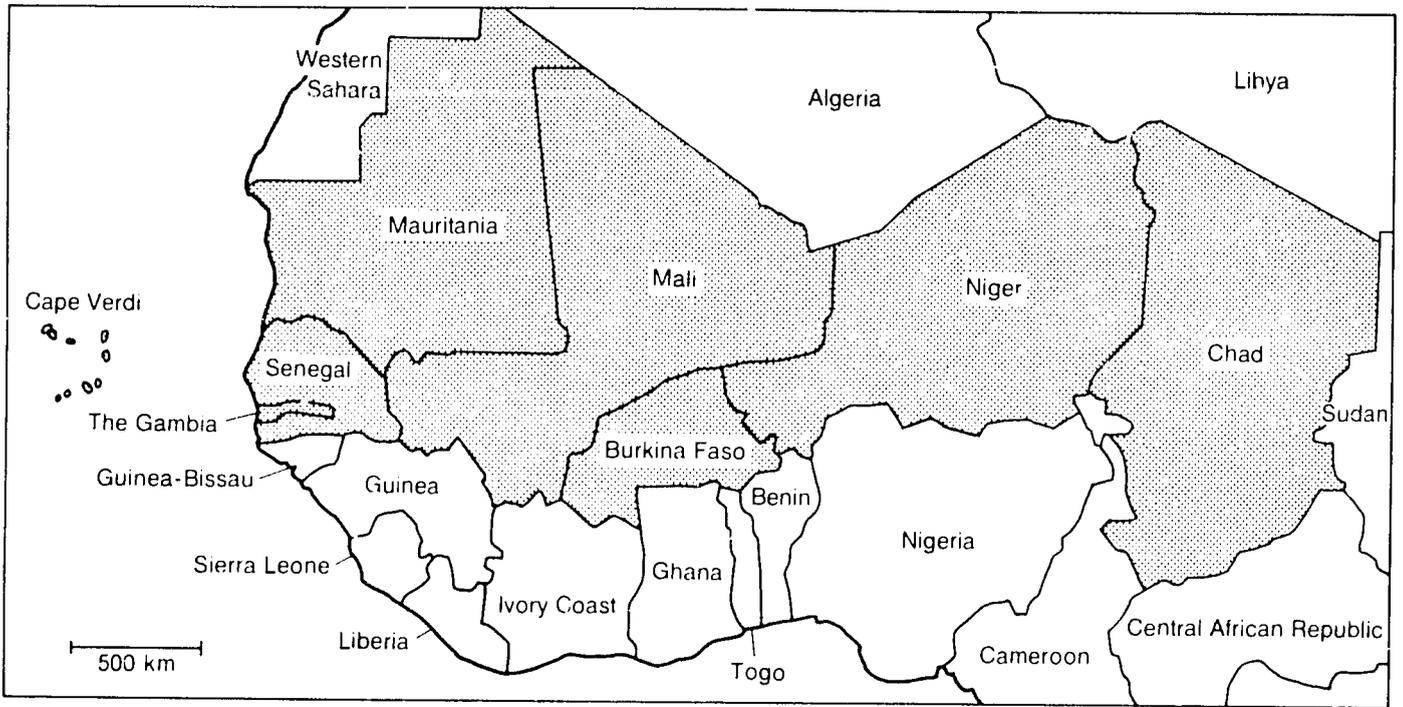
Deep sandy soils dominate the plains, which make up most of the central Sahel. These soils are moderately to strongly acidic and have a low to moderate phosphorus-fixation capacity. They have a low

---

<sup>1</sup> Italicized numbers in parentheses refer to literature citations in the References section.

Figure 1

**Principal countries of the West African Sahel**



**Table 1—Land use in the Sahel**

Country	Total area	Land area	Cropland			Permanent pasture	Forest woodland	Other land	Irrigated land <sup>3</sup>
			Arable <sup>1</sup>	Permanent <sup>2</sup>	Total				
<i>1,000 square kilometers</i>									
Total area in:									
Burkina Faso	274.2	273.8	26.2	0.1	26.3	100.0	70.2	76.7	Neg.
Chad	1,284.0	1,259.2	31.5	Neg.	31.5	450.0	202.6	575.1	Neg.
The Gambia	11.3	10.0	1.6	NA	1.6	.9	2.0	5.5	.3
Mali	1,240.0	1,220.0	20.5	Neg.	20.5	300.0	86.8	812.7	1.0
Mauritania	1,030.7	1,030.4	19.2	Neg.	19.2	392.5	151.3	484.6	.1
Niger	1,267.0	1,266.7	35.6	NA	35.6	92.2	27.2	1,111.7	.3
Senegal	196.2	192.0	52.3	Neg.	52.3	57.0	59.4	23.3	1.8
Total	5,303.4	5,252.1	169.5	.3	169.8	1,392.6	599.5	3,089.6	3.6
<i>Percent</i>									
Share of area in:									
Burkina Faso	5.2	99.8	9.5	Neg.	9.6	36.4	25.6	28.0	Neg.
Chad	24.2	98.0	2.4	Neg.	2.4	35.0	15.7	41.7	Neg.
The Gambia	.2	88.4	14.1	NA	14.1	.8	17.5	48.8	.3
Mali	23.4	98.3	1.6	Neg.	1.6	24.1	.7	65.5	Neg.
Mauritania	19.4	99.9	.4	Neg.	Neg.	38.0	14.6	47.0	Neg.
Niger	23.9	99.9	2.8	NA	2.8	7.2	2.1	87.7	Neg.
Senegal	3.7	97.8	26.6	Neg.	26.6	29.0	30.2	11.2	.1
Total	100.0	99.0	3.1	Neg.	3.2	26.2	11.3	58.2	Neg.

NA = Not applicable.

Neg. = Negligible.

<sup>1</sup> Land fit for cultivation.

<sup>2</sup> Land in tree crops, such as cocoa, coffee, and rubber.

<sup>3</sup> Irrigated land is also included in other categories.

Source: (29).

nutrient- and water-holding capacity, are low in organic matter (humus) content, and are highly permeable once wetted. Soils in the area, therefore, are susceptible to water and wind erosion, crusting and compaction of the surface, development of plow pans (hard subsoil layer formed by plowing or other tillage operations), and rapid runoff on all but the sandiest soils. Fertility is low because of pronounced deficiencies of nitrogen and phosphorus, moderate deficiency of sulfur, and widespread toxic amounts of aluminum and manganese. If there are no plow pans, rooting depth seldom limits crop growth because nearly all the soils are deep.

Three other kinds of soils are prominent in certain parts of the Sahel: clays, stoney soils, and sand dunes. Clay soils are extensive in southern Chad, in closed basins, in many of the valleys with intermittent streams (streams formed during rainy seasons), and in the inland delta of the Niger River in Mali. While the clays are potentially more productive than the sandy soils, they are difficult to cultivate.

Ironstone, gravelly, and stoney soils are prominent on the low hills, land surfaces worn from exposure to the humid weather. These soils are infertile because of intense leaching (nutrients dissolving and

washing away) and are too stony to support row crops. Stable and mobile sand dunes are common in the northern Sahel. These soils are unproductive and show little or no prospect as useful farmland (22).

### Climate

Sahelian farmers must cope with harsh environmental conditions. Rainfall is a major determinant of crop and livestock production. But the rainfall is highly variable and unpredictable in location, timing, and amount. Table 2 presents rainfall, temperature, and evapotranspiration (water lost by evaporation and plant use) data for three typical locations.

The Sahel experiences a distinct pattern of rainfall: a summer wet season followed by a prolonged dry season. If the rainy season arrives late or terminates early, the growing season may be too short for crops to mature. Crops will fail if rainfall is insufficient to provide the moisture plants need. Subsistence farmers with little capital, food, and resources cannot afford to gamble on production practices that may not pay off if the rains are not adequate. Given the understandably high aversion to risk that most Sahelian farmers exhibit, the variable and unpredictable nature of rainfall is a major difficulty for farmers and development planners.

**Table 2—Climate in selected locations in Mali, average conditions over 37 years**

Station	Mean monthly data													Mean annual PET <sup>1</sup>	Mean annual temperature
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	12-month total		
<i>Millimeters</i>															
Mopti:															
Rain	0	0	0	3	24	61	139	169	95	24	0	0	515	NA	
PET <sup>1</sup>	152	166	215	220	224	199	177	154	147	159	157	140	NA	NA	
Sikasso:															
Rain	1	3	15	45	105	152	253	326	217	84	19	4	1,225	NA	
PET <sup>1</sup>	173	177	211	192	185	163	152	142	147	163	164	165	NA	NA	
Tessalit:															
Rain	1	0	1	0	2	7	23	55	27	1	1	0	118	NA	
PET <sup>1</sup>	114	126	181	205	234	236	237	227	201	173	131	103	NA	NA	
<i>Degrees Celsius</i>															
Temperature:															
Mopti	32	35	38	40	40	38	34	32	32	34	35	31	NA	NA	
Sikasso	34	36	38	37	36	33	31	30	31	33	34	33	NA	27.8	
Tessalit	27	30	34	37	41	43	42	40	40	38	33	26	NA	27.2	

NA = Not applicable.

<sup>1</sup> PET = Potential evapotranspiration.

Source: (35).

The growing season in the Sahel lasts from 2–3 months in the north to 4–5 months in the south (66). Total seasonal precipitation in these areas averages 300–400 mm or less to about 1,400 mm. Coefficients of variation (CV's, the amount of variability around the mean) in seasonal rainfall totals range from 20 to 40 percent. Temperatures are high year round, with peaks of 35 °C to 45 °C during the spring and early summer. These high temperatures, coupled with high solar radiation, cause potential crop water use (potential evapotranspiration) to exceed rainfall much of the time (table 2). Although total rainfall could be sufficient for crop growth, there is usually too little moisture available at the right time for optimum plant growth. Poor soil water infiltration and soil water-holding capacity exacerbates the bad crop water situation.

Droughts are common in the Sahel but unpredictable in their occurrence and duration. Figure 2 indicates that there have been more below-average rainfall years than above-average years, particularly since the late 1960's. Annual rainfall has varied more since 1970 than that of the long-term record. The data also show that over the long term, annual rainfall has been highly variable in seasonal amount, but dry and wet periods seem to persist over multiyear periods (65). The droughts of 1972–73 and 1982–84 were part of a long spell of below-average rainfall beginning about 1968 (48).

### Demography

Eighty percent of the Sahel's 38 million inhabitants are supported by rainfed agriculture. This high de-

gree of dependence on agriculture occurs even though less than 4 percent of the land is fit for cultivation and less than 30 percent of the land is used for grazing.

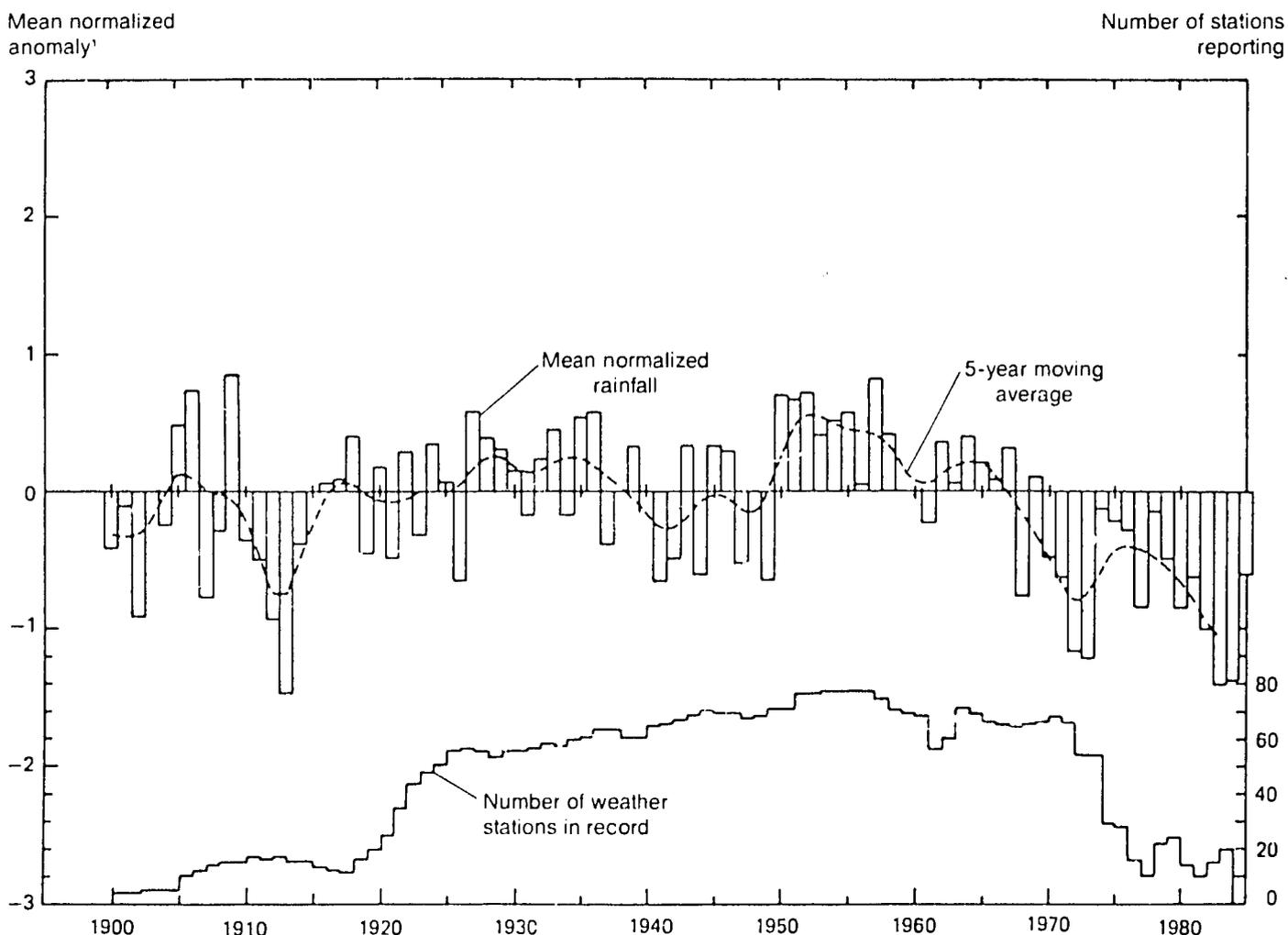
Population density varies throughout the region (table 3), and is highly related to rainfall. Nearly 80 percent of the rural population is concentrated in the more humid southern third of the region (47). But, tracts of fertile areas in the south have been totally abandoned for less productive land due to the prevalence of insect-borne diseases such as river blindness and sleeping sickness.

Population is growing at a rate of 2.8 percent in the Sahel, and will double in 25 years. Rapid urbanization will put increasing strain on the region's marketing institutions and infrastructure to cope with rising urban food demands. Urbanization also accounts for the slower growth in agricultural labor than in overall population growth.

Several studies indicate that population throughout the Sahel already exceeds its sustainable "carrying capacity" given traditional technology (101). Carrying capacity refers to the amount of food and feed that the ecosystem can provide for humans and animals over a given period without impairing the long-term productivity or sustainability of the system. Carrying capacity will vary as a function of technology (101). Under existing production technology, the Sahel exceeded its sustainable population 5–10 years ago (101). Given current demographic and agricultural production trends, it is imperative that the Sahel make the transition to a more productive

Figure 2

## Mean normalized rainfall in selected weather stations in the West African Sahel



<sup>1</sup> The ratio of annual rainfall minus long-term average rainfall to the long-term standard deviation in rainfall. Values for the mean normalized anomalies are seasonal, May to October, totals.

Source: (30). This figure is adapted with permission of the copyright holders, Butterworth Scientific Ltd (publisher). For use of the chart in this report, ERS added the graph labels and simplified the footnotes.

### Table 3—Population in the Sahel

Country	1984			Urban population growth, 1970-80	Expected population growth rate, 1980-2000	Doubling time	Projected density, 2000 <sup>1</sup>
	Total population	Density <sup>1</sup>	Share of population in agriculture				
	Thousand	Number	Percent			Years	Number
Burkina Faso	6,768	24.7	79	3.8	2.6	27	33.3
Chad	4,901	3.8	80	6.5	2.3	35	5.4
The Gambia	630	55.8	76	5.0	2.8	34	100.0
Mali	7,825	6.3	85	5.5	3.0	25	10.8
Mauritania	1,832	1.8	80	8.6	3.1	24	3.0
Niger	5,940	4.7	85	6.8	3.2	25	7.7
Senegal	6,352	32.4	72	3.3	2.9	24	50.0
Region	34,248	6.5	80	5.6	2.8	25	10.1

<sup>1</sup> Persons per square kilometer of area.

Sources: (29, 75, 101, 102).

and sustainable agricultural system if it is to produce the food and fiber needed for a viable society.

## Agricultural Productivity in the Sahel

Economic development and the quality of life in the Sahel depend on the productivity of the agricultural sector. Agriculture generates 30–70 percent of GNP (gross national product) in Sahelian countries, employs 75–90 percent of the laborforce, and generates a substantial portion of the region's foreign exchange (102). With average annual per-capita income about \$300 and a human life expectancy of about 44 years, the Sahelian countries are among the poorest of the world.

A critical question is whether the agricultural sector can generate the output and rural incomes needed to raise the general standard of living to acceptable levels using traditional technology. This section examines the implications of current trends affecting food production, availability, and consumption, and addresses the potential role of large-scale irrigation schemes as a means of meeting agricultural requirements.

### Factors Affecting Agricultural Productivity

The current trends in per-capita output, land quality and productivity, population growth, potential for expanded cropped area, and dependence on food imports and aid each affect future agricultural productivity in the Sahel.

**Declining Per-Capita Food Output** The Sahel appears to be slowly losing the ability to feed itself. The performance of the Sahelian countries contrasts markedly with trends in Asia and Latin America, and is poor even in comparison with other African countries (fig. 3). Per-capita food production declined about 1.6 percent per year during 1962–83 (table 4). Food output has varied considerably from year to year (71). Given projected population growth, food supplies must increase by 3 percent per year to maintain the present inadequate levels of per-capita consumption. Farmers, traders, consumers, and policymakers face considerable risks and uncertainties due to the wide fluctuations in annual food production.

**Declining Land Productivity** Food crop yields have declined over the past 20 years because rising population pressure has required increased cultivation of marginal land (54), the length of fallow periods has been reduced, and rainfall has become more sporadic (48). There is considerable variation in this ag-

gregate trend, however, because soil, moisture, marketing, and policy conditions vary widely throughout the region. Yet, crop yields and production in the Sahel generally have been very poor for the past 20 years (table 4). Population in the Sahel is growing faster than either the agricultural laborforce or cultivated area (60). These trends suggest that each hectare of arable land and proportionately fewer farmers must support more and more people unless spending on food imports or food aid increases to take up the slack.

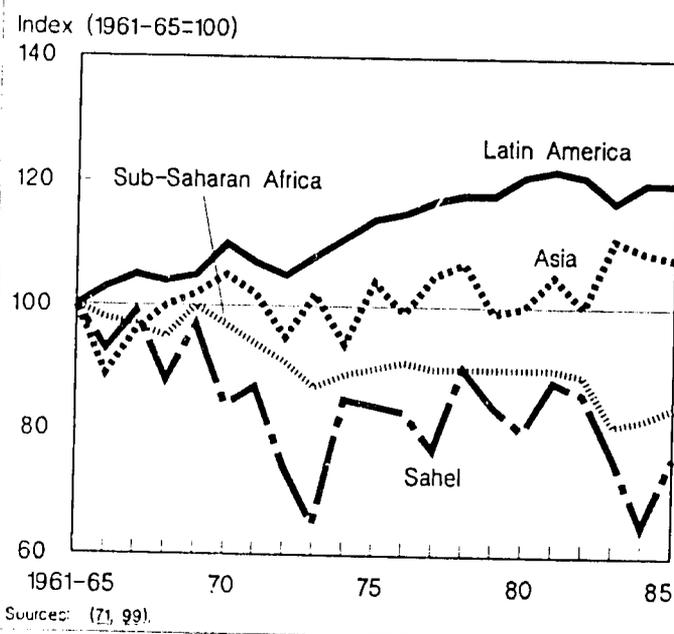
**Table 4—Average annual growth rates in 1962–83: Cropped area, yield, and per-capita production for principal crops in the Sahel**

Country and commodity	Cropped area	Yield per hectare <sup>1</sup>	Per-capita production
	<i>Percent</i>		
Sahel region	-0.3	-1.3	-1.6
Mali:			
Maize	-1.01	-2.46	-3.47
Rice	-.27	.32	.05
Millet	.28	-1.96	-1.68
Niger:			
Sorghum	4.18	-1.89	2.29
Rice	5.15	-1.38	3.77
Millet	3.51	-1.56	1.95
Senegal:			
Rice	-1.83	-.50	-2.33
Millet	-.85	1.67	.82

<sup>1</sup> 1 hectare equals 2.47 acres.

Sources: (14, 88).

**Figure 3**  
**Per capita food production in Latin America, Asia, Sub-Saharan Africa, and the Sahel, 1961–85**



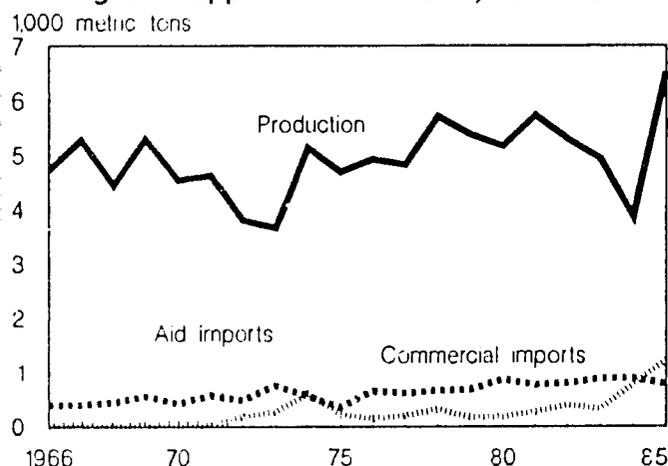
**Limited Strategies for Extensive Growth** Increases in food production that have occurred in some countries over the past several decades have come primarily from expansions in cropped area (table 4). But, continued reliance on extensive means to increase food production is not a realistic long-term option for most locations in the Sahel (14). For large areas of the Sahel, shortrun production increases are occurring at the expense of longrun soil fertility (54). Greater population density results in more frequent cultivation of existing farmland and less time in fallow periods (68, 78, 80). However, breakdown in the traditional fallowing practice accelerates soil degradation. Land pressures will become more severe as population density increases.

### Rising Dependence on Food Imports and Food Aid

Most countries in the Sahel continue to rely on substantial food imports and food aid, and this dependence may prevent a recovery in Sahelian agriculture. The share of imports in total food availability has been rising since 1970, reaching over 30 percent in 1984 (fig. 4). Commercial food imports in Mali, Niger, and Senegal increased 15, 23, and 11 percent per year between 1966 and 1983.

Continued and increasing dependence on imports means dependence on an unstable international grain market, which may hurt Sahelian countries. International grain prices have fluctuated significantly over the past two decades, pressuring national deficits and available foreign exchange. Moreover, while imports and aid help meet needs in the short run, such relief may be a partial cause, as well as consequence, of stagnant agriculture because increasing food aid and imports of preferred grains (such as wheat and rice) may stifle demand for locally produced grains.

Figure 4  
**Food grain supplies in the Sahel, 1966-85**



Source (99)

**Desertification** Desertification in arid regions refers to a process of land degradation, such as vegetative decline, water and wind erosion, and salinization and waterlogging of soils (21). Soils may also compact and accumulate toxic substances. Most desertification processes are reversible, but sometimes the degree of damage may not be reversible or may be too expensive to correct. Gully erosion, for example, usually represents an irreversible loss of soil. Overgrazing can lead to economically irreversible degradation because the costs of restoration may exceed the benefits.

Native plants and animals have adapted to the climatic variation in the Sahel. But every part of the Sahel has been disturbed to some degree, primarily from fire, agriculture, and hunting. Fires set by pastoralists and hunters have changed the normal distribution of trees, shrubs, and grasses. Fires have increasingly allowed the spread of less hardy annual grasses, and decreased the amount of trees and shrubs that are not fire-resistant. Cultivation and fuelwood cutting have destroyed much vegetation, thereby increasing water and wind erosion.

Rainfed agriculture has expanded throughout the Sahel for several decades. Increased population brought demands for more cropland to feed the growing numbers of people, and many nomads have become part-time farmers. With this expansion, crop production became riskier as cultivation spread into ever-drier areas and as fallow periods became shorter. Poor crops and rangelands less able to withstand heavy grazing led to greater susceptibility of the land to water and wind erosion and to a further decline in productivity. Salinization due to over-irrigation has affected irrigated land in Senegal, but the regional extent of this (and also of water-logging) is not known. Despite the apparent benefits from water-conservation practices such as terracing, field use of those techniques is not common (76).

### The Potential for Irrigation

Water is an important limiting factor in semiarid regions. Despite the popular appeal of irrigation to stimulate agricultural growth, about 2 percent of total arable land in the Sahel is irrigated (29). Most analysts concur that large-scale irrigation will generally remain a costly way of producing food, and will increase at a slow rate over the next 40 to 50 years (14, 26, 54, 88).

The history of irrigation in Africa has been marked with false expectations, cost overruns, and failures (9, 26). Matlon and Spencer note that ". . . ex post

assessments of the economics of large-scale irrigation projects have usually revealed economic losses or noncompetitive returns" (54). Reasons for such low performance include high investment costs, high maintenance costs, difficulties in organizing farmer irrigation associations (to manage operations effectively and maintain the structures and equipment), variable flow of major rivers, inappropriate agronomic packages, inadequate input delivery systems, and lack of a marketing infrastructure that accommodates more specialized production systems.

Prospects for economically viable irrigation schemes in the Sahel appear most promising for small-scale, labor-intensive schemes on the farm (27, 59, 101). Such small-scale schemes with simple pumps or manual water-lifting devices avoid high overhead costs of massive engineering works and management costs of large-scale irrigation. Incorporating improved practices into the traditional forms of irrigation (such as those using wells, recessional and flood-plain farming, and swampland farming) may also have high payoffs. Yet, such small-scale initiatives are also subject to management and coordination problems (71). The success of large and small irrigation schemes depends on institutional organization as well as technical viability. Bingen summarizes the irrigation efforts of Mali's Office du Niger: "If technical solutions alone could solve the Sahelian food crisis, then this grand irrigation scheme would now be playing a central role in feeding the Sahelian people" (10).

### Dryland Agriculture

Rapid economic growth depends on improving the performance of dryland agriculture because it produces a significant share of the region's GNP and employs a large share of the laborforce. Dryland production accounts for 97 percent of all area under cultivation in the Sahel (29). Considering the limited potential for large-scale irrigation, increased productivity of dryland agriculture is imperative if the Sahel is to meet food and fiber needs in the medium and long term. Increased agricultural productivity can raise cash incomes by promoting surplus production and increased market sales. Yield-increasing technologies may enable family food needs to be produced with less land and labor, thus freeing these resources for other income-generating activities such as cotton production or off-farm employment (28).

But can traditional dryland production techniques meet the Sahel's needs over the next several decades? Most economists are skeptical that a low-resource approach by itself can achieve these objectives (19, 26, 57, 80, 92). The historical record indi-

cates that low-resource, conservation-model approaches to agricultural development, focusing on labor-intensive cropping systems using organic manures and few purchased inputs, have proven incapable of achieving annual agricultural growth rates much above 1 percent (92).

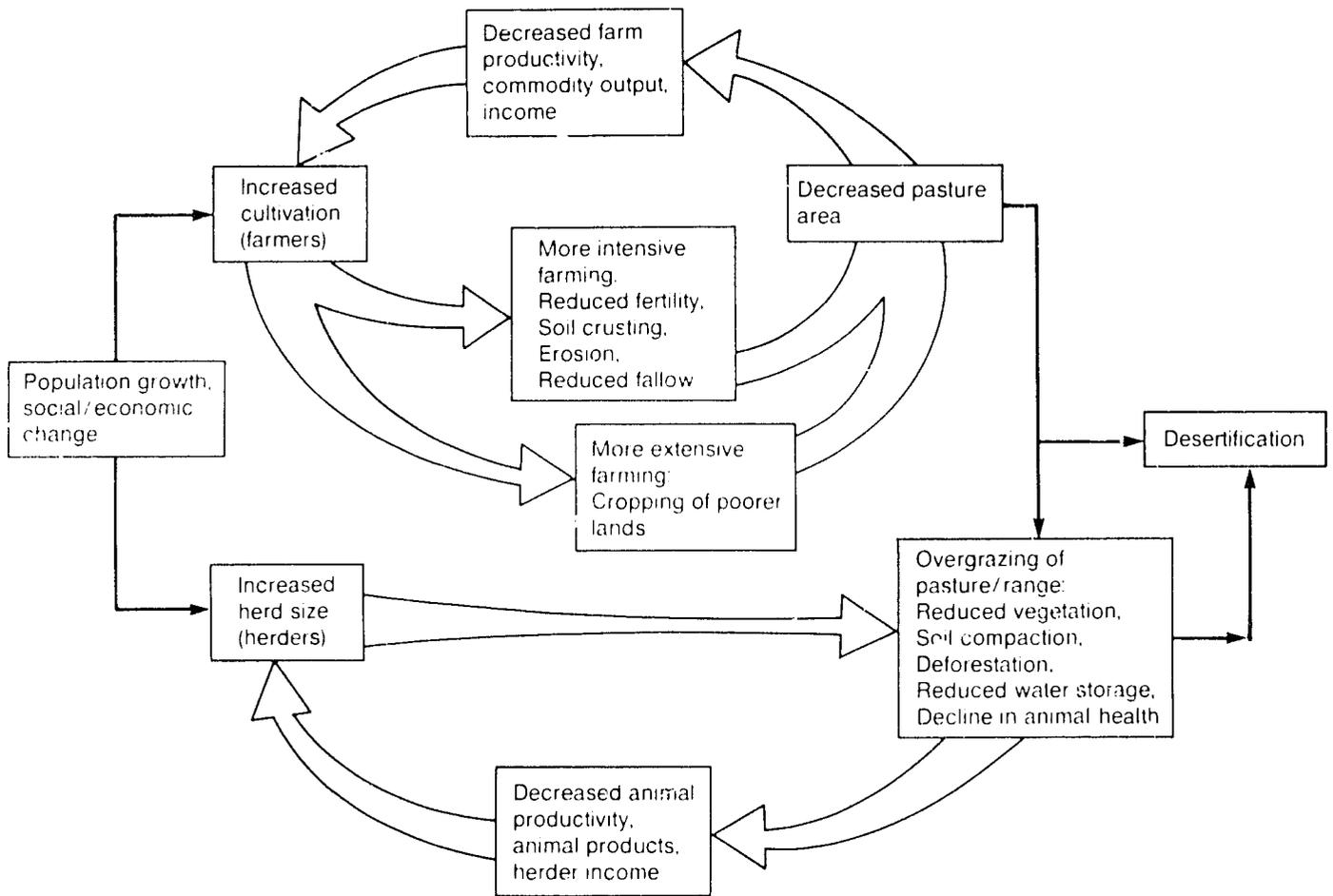
However, elements of the conservation model can be modified to include a greater reliance on purchased inputs in order to stimulate agricultural growth in a sustainable way (92). If we define technology to represent the whole system of cultivation, including fallowing, soil production, and water conservation methods, then improved conservation practices are technical inputs contained directly in crop production functions. These conservation inputs directly influence the productivity of conventional inputs (such as labor, fertilizer, and animal traction). Improved soil fertility and water management are critically important to enhance and sustain the land's longrun productivity.

Significant portions of the Sahel are locked in a vicious cycle of increased cultivation and falling productivity. Figure 5 illustrates this dynamic cycle of declining productivity in dryland agriculture. This cycle is driven by rapid population growth, slow technological advance, poor input delivery and support systems, and questionable government policies. Breaking the cycle will require introducing appropriate and cost-effective technologies and related land- and water-management practices that will enhance and sustain productivity.

Requirements for expanded food supplies create pressure on land resources which, in turn, breaks down traditional fallow systems and pushes more crop area onto marginal land. These changes reduce soil fertility and, therefore, land productivity. Facing increasing population densities and declining crop yields, many countries in the Sahel are under even greater pressure to further reduce fallow and expand cultivation. Expanded cropland and increased demand for meat have also put pressure on traditional livestock production systems (14). The loss of traditional trading opportunities for nomadic herders has increased the importance of livestock as a source of income; hence, herd size has tended to increase.

Both grazing and cropping patterns—the basic production system—have, therefore, contributed to declining productivity and increasing desertification in many parts of the Sahel. Given the difficulty of altering population growth and the strong interrelationships that exist between population growth, socio-

## Dynamics involved in dryland production in the West African Sahel



economic change, agronomic practices, soil quality, productivity of dryland farming, and standards of living in the region, new dryland farming systems are needed if the situation is to improve.

### Technology and Agricultural Productivity in the Sahel

While new technology and related farm management practices stimulated agricultural development elsewhere (3, 34, 45, 83, 85), new technologies have often fared poorly in the Sahel. For example, high-yielding fertilized seeds have dramatically increased food crop productivity in Asia, Latin America, and in other parts of Africa, but not in the Sahel. This section examines the potential for technological change in the Sahel and the role of improved soil- and water-management techniques in this process.

#### A Sahelian Green Revolution?

The increases in food grain output associated with the Green Revolution in Asia were based largely on

yield gains from high-yielding crop varieties (HYV's). Most HYV's were effective and profitable only when combined with water control and fertilization. This combination created a favorable agronomic environment for successful introduction of these new crop varieties. However, water control is largely absent in the Sahel (82). Sahelian soils are also shallower, have poorer texture, are prone to greater erosion, and have lower water-holding capacities than do soils in Asia (93).

Given the current state of water control and conservation, analysts are reassessing the appropriateness of the high input-dependent seed/fertilizer technologies for the Sahel (47, 51, 54). Sahelian farmers have generally rejected this approach because HYV's rarely outperform traditional crop varieties in areas with low soil fertility and soil moisture (54). In addition, applying fertilizers in semiarid regions lacking water control is very risky, with a high probability of economic loss (62). These technologies do little to improve soil moisture and maintain soil fertility in the long run—the most pressing problems in Sahelian agriculture.

## Improved Soil- and Water-Management Technologies

Making more water available and improving soil conditions are needed to improve the environment for crop growth and enhance agricultural productivity in the Sahel (62, 82). Research has focused on a variety of farm-level technologies in the Sahel aimed at improving land and water management, soil fertility, and the returns to scarce factors of production. The following techniques, all practiced to some extent in the Sahel, seem to have potential for the dry-land areas. These emerging technologies enhance the soil for crop and livestock production and improve general farming practices. Although they can create the kind of agronomic conditions necessary for a Sahelian Green Revolution, these approaches have not been widely adopted by farmers.

**Tied Ridges** This technique involves first pushing the soil into ridges and then constructing small dikes across the furrows, creating a depression where water accumulates instead of running off. Crops planted on the ridges receive greater and longer access to water throughout the season.

Tied ridges promote soil fertility and increase yields by conserving water and limiting erosion. Sanders, Nagy, and Shapiro reported that tied ridges increased sorghum yields between 29–71 percent in recent farm-level trials in Burkina Faso (82). Dugue (23); Nicou and Charreau (66); and Ohm, Nagy, and Sawadogo (70) also found consistently higher yields in tied-ridge fields in various semiarid environments. Day and Aillery (16) estimated that with small amounts of fertilizer and good farm management, conserving soil moisture could provide two-fold to fourfold increases in farm income and 60- to 90-percent increases in output. Other water-conservation techniques include depressions around the base of plants to capture rainfall, small catchment basins scattered throughout fields, stone or earth ridges on the contours (diguettes), wider spacing of plants, and planting across the furrows.

**Animal Traction** Soil tillage in Africa is very labor-intensive, traditionally performed by hand. Animal traction (ox and donkey) was introduced in the Sahel at the beginning of this century, and is used on 10 to 15 percent of cultivated area (18). Animal traction in the Sahel is primarily used for seeding and weeding operations and very irregularly for soil tillage, except in the more humid south, where cotton is grown as a cash crop (66).

Animal traction generally improves the land by increasing soil porosity, water infiltration, and conser-

vation of stored water. With this technique, more area can be cultivated with less labor.

**Fertilization** Soil fertility declines without chemical and organic fertilization. Extensive, shifting cultivation practices have an increasingly limited future in the Sahel as land pressures increase and fallowing systems break down (73). The expected shift toward intensification and continuous cropping will require cultural practices that restore fertility. While nitrogen and phosphate fertilizers can substantially increase yields of all food grains, hybrid varieties respond better to fertilizers than do traditional varieties (70, 73).

Integrating crop and livestock farming can provide manure, a way to expand use of organic fertilizers. Farms in densely settled regions need stables for the livestock and fodder and feed supplements, which then require a more intensive crop production system. Natural deposits of rock phosphate found in several locations in the Sahel (Mali, Niger, and Chad) could provide the needed phosphate, but processing improvements are necessary for widespread commercial viability.

**Anti-Erosion Dikes and Bunds** Dikes and bunds are barriers across runoff areas, created with bundles of stalks and branches fixed to the ground with stakes, or with low walls of rock or rock and earth. Dikes and bunds increase rainfall infiltration, limit land degradation from soil erosion, and limit the loss of manure and organic matter that would otherwise be washed-off from fields without runoff control. Wright found statistically significant yield improvements on farmer millet and sorghum fields in Burkina Faso from the use of anti-erosion barriers of this type (103).

**Mulching** Mulching consists of leaving crop residues on the soil surface to limit runoff and erosion, reduce evaporation, and enrich the soil with organic matter (66). The benefits of mulching are very sensitive to the volume of residue used on soil surfaces.

**Agroforestry and Alley Cropping** Planting trees in crop fields improves soil fertility through the nitrogen-fixing properties of the trees, provides shade and protects the soil from the scorching effects of the sun, provides a source of mulch, reduces erosion, recycles soil nutrients from the lower soil strata, and provides a source of firewood and animal forage.

Other potentially promising soil-management techniques include more efficient integration of crop and livestock production, use of green manuring and leguminous fodder crops for improving soil fertility,

and use of blue-green algae and other nonleguminous crops for nitrogen-fixing (54, 103).

## Constraints to Technology Diffusion in the Sahel

If the previously described techniques are viable, then why are they not widely used throughout the Sahel? The extent to which a given technology will be accepted by farmers depends on the characteristics of the technology and its compatibility with the physical environment, resources of the farming system, farmers' goals and adoption criteria, existing marketing institutions and rural infrastructure, and government policies that affect the farm sector (8).

### The Physical Environment

Crop and livestock production technologies must be tailored to the extreme climate and weather conditions and poor soil resources of the region. Because of the specific soil and water conditions, many areas of the Sahel are not receptive to some important technologies. The growing season is short. Precipitation is generally low and always irregular and unpredictable. Temperatures during the growing season are high, leading to high evaporation and crop water demands. Rainfall is intense and erosive. The soil surface often forms a hard crust that is difficult to break at land-preparation time. Soils also frequently seal-over following rains, causing increased surface runoff and decreased infiltration (38, 46). And much of the arable area in the Sahel is in fragile and low-fertility soils (82). These physical conditions constrain the use of tied ridges, animal traction, fertilization, and mulching.

**Tied Ridging** Tied ridging significantly improved yields in medium- to high-quality soils. Yet the effects on the poorer bush soils that constitute a large portion of cultivated land in the Sahel are less encouraging (78). Tied ridging does not appear to be viable on sandy soils, because the ridges easily wash or blow away. Upkeep of the ridges in this environment would require substantially more labor. Nicou and Charreau suggest that under such conditions, it is preferable to perform tilling later in the season so the ridges may at least be strong by plant blossoming, a very stress-sensitive period of plant growth (66). However, one must consider whether construction of tied ridges provides greater returns to labor than competing farm or off-farm activities.

Tied ridges increase yield more than simple ridges, except in lowland areas (66). The need for contour-

ing increases as the slope of the land becomes steeper. Yet the potential for breakdown makes tied ridging less viable on slopes greater than 3–4 percent in humid regions (46).

**Animal Traction** Although 125 animal traction (AT) projects have been initiated in French-speaking West Africa since the 1930's, farmer adoption remains spotty (18). Many farmers abandon animal traction after a short period of use. While nonadoption or abandonment is related to conflicts between AT and the resources and goals of low-resource farmers (examined later), there are several technical constraints.

The effectiveness of plowing with animals is limited. Donkeys, the primary traction animal in many areas, are not strong enough for intensive land preparation during the planting period. Oxen are often weakened by inadequate diets during the dry season. Poor health and high mortality of draft animals reduce the capacity of farmers to follow crop production calendars (that assume maximum animal health and efficiency) recommended by extension services (97).

Plowing is difficult in some areas until the first major rains have softened the soil. However, plowing at this time causes delays in planting and can thus reduce yields (16). Considering the importance of the timing of planting for the success of the crop, it is understandable why plowing whole fields with AT is subordinated to planting in pockets at this critical period. AT plowing is especially limited where the rainy season is short and sporadic, and where the soil does not support production of the higher valued cash crops that may generate the investment capital needed for profitable AT use. The parts of the Sahel where AT use is highest—southern Mali and southwestern Burkina Faso—have longer rainy seasons and produce cotton as a cash crop.

AT could accelerate soil deterioration and erosion in the absence of measures that improve soil fertility (66).

Small family size appears to impede AT use. Six or more family members appear to be necessary to profitably use a draft team. A study in Burkina Faso showed that families using AT were about twice as large as those not using AT (41).

There appears to be a long learning-curve phenomenon associated with AT. Training animals to perform takes time and effort. Jaeger concludes that it takes 3 to 5 years for farmers to master the technology (41). Farmers who are unable to devote the time and investment costs to becoming better AT operators and

managers may achieve only marginally better returns than with hand tillage and may soon give up (41).

**Fertilization** Use of chemical fertilizers is rare, averaging 6.4, 1.0, and 4.7 kilograms per hectare of arable land in Mali, Niger, and Senegal, respectively (88). Chemical fertilization is risky in semiarid areas such as the Sahel because it requires adequate water at the critical stages of plant development to be profitable. Use, therefore, is low, especially on local crop varieties. But response rates improve dramatically when fertilizers are used with improved water-control techniques (63).

High marketing costs also constrain the demand for fertilizer. Landlocked Sahelian countries without local petrochemical industries incur high transportation costs in order to make fertilizers available to farmers. Even when economically viable, fertilization remains low in many rural areas because of poorly developed input markets. Weak fertilizer marketing systems also impede the use of other technologies whose profitability depends on adequate soil fertility.

Moreover, chemical fertilizer does little to enhance soil fertility over the long run. More intensive cultivation requires complementary applications of organic matter to sustain an agricultural system.

**Mulching** Reduced evaporation is a key condition for increased yields in dry regions. The moisture-retaining advantages of mulching are directly related to the volume of mulch put on top of the soil. In the Sahel, crop residues are the main, and sometimes the only practical, source of mulching material. If crop output from the previous season was low, the quantity of residue may be insufficient to significantly benefit the farmer. Inadequate supply is the major constraint to adopting mulching. There are many competing demands for crop residue, such as livestock fodder, fuel, and construction material.

No one particular technology package will likely be viable throughout the Sahel, because environmental conditions vary considerably. Agriculture is site-specific; what works in one location may not work in another, even in the same country. Soil composition and fertility, the degree of population pressure on the land, the amount of rainfall, and the crop mix vary from area to area.

### **Farmers' Goals and Technology Adoption Criteria**

The crops grown and the technologies used on farms depend on farmers' resources, goals, and deci-

sion criteria. These factors must be considered together, because the resources available to farmers largely determine the goals they strive to fulfill, which then help establish the basis for many farm-management decisions (8). A detailed treatment of the objective functions and decision behavior of subsistence farmers in the Sahel is beyond the scope of this report [see Dupriez (25) for a more complete treatment of these issues].

We discuss four factors that weigh heavily in decisions regarding the adoption of new technologies: farmers' sequential versus "package" adoption preferences; farmers' attitudes toward risk; the availability of, and economic returns to, scarce labor; and the capital outlays required for investment in new practices.

**Adoption Preferences** Farmers must decide which technologies to adopt and how to combine them. The technologies considered above complement each other. For example, the yield effects of tied ridges and fertilizer are greater together than is the sum of measured increases when each technique is applied alone (61, 78). Clear superiority of any one technique over traditional practices is not always assured unless a combination of two or more new techniques is adopted.

"Package" adoption, such as combining animal traction, tied ridges, and chemical fertilization into an operational package, differs from the typical sequential adoption patterns followed by subsistence farmers (25, 27). Information about the behavior of subsistence farmers suggests that they are reluctant to invest simultaneously in innovations with which they have little experience. Simultaneously mastering several new techniques requiring substantial changes in the household's resource allocation is understandably difficult. Moreover, the learning curve associated with new adoption shows a rationale to master one component quickly and benefit from its proper use rather than making slower progress in attempting to learn several new methods at once.

AT appears to achieve the greatest returns when used on high-quality soils. The economic viability of AT on poorer soils is uncertain. In such cases, the success of AT to enhance land productivity depends on related soil- and water-management techniques (50, 51, 67). For example, tied ridges and fertilization have significantly increased the productivity of AT in Burkina Faso (61). Without these complementary practices, AT in eastern Burkina Faso was profitable only with a subsidized credit rate and high salvage value of mature oxen (4).

Manual construction of tied ridges requires much labor at times that compete with planting and weeding activities (62). Tied ridges seem most economical when constructed with labor-conserving ridgers drawn by AT (82).

Fertilizer by itself also appears to be a questionable technology in many arid regions of the Sahel, since the risk of losing the cash outlay is significant without more effective water control. On the other hand, yields from fields prepared with tied ridges without fertilization are constrained by relatively lower soil fertility (62). Although tied ridges alone can alleviate erosion, they cannot combat low soil fertility. Nagy, Ames, and Ohm concluded from their Burkina Faso study that "only when used in combination do the two technologies provide a substantial net return and return per hour of additional labor at a level of risk of losing the cash outlay that may be acceptable to farmers" (62).

Despite the clear benefits on yields when used together, the package of tied ridges, fertilization, and AT has made slow inroads over the years. The simultaneous adoption of these techniques constitutes a major change in traditional Sahelian farming systems and may be perceived as very risky to Sahelian farmers. Yet, adopting one technique without another may impede the viability of either.

**Risk Reduction** Uncertainty connected with farm output and economic returns pervades farming everywhere, but the risks associated with uncertainty are much greater for those living on the edge of subsistence. The major source of uncertainty in Sahelian agriculture is the highly variable and unpredictable seasonal rainfall. Other causes are the existence of a wide range of crop and animal pests, unforeseeable price fluctuations for farm inputs and outputs, unreliable input availability, sudden influences of price-depressing food aid, and government policies that make farming risky.

Subsistence farmers in a naturally difficult and unpredictable environment cannot afford to make mistakes that may jeopardize their very survival. Uncertainty and the limited reserves held by the majority of farmers have the effect, therefore, of producing very strong risk-averse attitudes and behavior patterns. In the face of uncertainty, farmers tend to follow safe, time-tested production and marketing strategies.

It is difficult for risk-averse, low-resource Sahelian farmers to adopt a new farming technique. Adopting new technologies involves consideration of the finan-

cial outlays and also the costs of getting information about the technique, the costs associated with the risk of using it, and the psychological costs that stem from a resistance to change. Even if technically and economically viable, a new practice may not be readily adopted until the subjective risk of adoption decreases as farmers observe the experiences of early adopters under conditions similar to their own.

Use of technologies such as chemical fertilizers and new HYV's has fared poorly in the Sahel, partly because the technologies are too risky without assured soil moisture. Techniques that stress planting single crops in rows also appear poorly geared to farmers' risk preferences: traditional intercropping (planting a crop between the rows of another crop) practices are better designed to reduce risk of disease and pest damage (68).

Risk-averse farmers also seem to exhibit: reluctance to depend on unreliable markets as a primary source of items for household food consumption (20); large family size, which helps to ensure an adequate supply of farm labor; and a preference for local seed varieties that are adapted to different forms of risk rather than high-yielding but drought- and disease-sensitive varieties (97).

New technologies must be compatible with subsistence farmers' risk-minimizing objectives and food needs. Techniques that increase average yields or average net farm income over a series of good and bad conditions, but also increase their variability from year to year, are not the kind of change farmers want. Norman observes that:

The relatively low incomes of farmers seriously hamper their ability to shoulder much risk. This implies that adoption of new technology will be much greater if, in addition to proved increased profitability, the risk or standard deviation in returns of the improved technology is the same or preferably less than traditional technology (68).

**Returns to Labor** Rainfall conditions throughout the Sahel compress almost all dryland crop cultivation into a very short period, putting great demands on family labor. Evidence suggests that labor shortages at peak periods during the production season constrain farmers' ability to make greater use of new soil- and water-management technologies (27, 63). Labor shortages occur even in densely populated areas, such as in Burkina Faso's Mossi Plateau (78) and northern Nigeria's Zaria region (68), where the

area planted to millet was constrained not by land but by labor during planting time. Local nonfarm employment opportunities, increased school attendance, urban and foreign migration of working adults, and/or cultural customs and activities prevent farmers from using labor much beyond that available from the family (51). Roth and Sanders found that in the highly populated Mossi region of Burkina Faso, less than 10 percent of agricultural labor worked on a hired or exchange basis (78).

Some of these factors, however, do not reflect labor shortages *per se*. Rather, they indicate the effects of the low productivity of agricultural labor, which has induced people to work off the farm. If a technology increased labor productivity, households might reallocate labor back to agriculture, thus removing the labor constraint.

Because productivity is usually measured with respect to the scarcity factor, output per labor hour may be a more meaningful measure of productivity than output per hectare in regions with a short supply of labor (14, 19, 51, 64). In these areas, farmers' choice of technology may be greatly influenced by the relative returns to labor in the peak labor-demand periods (68).

Increased farm-level productivity, therefore, depends on technologies that are compatible with farm labor patterns. New technology must either reduce peak labor bottlenecks by reallocating labor from high demand (expensive) periods to lower demand (cheaper) periods, or the technology must raise the returns to agricultural labor so that labor resources shift from urban to agricultural activities.

Lele (51) reports that urban workers in Africa earn four to nine times more than rural workers. Considering the magnitude of estimated urban-rural income disparities and a generally inelastic labor supply in agriculture, marginal improvements in farm labor productivity (caused by either price policy or technological innovation) cannot be expected to substantially shift labor to farm activities. Therefore, new technology may be more readily accepted if it can shift labor demand from peak to slack periods.

**Returns to Labor with AT.** AT is highly correlated with large family size, indicating a high labor requirement for profitable use (41, 20). Although theoretically labor-saving, AT may actually raise the demand for labor in peak periods when labor poses serious constraints. AT reduced labor requirements on sorghum fields in Burkina Faso by 17 percent in seedbed preparation, but raised requirements by 10 percent at weeding time compared with traditional

hoe cultivation (24). Le Moigne and Rotenhan also conclude that ox-plowing reduces land preparation time but significantly increases the demand for labor for weeding (50, 77). The need for more labor occurs because area expansion that usually accompanies AT increases weeding requirements. Also, weed growth per hectare increases in areas where row cropping is used, because crops must be grown in rows far enough apart to accommodate oxen (18).

Since the greatest labor bottlenecks usually occur during the first weeding, AT may shift labor requirements to the time in which labor is more constrained, reducing the returns to labor in peak periods. Development and adoption of adequate mechanical weeders may significantly reduce this constraint. AT weeders are used in several areas (41) and have permitted increased production of cash crops.

**Returns to Labor with Tied Ridges.** Tied ridges can significantly raise crop yields, especially when combined with fertilization. But ridges—which are usually constructed by hand—are also very labor-intensive. Although yields are higher when tied ridges are constructed at planting time, farmers in Burkina Faso said this activity interferes with their planting schedules. Farmers expressed a priority for getting their principal crops (millet and sorghum) planted as early as possible after the first major rains (78). The technique nevertheless appears to be gaining acceptance, especially in low rainfall areas with available labor, indicating its income-providing and risk-reducing benefits. Researchers concluded that tied ridges and fertilization “. . . can fit into the production system of AT farmers . . . but labor constraints still prevent the technologies from being adopted on all the hectareage . . . Manual tillage farmers would adopt the techniques to a lesser extent than AT farmers” (62). These farmers benefit most from the labor-saving advantages of recently developed animal-drawn ridgers.

**Returns to Labor with Fertilizers.** Fertilization alone does not appear to greatly increase labor demands. But unless highly subsidized, fertilizing cereals may not be economically viable unless used with tied ridges or other water-control practices. In this sense, fertilization is also subject to the labor constraints of those practices.

**Capital Availability** Weak financial markets are both the cause and consequence of low-productivity agricultural techniques. Underdeveloped capital markets lacking risk-sharing mechanisms contribute to low agricultural productivity. “Package” adoption may require cash outlays beyond the means of many low-resource farmers. Many creditors attempt to mini-

mize risk by lending to farmers that have the greatest capacity to repay (5). Under the usufructuary systems that characterize land tenure in the Sahel (where land is not privately owned but rather temporarily provided to individuals by a village authority), small farmers have little collateral. Subsistence farmers represent a particularly high credit risk in areas prone to frequent droughts and lacking institutionalized insurance arrangements. Farmers may not be able to borrow against a project (even with high returns) in the future if creditors have no protection or recourse; as a result, missed opportunities abound (86). The situation generates a gridlock in which creditors are reluctant to lend to farmers with little collateral; and these farmers build up little equity and collateral because they lack access to credit.

Low agricultural productivity also produces weak capital markets. A technologically stagnant agriculture, unable to generate a surplus, clearly affects the level of profits and the supply of capital in rural areas (33, 57). Farmers without access to productivity-increasing technology and with limited access to markets will less fully enter into the cash economy and thus will not participate in the development of rural capital markets.

### The Marketing System

Farm production and marketing improvements affect each other (1). The profitability of new farm technology often hinges on the organization of the marketing system, because the rates of return on investment in new technology depend on input and output prices determined directly in the marketing system.

The mechanisms of exchange between farmers, wholesalers, and retailers affect the feasibility of technologies. At pre-planting time, for example, the profitability of using commercial inputs depends on the probability of timely delivery, the level of input and output prices throughout the marketing year, the degree of predictability associated with future input and output prices later in the season, and access to credit.

Government marketing boards have received mixed reviews over the past decade regarding their ability to stimulate input use among farmers. The most common criticisms include:

- Low producer prices that inhibit production incentives and investments.
- Under-investment in physical infrastructure, such as feeder roads and communications, that

could improve market access and reduce per-unit transportation costs.

- Inadequate and late delivery of input supplies, especially of fertilizer.
- Subsidies on government-distributed inputs, which impede the emergence of private input traders.

It would be grossly inaccurate, however, to conclude that replacing government marketing institutions with private open-market trading would solve the marketing problems in the Sahel. Uncertainty, high transaction costs, and opportunistic behavior pervade traditional African markets. Substantial public support may be required to create a well-functioning private trade (86, 93). Shultz's "efficient but poor" description can be applied to the marketing system to illustrate that while the private sector operates fairly efficiently given the normal constraints present in African economies, its longrun performance is clearly not desirable or optimal (85).

It should be stressed that technology adoption depends not just on input markets. Volatile and unpredictable price swings common in Sahelian commodity markets send confusing signals to producers and increase the risks of investing in food production for the market. If grain production is an unreliable source of income, few surpluses are produced or marketed. This reduces private sector trading in the area, which in turn reduces the availability of new technology. Without more stable and reliable markets, investments in new productive technologies may be impeded (44, 68, 87).

### Economic Policies

Economic policies can stimulate or stunt farm-level incentives to adopt new technology (84, 96). Timmer's study on rice milling in Indonesia demonstrates that exchange rates, wage rates, price policy, interest rates, and trade policies strongly affect choice and adoption of particular techniques (94).

**Minimum Wage Rates** Minimum urban wages contribute to the skewed urban-rural income disparities found throughout Africa by drawing labor out of the rural sector. Because labor is a scarce and often limiting factor in Sahelian agriculture, slack or unproductive labor in the urban sector is a serious misallocation of resources. Inflated urban wages also contribute to an inelastic supply of agricultural labor, because marginal increases in returns to farm labor will not significantly reduce the incentive to

remain in urban employment. Urban-rural wage rate disparities, therefore, may strongly limit adoption of even moderately income-enhancing, but labor-intensive, techniques such as tied ridges.

**Food Aid and Food Imports** For a variety of reasons, many African governments attempt to maintain low urban retail grain prices (6, 37). Imports and food aid help achieve this objective. However, without an effective targeting mechanism, consumers of all income classes are subsidized. Injections of foreign grain may depress domestic prices, depending on the size and strength of the domestic market (31, 55). Theoretically, the risks and costs of grain storage should also rise, because unpredicted increases in market volume alter price movements within each season.

Imports and food aid constitute large shares of available food for at least three Sahelian countries for which relevant data are available (table 5). Mali, Niger, and Senegal show rapidly rising dependence on

**Table 5—Declining food self-sufficiency in the Sahel, 1966–83**

Item	Mali	Niger	Senegal
	<i>1,000 tons</i>		
Commercial food imports:			
1966–68	14.0	8.3	234.7
1971–73	47.7	13.3	270.7
1981–83	95.0	29.3	427.3
	<i>Percent</i>		
Annual growth rate, 1966–83	15.3	22.8 <sup>1</sup>	10.8
Ratio of cereal imports to cereal production:			
1966–68	1	1	33
1981–83	9	7	55
	<i>1,000 tons</i>		
Food aid:			
1966–83	0	0	31.6
1971–73	50.4	19.1	30.1
1981–83	54.5	30.3	93.2
	<i>Percent</i>		
Dependence on food aid: <sup>2</sup>			
1966–68	0	0	5.1
1971–73	5.9	3.0	4.6
1981–83	6.1	3.0	9.1
Food aid's share of total marketings: <sup>3</sup>			
1966–83	14.5	14.1	32.8
1981–83	17.7	10.9	44.9

<sup>1</sup> 1966–80 only

<sup>2</sup> A 3-year moving average of the percentage of food available (the sum of production, net imports, food aid, and change in ending stocks) accounted for by food aid.

<sup>3</sup> Proxy estimate: food aid as a share of 25 percent of domestic production

Source: (88)

imported food. Food aid accounted for 9 percent of total food availability in Senegal during 1981–83. Yet these data underestimate the effect of food aid on domestic prices. Where a large portion of production is consumed by households, prices are determined by marketed supplies, not total availability. Analysts generally agree that throughout Africa, smallholder marketings rarely exceed 25 percent of their production, and are usually much less (12, 15). Table 5 provides a rough estimate of food aid's share of total marketings for these Sahelian countries. Small changes in supply caused by imports or food aid may greatly affect producer prices and cash incomes since demand elasticities for staple grains are generally quite low in most developing countries.

These policies very likely will increase the longrun disparity between rural and urban living standards, accelerate urban migration, raise budget deficits, and depress agricultural incentives for technology adoption. Imports and food aid may serve important short-term needs. But without the stimulus of technologies to increase agricultural incentives and production, increasing reliance on food imports may be a cause as well as a result of a stagnant agriculture.

**Exchange Rates and Inflation** Agricultural imports are relatively cheap if a country's exchange rate is overvalued. Although helping urban consumers, overvaluation serves as an implicit tax on agriculture by depressing commodity prices below what would prevail if exchange rates were market-determined.

Macro (general economic) policies that depress agricultural incentives tend to depress land values, which, in turn, reduce the present value of land-augmenting investments that would protect and raise land productivity (90). Overvalued exchange rates also widen rural-urban income disparities, thus producing the same effect on agricultural labor supply as inflated urban wages. Overvaluation does, however, reduce the cost of imported fertilizer, and would probably make its use more cost-effective to farmers.

Inflation and exchange rates are considered together here because inflation can bring fixed exchange rates out of equilibrium. If domestic inflation is rising faster than world rates, which appears to be the case for much of the Sahel (table 6), demand for relatively lower priced imports will increase while foreign demand for the Sahel's export crops will decline, unless local currencies are devalued by a commensurate amount. Without such adjustments, the effects of high inflation cannot promote agricultural productivity, especially in the long run (96).

**Table 6—Annual inflation, selected countries, 1973–84**

Country	Average annual rate of inflation, 1973–84
Chad	N/A
Mali	10.4
Burkina Faso	10.6
The Gambia	N/A
Senegal	9.0
Mauritania	7.7
Niger	11.5
Average for the Sahel	9.84
Average for industrialized countries	7.90
Differential	1.94

N/A = Not available.  
Source: (102).

## Conditions Necessary for Technology Diffusion

The conditions necessary for widespread diffusion of new technologies and farm management practices must be promoted if the agricultural sector is to become more productive. These conditions may be grouped into two categories: those involving soil- and water-management techniques that improve basic practices and exhibit characteristics that farmers want, and those involving the general institutional and economic policy framework that affects the whole farm sector.

### Characteristics of Improved Technologies

To be interested in new innovations, traditional Sahelian farmers must feel that the techniques are compatible with the resources and goals of the household. Given the existing farming system as the starting point for change, new technologies must have specific characteristics.

**New Technologies Must Improve the Agronomic Environment** Techniques must address the basic need to enhance soil fertility and water retention, thus creating an agronomic environment with high potential gains from introducing HYV's. New technologies must also promote a sustainable production system, compatible with more intensive land use that is inevitable given the rapid population growth of the Sahel.

Pieri contends that a relatively intensive, land-augmenting system with high yields is the only production system in the Sahel that can sustain the productivity of the soil and provide adequate financial returns (73). Studies on fertility trends by Siband (89) and by Morel and Quantin (58) suggest that organic

and chemical fertilization, cereal-legume crop rotations, subsoil tillage, and water conservation are desirable and indispensable features of a sustainable agricultural system in the Sahel.

### New Technologies Must Stabilize Farm Returns

Most subsistence households do not have the desire or ability to assume much risk. Therefore, technologies must reduce risk by minimizing losses from low rainfall while performing as well as, or better than, traditional practices during good seasons if the technologies are to be viable alternatives.

**New Technologies Must be Affordable** Most Sahelian producers are low-resource farmers who use few inputs. Financial assets and cash savings are usually low, and terms of borrowing generally reflect the high risk and transaction costs associated with underdeveloped rural capital markets. Farm cash-flows and incomes are highly variable because surplus marketings depend on the weather. New technologies will be used in cereal cultivation only if the cost is low because of the relatively low economic return to most of the principal cereal crops. Expensive technology such as AT may be viable if cultivation of higher valued cash crops provides a source of investment capital. Risk-averse farmers want to minimize the magnitude of the potential loss of cash outlays, suggesting that (other factors being equal) low-cost technologies stand a better chance of adoption than high-cost technologies.

**New Technologies Must Relieve Seasonal Labor Constraints** Seasonal labor shortages constrain productivity in many areas of the Sahel. These shortages impede adoption of soil and water technologies that require much labor. New techniques must reduce labor requirements or shift the use of labor from peak periods to slack periods.

Farmers may need to combine operations to profitably use AT (51, 63). For example, there appears to be a high demand for animal-powered multicultivators that would permit farmers to perform several functions with the same basic set of equipment. Jaeger and Sanders report that multiple use of AT implements (weeders, ploughs, and ridgers) is crucial for overcoming seasonal labor problems and enhancing profitability (42). Combining AT operations can also spread the capital costs of equipment over several activities, produce higher yields, enhance longrun fertility and productivity of the land, and create multiplier effects between the agricultural sector and the small industry sector. The small industry sector would become more active due to increased demand for the services of local blacksmiths, craftspeople, and manufacturers.

The use of herbicides may also boost labor productivity in peak periods, since labor constraints are often seen to be most critical during weeding periods (68). The success of this practice is very sensitive to the efficiency of the marketing system through which such herbicides are distributed.

Faster maturing seed varieties may also reduce seasonal labor constraints, especially during harvest periods (40). For example, by planting faster maturing maize with slower maturing millet or sorghum, labor demands can be staggered to reduce peak period bottlenecks.

**New Technologies Must Apply to Food Crop Production** Small, risk-averse farm households will generally devote most of their land to food crops to feed the family because rural food markets are unreliable and have highly volatile prices. New technologies will be more widely used if they apply to the dominant staple food crops such as millet, sorghum, and maize, which account for about 90 percent of all cultivated area in the Sahel (87). This is especially true in the regions of the Sahel where climate or lack of marketing infrastructure prohibits significant cash crop production. Constraints to food production can be alleviated in areas where cash crop cultivation facilitates adoption of new soil- and water-management techniques (92).

### **Institutional and Policy Conditions**

The question of technology adoption cannot be addressed apart from critical institutional and policy considerations that affect the decisions of rural farmers. More productive, sustainable soil and water technologies as well as conducive legal, marketing, financial, and general policy environments are complementary inputs in agricultural production. Without soil and water technologies, yields and productivity in the Sahel will decline over time. Without viable institutional policies, incentives to adopt otherwise viable technology may not exist.

**Land Tenure** Emerging evidence indicates a strong relationship among increasing population pressure, soil degradation, and declining labor productivity with traditional technology (74). Traditional land-use patterns based on shifting cultivation and long fallow periods have been feasible in the past with lower population densities. But, population growth and resulting land pressures are making traditional practices infeasible, especially in semiarid or arid regions with poorer, shallow types of soils found in much of the Sahel (71, 97). The capacity for agricultural production throughout the Sahel in the

medium to long term will be reduced if soil loss is allowed to continue at current rates (90, 98).

Greater incentives for farmers to invest in land-conserving and land-augmenting techniques and practices need to be developed and put in place. Southgate, Hitzhusen, and MacGregor consider that changing property laws in developing countries could promote resource conservation and technology change in agriculture (90). Incentives to conserve the soil are relatively weak in usufructuary property right systems. For example, a farmer who perceives that it is possible to lose long-term access to a particular plot of land is less willing to incur the short-run costs to enhance the future productivity of that plot. By foregoing cultivation to restore soil fertility, the farmer may lose access to the land as well as the income from not farming it.

Additional research on the relationships between land tenure and land use may provide a better understanding of how to stimulate adoption of agricultural technology. The Office of Technology Assessment concluded:

Reforms in land tenure and other legal and informal systems determining access to and control of natural resources are policy questions needing better analysis. A major constraint to effective analysis of the impact of land tenure and resource access is the lack of knowledge of the traditional rules and customs that are often more influential in determining use patterns than formal laws. Evidence of rapid changes and of disruption in what may have been the environmental balance in these traditional systems as the result of drought, the growth of the market economy, the introduction of new public domain laws, and increased population pressures underline the urgency of these aspects of policy (71).

**Private and Social Returns to Investment** Because poor people living at subsistence levels have high current cash needs, they may be reluctant to make investments with only long-run benefits. However, such investments may be very important for the long-run productivity of agriculture in the Sahel.

Investment in new technology benefits society if the economic rate of return exceeds the social time preference rate (the rate that expresses the preference of society as a whole for present returns rather than future returns) (32). But investments in soil and water conservation are attractive to farmers only when the rate of return on the investment is higher than

the farmer's time preference rate. However, the time preference rates of poor people living at subsistence levels appear to be higher than typically estimated social time preference rates, because the immediate needs of the poor are usually very pressing (90). Therefore, investments with mainly longrun payoffs may be socially attractive, but would not be viable to an individual farmer. That is, a high time preference rate reflects immediate cash needs, while a low rate reflects a greater willingness to make investments with longer run payoffs. This would result in an underinvestment of new technologies. For example, numerous studies indicate that AT requires at least 6 to 8 years to achieve full economic benefits, suggesting negative net benefits during the early years of adoption (54). Even though such investments may be socially worthwhile as measured by internal economic returns, the investments may be unattractive to subsistence farmers with high current cash needs. In such situations, social welfare may be increased by driving private time preference rates down through credit or subsidy arrangements to encourage land-augmenting investments with primarily longrun payoffs.

Soil conservation efforts may require individual farmers to forego short-term gains (such as fallowing land to which the farmer has usufructuary rights that could otherwise have been farmed for immediate gain). Because a broad cross-section of society benefits from the conservation methods, especially in the long run, it is questionable whether the farmer should absorb all the costs associated with the needed remedial measures. For example, the U.S. Government has spent over \$15 billion to finance a range of subsidized domestic conservation programs since the 1930's (72). The ability of local governments to finance broad conservation schemes is extremely limited in the Sahel. Nevertheless, private incentives to invest in conservation practices having longrun social benefits are crucial and need to be strengthened.

**Credit** Credit availability and the performance of rural financial markets influence the adoption of technologies requiring high cash outlays. Sahelian farmers frequently attribute failure to adopt new technology to a lack of affordable credit (25, 63, 60). We must determine whether this common response reflects a true credit constraint or simply a lack of economically viable technology.

Use of new technologies generally requires a cash outlay, making farmers more vulnerable to price swings (57) and to cash shortages. But many farmers have their own ways of raising capital when it is

needed (7, 11). Credit policy should recognize the potential for farmers to finance their own technological change (57). A major issue is whether these informal capital markets are relatively efficient or whether transaction costs, high risk premiums, and other costs of borrowing borne by farmers impede or prohibit adoption of new productive technologies where they might otherwise be used in a more favorable credit environment. Problems of implementation have plagued credit programs throughout the developing world (5). The transactions cost of receiving credit, disbursed to individual farmers in small amounts and through frequent transactions, often amounts to as much as 60 to 100 percent of the credit advanced (33).

Poor credit availability may be both a cause and a consequence of low agricultural productivity, resulting in a low-input, low-productivity farm sector. High risk of crop failure—and thus nonrepayment of credit—in the Sahel invariably increases interest rates. Low cash resources (caused by poor agronomic conditions that permit production of mainly low-value coarse grains) inhibit the savings necessary to self-finance investment in new technology. Farmers in such an environment cannot contribute much to the growth of local capital markets. This balance of low-input, low-productivity farming reflects the relationship between poor agronomic conditions, low incentives to adopt new technology, constrained rural capital markets, and agricultural stagnation.

Given the longrun need for increased land conservation by dryland farmers, it is necessary to know where the most serious land degradation problems occur and how much farmers must be compensated before they will adopt improved soil-management practices. The political process can then determine where and how much scarce government credit should be allocated to enhance social welfare through more rapid farm technology transfer in dryland areas.

#### **Coarse Grain Demand and Technology Transfer**

The potential for increased technology adoption cannot be fully considered apart from commodity demand. Although millet and sorghum constitute the bulk of dryland cultivation, the importance of these grains in Sahelian diets is falling due to rapidly increasing rice and wheat imports (87). Urbanization is largely responsible for this consumption shift, because rice is easier and quicker to prepare and requires less cooking fuel, which are particularly important issues in urban areas (17). Depressed demand for domestic crops invariably reduces farm prices, net returns to surplus production, and the

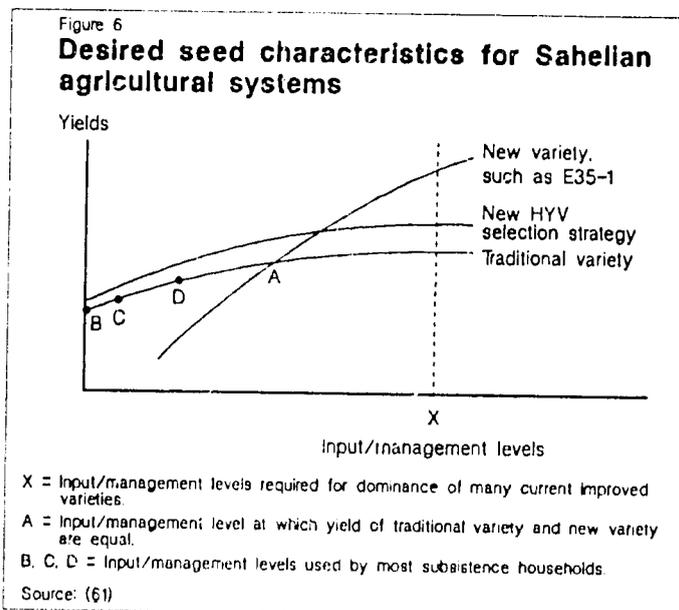
economic payoff to new technology. Soil and water technologies that require cash outlays will likely yield low economic returns and suffer low adoption rates in this kind of environment.

Strategies are needed to increase the demand for domestic cereals. Raising that demand would raise farm prices and the incentive to invest in productivity-increasing technology. For example, improved processing techniques that reduce cooking time and cost and appeal more to urban tastes may increase urban demand for sorghum and millet. Methods to process millet to taste similar to rice can do the same (71). Reduced consumer subsidies on imported grains would also improve the demand for local cereals.

**Improved Seed** An improved agronomic environment can create considerably greater potential for the successful introduction of new HYV's. Sanders, Nagy, and Shapiro stress that crop breeding must follow and be geared to an improved agronomic environment (82).

But we must realistically evaluate the potential for current soil- and water-management techniques to transform the agronomic environment. Use of tied ridges, diking and contouring, fertilization, animal traction, mulching, and windbreaks can conserve the resource base, can increase and stabilize crop production, and can be adopted given existing local resources (except for fertilization). However, these techniques cannot ensure a harvest in a low-rainfall year. For example, tied ridges cannot improve infiltration for the benefit of crops if the rains do not come at critical periods. Fertilization cannot complement high-yielding, input-dependent seed varieties if the input delivery system to rural areas is erratic or ineffective. HYV's must be successful within the present context of sporadic input availability, poor market infrastructure, limited farm-level capital, and low and erratic rainfall.

New seed varieties should be capable of outperforming traditional varieties at low levels of management and fertilization, reflecting the current low-input orientation in the Sahel (fig. 6). The poor record of HYV adoption in the region has been traced to excessive emphasis on input-dependent varieties that provide high yields under controlled research-station conditions, which bear little resemblance to typical subsistence farm conditions (54). The dramatic HYV-driven yield increases of the Green Revolution in Asia may not be expected in the Sahel unless agronomic and input-marketing constraints are alleviated. Several international centers have re-oriented



their breeding strategies (as shown in fig. 6) to combat these constraints.

Because of the Sahel's harsh rainfall and soil conditions, breeding strategies must improve drought tolerance, seedling vigor, and disease resistance. Varieties with shorter crop cycles or modified plant structures may also hold considerable promise for the Sahel. Improvements in seed varieties should require less from, and depend less on, a country's input distribution system or extension capabilities in order to raise farm productivity and income. By following these breeding strategies in the short run, new crop improvements will be more robust to the unavoidably difficult growing conditions in the region.

**Extension** The pace of acceptance influences the rate of growth in production that an innovation provides. An innovation that doubles production provides only a 3-percent growth rate if diffusion occurs evenly over a period of 25 years (57). Yet, if accepted by all farmers in 8 years, the innovation raises production 10 percent. Extension services must vigorously promote new technology adoption if the technology is to have a meaningful impact.

Although a given technology may be economically viable under certain conditions replicable on producers' fields, the farmer's subjective evaluation of its profitability and risk are the critical determinants of adoption. A well-trained extension service can help bridge the gap between the widely differing objective and subjective evaluations (68).

Moreover, much new agricultural technology is location-specific, which potentially allows large pockets of the

region to be bypassed by the diffusion process. Local research and extension resources can help merge new technologies and local farming practices. Adapting general agricultural techniques to particular farming environments is a major responsibility of local research and extension (71).

**Marketing and Policy Considerations** The level and reliability of input and output prices influence adoption of new technology (36). Risk and uncertainty heighten the potential for inefficient resource allocation and the potential for a loss of output from a given bundle of resources.

Institutions and policies designed to reduce price uncertainty and volatility, without draining the national budget, can spread adoption of new technologies. More research on small-farm and trader responses to price risk is needed to evaluate the dynamic costs and benefits of these strategies.

A reliable input delivery system is needed to increase technology adoption. For example, successful AT requires reliable veterinary supplies, medicine, and equipment. Some success has been noted with vertically integrated crop marketing organizations that have actively promoted the adoption of AT through comprehensive support of input needs and reliable market access for surplus production (54).

Many Sahelian countries have emphasized food self-sufficiency in their national development plans (14). Achieving this objective may depend not only on viable technology, but also on carefully guided policies, some of which may be politically unpopular. For example, in the absence of labor-saving technologies, labor shortages may be mitigated somewhat by reducing the gap between rural and urban incomes. If this is done by raising agricultural prices, governments may incur sizable operating deficits unless urban retail prices increase. If it is done by lowering urban wages or real incomes, urban interests can affect political stability, and often have (6).

Wage rate, interest rate, trade, and food aid policies are powerful tools for influencing incentives in agriculture. Efforts to promote the adoption of viable technology must include a conducive economic environment for success (96).

## Conclusions

Rainfed agriculture supports 80 percent of the Sahel's 38 million inhabitants. The high population growth rate, averaging 2.8 percent per year, means

that total population in the region will double in 25 years. This population growth rate, coupled with lower per-capita food production since 1970 (primarily due to declining yields), has increased the dependence on food imports and food aid throughout the Sahel. The food situation and the land degradation and desertification problems will probably worsen over time. These problems are caused in part by cultivation practices incompatible with high population densities and more intensive land use.

Because of the limits of large-scale irrigation in the Sahel, productivity in the vast rainfed areas must increase if food production, income, and standards of living are to rise. Improved onfarm soil and water management alone can stimulate agricultural productivity. Better resource management may be of even greater importance in expanding the potential for the successful introduction of new HYV's that require a more fertile agronomic environment.

Adoption of soil- and water-management techniques in the Sahel is highly influenced by the natural environment; farmers' resources, goals, and adoption criteria; and the institutional and economic setting in which crops and livestock are produced. These conditions can seriously constrain or prevent the widespread diffusion of new technology.

The environmental constraints to developing appropriate technology have been underemphasized in recent agricultural policy forums. Some development specialists argue that agricultural growth is mainly a matter of getting the "right" set of prices; that is, prices that create incentives for farmers to operate more efficiently. While farmers will produce more efficiently with better prices, farmers will do so *only* with the existing production resources.

A new production function based on technology that is fully integrated with proven traditional methods and the cultural setting is needed along with appropriate price signals. Without land and water conservation, price incentives may simply intensify current cultivation practices and continue to encourage the degradation of land at the expense of longrun sustainable agriculture.

The relationship between new technologies, improved farm management, and the physical and socioeconomic environment in which they operate is complex. The environment sometimes prohibits the use of some production practices, such as tied ridges on sandy soils. But sometimes technologies such as mulching can modify the environment. Technologies may be compatible with certain environmental as-

pects, but not others. For instance, tied ridges may be technically feasible on heavier soils but beyond farmers' means because of availability or timing of required labor. Because of the variation in soils, climate, infrastructure, and policies in the Sahel, it is difficult to identify technological innovations that are viable options without information about specific situations. However, the following are some general guidelines that may be helpful.

Technology in the Sahel needs to improve soil fertility and increase soil moisture. Without improved fertility and better means of capturing and storing water for plant use, crop and livestock production will not significantly increase.

Farm returns need to be stabilized. More stable agricultural returns will enhance investment incentives. Viable technologies must minimize losses resulting from low rainfall while equaling or outperforming traditional practices during average or normal seasons.

New technologies should apply to staple grain crops, which account for 90 percent of cultivated area in the Sahel, if they are to affect overall agricultural productivity and rural diets. This is especially imperative where climate and/or marketing infrastructure prohibit cash crop production. Risk-averse farmers will devote most resources to meet family food needs when rural food markets are unreliable.

New technologies must be affordable to the low-resource, capital-limited Sahelian farmers.

New technologies and/or management practices will be more readily adopted if they reduce farm labor requirements or shift labor from peak to slack periods. Labor shortages are likely to arise at certain stages of the crop production cycle, such as tilling, planting, and weeding stages.

Farmers' incentives to adopt new technologies also depend on institutions and policy conditions. More secure land tenure arrangements will create an incentive for farmers to invest in land-conserving techniques and practices.

Improved access to production credit with low transaction costs is also needed. The terms of credit should reflect the fact that much of the returns to land- and water-conserving practices accrue over a long time.

Credit arrangements and/or other means of assisting farmers to make necessary capital improvements

should be designed so that society shares some portion of the cost with farmers. Some of the long-term benefits of resource conservation will also be enjoyed by society.

Demand for domestic food and fiber commodities needs to be stimulated, or else there will be little economic incentive to produce them for the market.

A reliable input delivery and support system is needed to increase technology adoption. Extension systems must be strengthened to increase farmer knowledge and understanding of new technological options.

Successful efforts to promote the adoption of viable technology must include a conducive general policy environment. Wage rate, interest rate, trade, and food aid policies are powerful tools for influencing incentives in agriculture.

Further increases in population density will soon push the returns per hectare with traditional rainfed technology to an upper limit. Substantially increasing this return depends on improved yields, which, in turn, depend on labor-saving and risk-reducing soil- and water-management practices. The resulting improved agronomic environment will also be important for the introduction of high-yielding crop varieties. Better resource management must receive greater attention in the Sahel's efforts to align food production growth with rapidly expanding population.

## References

- (1) Abbott, J. "Agricultural Marketing Mechanisms," *Agricultural Marketing Policy*, Dieter Elz and C. Hoisington, eds. Economic Development Institute, The World Bank, 1985.
- (2) Askari, H., and T. Cummings. "Estimating Agricultural Supply Response with the Nerlove Model: A Survey," *International Economic Review*, Vol. 18, No. 2, 1977.
- (3) Ayer, H., and G.E. Schuh. "Social Rates of Return: Cotton Research in Sao Paulo," *American Journal of Agricultural Economics*, Nov. 1972, pp. 557-69.
- (4) Barrett, V., G. Lassiter, D. Wilcock, D. Baker, and E. Crawford. *Animal Traction in Eastern Upper Volta: A Technical, Economic, and Institutional Analysis*, International Development

- Paper No. 4. East Lansing, MI: Dept. Agr. Econ., Michigan State Univ., 1981.
- (5) Basu, K. *The Less Developed Economy: A Critique of Contemporary Theory*. New York, NY: Basil Blackwell Inc., 1984.
  - (6) Bates, R. *Markets and States in Tropical Africa: The Political Basis of Agricultural Policies*. Berkeley, CA: Univ. California Press, 1981.
  - (7) Belloncle, G. "Non-Formal Education and Farm Cooperatives in West Africa," Occasional Paper No. 8. Non-Formal Education Information Center, Michigan State Univ.-East Lansing, 1982.
  - (8) Bernstein, R. "Pre-Screening Alternative Component Technologies to Identify Probable Constraints to Farmer Adoption," Draft paper presented for the Cropping Systems Economic Training Program. Bogor, Indonesia, 1980.
  - (9) Biswas, A. "Irrigation in Africa," *Land Use Policy*, Vol. 3, No. 4, 1986, pp. 269-85.
  - (10) Bingen, R. *Food Production and Rural Development in the Sahel: Lessons From Mali's Operation Riz-Segou*. Boulder, CO: Westview Press, 1985.
  - (11) Blackie, M. "Restructuring Agricultural Delivery Systems in Sub-Saharan Africa: A Case Study of Zimbabwe," Department of Land Management Working Paper, Univ. Zimbabwe, 1984.
  - (12) Bremer, J., and L. Ellsworth. "Consolidating Cereal Market Reform in Mali: An Analysis of Current and Potential Roles for Public and Private Sector Institutions in the Grain Market," Report prepared for USAID Bamako, Mali, 1986.
  - (13) Bromley, D. "Markets and Agricultural Development: The Promise and the Challenge," Unpublished working paper. Dept. Agr. Econ., Univ. of Wisconsin-Madison, 1986.
  - (14) Christensen, C., A. Dommen, N. Horenstein, S. Pryor, P. Riley, S. Shapouri, and H. Steiner. *Food Problems and Prospects in Sub-Saharan Africa*, FAER-166. Econ. Res. Serv., U.S. Dept. Agr., 1981.
  - (15) CILSS (Comite Perminant Inter-Etats du Lutte Contra la Secheresse dans le Sahel). "Cereals Policy Reform in the Sahel," Draft executive summary. CILSS/Club du Sahel, Paris, France, 1985.
  - (16) Day, J.C., and M. Aillery. "Economic Impacts of Soil and Water Management Technologies: Preliminary Results from a Case Study Analysis in Mali," Proceedings of Workshop on Soil, Water, and Crop Management Systems for Rainfed Agriculture in the Sudano-Sahelian Zone. International Crops Research Institute for the Semi-Arid Tropics, Niamey, Niger, 1987.
  - (17) Delgado, C. "The Scope for Price Policy to Slow Down the Consumption of Imported Rice and Wheat in West Africa," Draft working paper. International Food Policy Research Institute, Washington, DC, 1988.
  - (18) Delgado, C., and J. McIntire. "Constraints on Oxen Cultivation in the Sahel," *American Journal of Agricultural Economics*, Vol. 64, No. 2, 1982.
  - (19) Delgado, C., and J. Mellor. "A Structural View of Policy Issues in African Agricultural Development," *American Journal of Agricultural Economics*, Vol. 66, No. 5, Dec. 1984.
  - (20) Dione, J., and J. Staatz. "Market Liberalization and Food Security in Mali," Paper presented at the Third Annual Conference of Farming Systems in Southern Africa. Harare, Zimbabwe, 1987.
  - (21) Dregne, H.E. *Dryland Soil Resources*. Washington, DC: Agency for International Development, 1982.
  - (22) . . . . . "Aridity and Land Degradation," *Environment*, Vol. 16-20, Nos. 28-33, 1985.
  - (23) Dugue, P. "Soil Preparation in the Sudan-Sahelian Zone: Prospects and Constraints," *Appropriate Technologies for Farmers in Semi-Arid West Africa*. West Lafayette, IN: Purdue Univ. Press, 1985.
  - (24) Dupont De Dinechin, B., C. Malcoiffe, and J. D'Arondel de Hayes. "Donnees Actuelles sur l'Association de l'Agriculture et d'Elevage en Haute Volta," *Coloque sur*

- l'Elevage, ed. Paris, France: Institute d'Elevage et de Medicine Veterinaire des Pays Tropicaux, 1969.
- (25) Dupriez, H. *Integrated Rural Development Projects Carried Out in Black Africa with EDF Aid*, Collection Study No. 1. Commission of the European Communities, Brussels-Luxembourg, 1979.
- (26) Eicher, C. "Food Security Research Priorities in Sub-Saharan Africa." Paper presented at the Organization of African International Drought Symposium, Nairobi, Kenya, 1986.
- (27) Eicher, C., and D. Baker. *Research on Agricultural Development in Sub-Saharan Africa: A Critical Survey*, MSU International Development Paper No. 1. East Lansing, MI: Michigan State Univ. Press, 1982.
- (28) Eicher, C., D. Baker, and J. Staatz. "Food Security Policy in Sub-Saharan Africa," Paper presented at the 19th Conference of the International Association of Agricultural Economists, Malaga, Spain, 1985.
- (29) Food and Agriculture Organization, United Nations. *FAO Production Yearbook*. Rome, Italy, 1985.
- (30) Farmer, G. "Rainfall Variability in Tropical Africa: Some Implications for Policy," *Land Use Policy*, Vol. 3, No. 4, Oct. 1986.
- (31) Fisher, E.M. "A Theoretical Analysis of the Impact of Food Surplus Disposal on Agricultural Production in Recipient Countries," *Journal of Farm Economics*, Vol. 45, 1963, pp. 863-75.
- (32) Gittinger, J.P. *Economic Analysis of Agricultural Projects*. Econ. Devel. Inst., World Bank, 1982.
- (33) Gonzalez-Vega, C. "The Ohio State University's Approach to Rural Financial Markets: A Concept Paper," Unpublished working paper. Dept. Agr. Econ. and Rural Sociology, Ohio State Univ., 1986.
- (34) Griliches, Z. "Research Costs and Social Returns: Hybrid Corn and Related Innovations," *Journal of Political Economy*, Vol. 66, No. 2, 1958, pp. 419-31.
- (35) Hargreaves, G., and Z. Samani. "Rainfed and Water Requirements Manual for Mali," International Irrigation Center, mimeograph. Dept. Agric. and Irrig. Engineering, Utah State Univ.-Logan, 1986.
- (36) Hayami, Y., and V. Ruttan. "Induced Innovation Model of Agricultural Development," *Agricultural Development in the Third World*, C. Eicher and J. Staatz, eds. Baltimore, MD: Johns Hopkins Univ. Press, 1984.
- (37) Hesp, P., and L. van der Laan. "Marketing Boards in Tropical Africa. A Survey," *Marketing Boards in Tropical Africa*, K. Arhin, P. Hesp, and L. van der Laan, eds. London, England: Royal Tropical Institute, 1985.
- (38) Hoogmoed, W.B., and L. Stroosnijer. "Crust Formation on Sandy Soils in the Sahel: Rainfall and Infiltration," *Soil and Tillage Research*, Vol. 4, No. 1, 1984, pp. 5-23.
- (39) Hooper, W.D. "Allocation Efficiency in a Traditional Indian Agriculture," *Journal of Farm Economics*, Vol. 47, No. 2, Aug. 1965.
- (40) International Crop Research Institute for Semi-Arid Tropics. *1984 ICRISAT Cooperative Program in Mali*, Annual Report. Bamako, Mali, 1984.
- (41) Jaeger, W. "Agricultural Mechanization: The Economics of Animal Traction in Burkina Faso," Ph.D. thesis. Stanford Univ., 1984.
- (42) Jaeger, W., and J. Sanders. "Profitability of Animal Traction: Field Study in Burkina Faso," *Appropriate Technologies for Farmers in Semi-Arid West Africa*, H. Ohm and J. Nagy, eds. West Lafayette, IN: Purdue Univ. Press, 1985.
- (43) Jaffee, S. *Somalia Agricultural Sector Survey, Task Force No. 4—Economic Marketing Working Paper No. 2: The Marketing of Grain and Products*. Government of Somalia, 1985.
- (44) Johnson, D.G. *Forward Prices for Agriculture*. Chicago, IL: Univ. of Chicago Press, 1947.
- (45) Krishna, R. "Some Aspects of Agricultural Growth, Price Policy, and Equity," *Food and Research Institute Studies in Agricultural Economics, Trade, and Development*, Vol. 18, No. 3, 1982.

- (46) Lal, R. "Managing the Soils of Sub-Saharan Africa," *Science*, Vol. 236, 1987, pp. 1,069-76.
- (47) Lallemand, D. "Prospects for Rainfed Agriculture in Arid and Semi-Arid Areas of West Africa," Paper presented to the Sixth Agricultural Sector Symposium: Development of Rainfed Agriculture Under Arid and Semi-Arid Conditions. World Bank, Washington, DC, 1985.
- (48) Lamb, P.J., R.A. Pepler, and S. Hastenrath. "International Variability in the Tropical Atlantic," *Nature*, Vol. 322, No. 6,076, 1986, pp. 238-40.
- (49) LeHouerou, H.N. "The Role of Browse in the Sahelian and Sudanian Zones," *Browse in Africa*, H.N. LeHouerou, ed. International Livestock Center for Africa, Addis Ababa, Ethiopia, 1980, pp. 83-100.
- (50) Le Moigne, R. "Animal Draft Cultivation in French-Speaking Africa," Paper presented at a Workshop on Socioeconomic Constraints to Development of Semi-Arid Tropical Agriculture. International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India, 1979.
- (51) Lele, U. *The Design of Rural Development: Lessons from Africa*. Baltimore, MD: Johns Hopkins Univ. Press, 1975.
- (52) . "Rural Africa: Modernization, Equity, and Long-Term Development," *Agricultural Development in the Third World*, C. Eicher and J. Staatz, eds. Baltimore, MD: Johns Hopkins Univ. Press, 1984.
- (53) Massel, B.F. "Farm Management in Peasant Agriculture: An Empirical Study," *Food Research Institute Studies*, Vol. 7, No. 2, 1967.
- (54) Matlon, P., and D. Spencer. "Increasing Food Production in Sub-Saharan Africa: Environmental Problems and Inadequate Technological Solutions," *American Journal of Agricultural Economics*, Vol. 66, No. 5, 1984.
- (55) Maxwell, S.J., and H.W. Singer. "Food Aid to Developing Countries: A Survey," *World Development*, Vol. 7, 1979, pp. 225-47.
- (56) Mellor, J. "Accelerated Growth in Agricultural Production and the Intersectoral Transfer of Resources," *Economic Development and Cultural Change*, Vol. 22, No. 1, Oct. 1973, pp. 1-16.
- (57) . "The Role of Government and New Agricultural Technologies," Food Policy Statement No. 4. International Food Policy Research Institute, Washington, DC, 1985.
- (58) Morel, R., and P. Quantin. "Observations sur L'Evolution a Long Terme de la Fertilité des Sols Cultivés a Grimari," *Agronomique Tropicale*, Vol. 27, 1972, pp. 667-739.
- (59) Moris, J., D. Thom, and R. Norman. "Prospects for Small-Scale Irrigation Development in the Sahel," Water Management Synthesis II Project Report No. 26. Dept. Agric. and Irrig. Engineering, Utah State Univ.-Logan, 1984.
- (60) Morris, W.H.M. "Mali Study," Unpublished working paper. Purdue Univ.-West Lafayette, IN, 1988.
- (61) Nagy, J., H. Ohm, and S. Sawadogo. "Burkina Faso: A Case Study of the Purdue University/SAFGRAD Farming System Project," Mimeograph. Purdue Univ., West Lafayette, IN, 1985.
- (62) Nagy, J., L. Ames, and H. Ohm. "Technology Evaluation, Policy Change and Farmer Adoption in Burkina Faso," Paper presented at the Farming Systems Symposium. Kansas State Univ., Manhattan, KS, 1985.
- (63) Nagy, J., and H. Ohm. "Workshop Summary," *Appropriate Technologies for Farmers in Semi-Arid West Africa*, H. Ohm and J. Nagy, eds. West Lafayette, IN: Purdue Univ. Press, 1985.
- (64) Newman, M., I. Ouedraogo, and D. Norman. "Farm Level Studies in the Semi-Arid Tropics of West Africa," Paper presented at a Workshop on Socioeconomic Constraints to Development of Semi-Arid Tropical Agriculture. International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India, 1979.
- (65) Nicholson, S. "The Climatology of Sub-Saharan Africa," *Environmental Change in the West African Sahel*. Washington, DC: National Research Council, 1982, pp. 71-92.

- (66) Nicou, R., and C. Charreau. "Soil Tillage and Water Conservation in Semi-Arid West Africa," *Appropriate Technologies for Farmers in Semi-Arid West Africa*. West Lafayette IN: Purdue Univ. Press, 1985.
- (67) Nicou, R., and J.F. Poulain. *Les Effets Agronomiques du Travail du Sol en Zone Tropicale Seche*. Paris, France: Machinisme Agricole Tropicale, 1972.
- (68) Norman, D. "Economic Rationality of Traditional Hausa Dryland Farmers in the North of Nigeria," *Tradition and Dynamics in Small-Farm Agriculture*, Robert Stevens, ed. Ames, IA: Iowa State Univ. Press, 1977.
- (69) Nowshirvani, V.F. "Allocation Efficiency in a Traditional Indian Agriculture: Comment," *Journal of Farm Economics*, Vol. 49, No. 1, Feb. 1967, pp. 218-21.
- (70) Ohm, H., J. Nagy, and S. Sawadogo. "Complementary Effects of Tied Ridging and Fertilization with Cultivation by Hand and Donkey and Ox Traction," *Appropriate Technologies for Farmers in Semi-Arid West Africa*. West Lafayette, IN: Purdue Univ. Press, 1985.
- (71) Office of Technology Assessment, U.S. Congress. *Continuing the Commitment: Agricultural Development in the Sahel*. 1986.
- (72) . . . "Low Resource Agriculture in Africa." Unpublished working paper. 1987.
- (73) Pieri, C. "Food Crop Fertilization and Soil Fertility: The IRAT Experience," *Appropriate Technologies for Farmers in Semi-Arid West Africa*. West Lafayette, IN: Purdue Univ. Press, 1985.
- (74) Pingali, P., and H. Bingswanger. "Population Density and Agricultural Intensification: A Study of the Evolution of Technologies in Tropical Agriculture," Unpublished working paper. The World Bank, 1985.
- (75) Population Reference Bureau, "World Population Data Sheet," Washington, DC, 1986.
- (76) Roose, E.J. "Approach to the Definition of Rainfall Erosivity and Soil Erodibility in West Africa," *Assessment of Erosion*, M. De Boodt and D. Gabriels, eds. New York, NY: John Wiley and Sons, 1980, pp. 153-164.
- (77) Rotenhan, D. "Cotton Farming in Sukumaland," *Smallholder Farming and Smallholder Development in Tanzania*, Hans Ruthenberg, ed. Weltforum Verlag, Munich, 1968.
- (78) Roth, M., and J. Sanders. "An Economic Evaluation of Selected Agricultural Technologies with Implications for Development Strategies in Burkina Faso," Paper presented at Farming Systems Research Symposium. Kansas State Univ., Manhattan, KS, 1984.
- (79) Royal Tropical Institute. *Food Strategies in Four African Countries*. Prepared for European Economic Community by the Royal Tropical Institute, Amsterdam, The Netherlands, 1984.
- (80) Ruthenberg, H. *Farming Systems in the Tropics*, 3d. ed. London, England: Oxford Univ. Press, 1980.
- (81) Sahn, D., and C. Delgado. "A Review of the Magnitude, Causes and Implications of Seasonal Price Variability," International Food Policy Research Institute/Food and Agriculture Organization of the United Nations/U.S. Agency for International Development Workshop on Seasonal Causes of Household Food Insecurity Policy Implications and Research Needs. International Food Policy Research Institute, Washington, DC, 1985.
- (82) Sanders, J., J. Nagy, and B. Shapiro. "Developing and Evaluating New Agricultural Technology for the Sahel: A Case Study in Burkina Faso," Paper presented at Conference on African Agricultural Development: Technology, Ecology, and Sociology. California State Polytechnic Univ., Pomona, CA, May 1985.
- (83) Schmitz, A., and D. Seckler. "Mechanized Agriculture and Social Welfare: The Case of the Tomato Harvester," *American Journal of Agricultural Economics*, Vol. 52, No. 4, Nov. 1970, pp. 569-77.
- (84) Schuh, G.E. "The Role of Markets and Governments in the World Food Economy," *The Role of Markets in the World Food Economy*, D.G. Johnson and G.E. Schuh, eds. Boulder, CO: Westview Press, 1983.

- (85) Schultz, T.W. *Transforming Traditional Agriculture*. New Haven, CT: Yale Univ. Press, 1964.
- (86) Shaffer, J., M. Weber, H. Riley, and J. Staatz. "Influencing the Design of Marketing Systems to Promote Development in Third World Countries," Paper presented at International Workshop on Agricultural Markets in the Semi-Arid Tropics. International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India, 1983.
- (87) Shapiro, K., and E. Berg. "The Competitive-ness of Sahelian Agriculture," Paper presented at the Beyond Mindelo Conference on Food Security in the Sahel, Washington, DC. Elliot Berg Association, Alexandria, VA, Oct. 1988.
- (88) Shapouri, S., A. Dommen, and S. Rosen. *Food Aid and the African Food Crisis*, FAER-221. Econ. Res. Serv., U.S. Dept. Agr., June 1986.
- (89) Siband, P. "Etude de l'Evolution des Sols sous Culture Traditionnelle en Haute Casamance," *Agronomie Tropicale*, Vol. 27, 1972, pp. 574-89.
- (90) Southgate, D., F. Hitzhusen, and R. MacGregor. "Remedying the Third World Soil Erosion Problems," *American Journal of Agricultural Economics*, Vol. 66, No. 5, Dec. 1984.
- (91) Spencer, D. "A Research Strategy to Develop Appropriate Agricultural Technologies for Small Farm Development in Sub-Saharan Africa," *Appropriate Technologies for Farmers in Semi-Arid West Africa*. Lafayette, IN: Purdue Univ. Press, 1985.
- (92) Staatz, J. "The Potential of Low-Resource Agriculture in African Development," Unpublished working paper prepared for the Office of Technology Assessment, U.S. Congress, 1986.
- (93) Stoop, W.A., C. Taptanayaka, P. Matlon, and W. Root. "A Strategy to Raise the Productivity of Subsistence Farming Systems in the West African Semi-Arid Tropics," *Sorghum in the Eighties*. International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India, 1981, pp. 519-26.
- (94) Timmer, C.P. "Choice of Technique in Rice Milling on Java," *Bulletin of Indonesian Economic Studies*, Vol. 9, No. 2, 1973.
- (95) \_\_\_\_\_ . "Private Decisions and Public Policy: The Price Dilemma in Food Systems of Developing Countries," *International Development Paper*, No. 7. Michigan State Univ., 1985.
- (96) Timmer, C.P., W. Falcon, and S. Pearson. *Food Policy Analysis*. Baltimore, MD: Johns Hopkins Univ. Press, 1983.
- (97) U.S. Agency for International Development. *Country Development Strategy Statement: Mali*. Washington, DC, 1983.
- (98) \_\_\_\_\_ . *Mali Project Paper: Farming Systems Research and Extension*. Washington, DC, 1984.
- (99) U.S. Department of Agriculture, Economic Research Service. Unpublished data series.
- (100) World Bank. *Accelerated Development in Sub-Saharan Africa: An Agenda for Action*. Washington, DC, 1981.
- (101) \_\_\_\_\_ . *Desertification in the Sahelian and Sudanian Zones of West Africa*. Washington, DC, 1985.
- (102) \_\_\_\_\_ . *World Development Report*. New York, NY: Oxford Univ. Press, 1986.
- (103) Wright, P. "Water and Soil Conservation by Farmers," *Appropriate Technologies for Farmers in Semi-Arid West Africa*. Lafayette, IN: Purdue Univ. Press, 1985.