Chapter 4

A Decade of Lessons: Technologies Past and Future

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IN BRIEF . . .

The Sahelian environment is challenging. In the past, Sahelian farmers and herders developed a diversity of productive agricultural systems in response to their harsh environment. But changes in the last century have destabilized these traditional systems, leaving the people increasingly vulnerable to the vagaries of weather and economic forces. Changing social, agricultural, and economic systems, including a growing dependence on world markets, as well as drought, land degradation, and declining fuelwood supplies, all contribute to the region's vulnerability. The results are increasing poverty, food shortages, indebtedness, budget crises, and worries about the future.

The Club/CILSS effort, and the U.S. contribution to it, have provided only modest tangible successes, and technologies appropriate for the Sahelian environment have proved elusive to develop or adapt. But donors and Sahelians have learned important lessons that can serve as a foundation for future efforts. Chapter 4 analyzes the decade's efforts at technology development in the Sahel and discusses guidelines for future programs. Highlights of the chapter include:

- Contrary to early expectations, technologies appropriate for the Sahel did not exist and many agricultural technologies transferred to the Sahel proved to be ineffective. Efforts to develop technologies for the Sahel were disappointing in large part because the environment and socioeconomic systems of the region were poorly understood.
- Agricultural technologies appropriate for the Sahel must be low risk, affordable, sustainable, and they must offer at least stabilized production along with the potential for substantially increased returns. Farmers and herders need to be included in project design and implementation and special attention should be focused on the low-resource farmers and herders—women and men—who comprise the majority of Sahelian agriculturalists.
- In general, technology development, adaptation, and transfer is more complex and slower than had been assumed. The lessons learned through both successful and unsuccessful projects in the Sahel can serve as foundations for future efforts, and justify a cautious optimism about the future in the region.

DISAPPOINTMENTS AND ACCOMPLISHMENTS

In 1984 and 1985, major drought again struck the Sahel. Though Sudan and Ethiopia further to the east were the most severely affected, the CILSS countries still required 1.2 million tons of food aid (139). Relatively few people starved, but malnutrition, increased endemic disease, economic disruption, and displacement of people led to considerable human suffering. Agriculture-based foreign exchange earnings declined significantly, adding a crippling blow to national economies already on the brink of bankruptcy,

After almost one-third of the 25-year timeframe set under the Club/CILSS framework, little headway apparently has been made in at-

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taining food self-sufficiency, environmental stabilization, and economic growth. Despite the high expectations with which the "Sahel Experience" was launched and the unprecedented mobilization of over $15 billion in international assistance, the situation in the Sahel remains critical. While there have been exceptions from year to year and from country to country, data point to a decade characterized by declining per capita food production, stagnant or declining yields of major crops, continuing environmental degradation, and little diminution of the region's high vulnerability to drought. Moreover, a 1985 CILSS study predicts continuing deterioration and recurrent crisis in the Sahel if the trends of the past two decades are not radically reversed (22).

Experts have tried to attribute the ongoing problems in the Sahel to a continuing succession of years with low and highly variable rainfall. But one of CILSS's goals was to reduce the region's vulnerability to drought—a goal that obviously has not been met successfully. In part, Sahel experts now admit, the gap between expectations and performance is a product of unrealistic original assumptions and goals (110). Both Sahelians and donors lacked knowledge about fundamental ecological and socioeconomic realities and unrealistically believed that technologies and models of development were available or could be easily transferred and adapted from elsewhere. Disappointment was therefore inevitable. According to Club du Sahel Executive Director, Anne de Lattre: "In those early days, the Sahel program just didn't do its homework" (38).

On the average, the record of individual development efforts in the Sahel is poor, Programs to develop and disseminate improved, appropriate technologies for rainfed agriculture have failed to improve on traditional approaches (128). Programs to develop irrigation have proven costly, slow, and of questionable economic viability. Livestock and range management programs have offered little improvement over existing systems. And despite the oft repeated importance of the environment and particularly the critical status of fuelwood resources, investment in these areas has been low, costs high, and success limited,

Examples of poor performances are visible in all sectors of development. Technologies appropriate to the Sahelian environment and its socioeconomic realities proved illusive to develop or adapt. Systems to deliver those technologies to farmers and herders proved inadequate. Infrastructure was a constraint; management skills were insufficient and projects were poorly designed, The policies of the Sahelian countries proved to be disincentives to growth.

But this litany of failures to meet overall goals and the lack of significant impact on the key indicators of Sahelian food insecurity mask individual project successes and positive changes that have resulted from the past decade's efforts by Sahelians and their international partners. A few of the successes include:

- Better early warning systems, improved logistics, and far better organization and coordination of food aid on the part of both external donors and Sahelians were all factors that helped prevent the 1984 to 1985 drought from causing a wide-scale famine in the CILSS countries. The combined lessons of a decade of activity had resulted in a Sahel better prepared and more capable of responding to disaster.
- A significant factor in the relative success of relief efforts in 1984 to 1985 is the greatly improved infrastructure of the Sahel, especially its road networks. Poor maintenance, however, is a continuing problem.
- Thousands of Sahelians have received training, increasing the long-term capacity of Sahelian institutions, Many are moving into key positions, Through the U.S. Sahel Development Program alone, over 1,350 Sahelians received high-level training since 1978 (123).
- Production of millet and sorghum nearly doubled in Niger; maize production has expanded impressively in Senegal, The Gambia, and Burkina Faso; and cereal yields, though on the average stagnant, have shown some strong local increases such as those

in southern Mali. (22). Improved local varieties of sorghum are being used by farmers in Burkina Faso and Mali.

- Coordinated donor dialog with Sahelian governments on the crucial need for policy changes have resulted in promising reform programs in Senegal, Niger, and Mali. Using the resources provided by Public Law 480, the Economic Support Fund, and the Economic Policy Initiative, as well as its other ongoing bilateral programs, the United States has been a major participant in these efforts.
- Cotton production, using relatively intensified methods, expanded fivefold since the 1960s and reached record levels in 1982 to 1983 and 1983 to 1984 despite low rainfall. Yields per hectare in some areas have reached those of major world producers.
- Access to education and health care has expanded rapidly, producing major increases in literacy and life expectancy rates. New models of primary health care, such as those developed by the Agency for International Development (AID) in Senegal, have succeeded in bringing health care to rural areas and are being expanded elsewhere in the Sahel. An international program to control onchocherciasis (river blindness) gives hope that large tracts of underused land in southern Burkina Faso and Mali might be farmed.
- Despite the poor performance of large irrigation schemes, a growing number of community or individually managed, smaller schemes show promise.
- Although the livestock sector programs have generally been judged failures, there have been instances of success such as improved animal health services and increased use of crop residues for fodder. In Mali, the vaccine production unit of the Central Veterinary Laboratory, supported by the United States, has become largely self-sustaining.
- In Burkina Faso, farmer-level techniques to reduce erosion and improve soil quality have been developed and are being adopted by farmers.
- Dune stabilization in Niger, the use of animals for power in parts of Senegal, and the success of some community reforestation projects all provide evidence that some new technologies are working.

These successes and others may have, at best, slowed the decline in Sahelian production and environmental systems. But they are the basis for a cautious optimism about the future in the Sahel. Though revealing a much more arduous and perhaps slower process of technology development and exchange than had been expected, the experiences of the past decade have not fundamentally called into question the potential of the Sahel to reach Club/CILSS goals of increased food security.

A major change in the past decade has been an impressive increase in Sahelians' skills. This is partly a product of the training and partly the experience learned through the development efforts of the last decade. It is a learning process shared by both Sahelians and donors, and it has helped participants to reach a growing consensus on the nature of the most important issues facing the Sahel (110).

These lessons are beginning to be incorporated into action. Many donors, including the European community, the World Bank, a number of private voluntary organizations, as well as the Club du Sahel and CILSS, have been involved in major evaluations and reorientations of their Sahel strategies similar to those performed by AID during 1983 and 1984. Some Sahelian governments are going through the same process.

The lessons include new perspectives and guidelines for technology development, organization of programs and projects, and the need for policies to allow them to work. Club du Sahel Executive Director Anne de Lattre and others see these shared lessons as the greatest accomplishment of the Club/CILSS process and an essential reason for their optimism.

WHY TECHNOLOGY FAILED TO SOLVE THE PROBLEMS AND MORE PROMISING APPROACHES

Many Sahel development experts now agree that technologies to improve Sahelian agricultural production substantially did not exist at the beginning of the Sahel effort nor do they now (38,45,125). A good portion of the first generation of Sahel projects had been based on the assumption that technologies already available in the Sahel, supplemented by those transferred and adopted from other arid areas, would be sufficient to meet medium-term objectives. This mistaken belief was a major factor in the poor performance of many agricultural development programs.

The best illustration of the disappointing results of technology transfer in the Sahel are seen in the failed attempts to increase cereal crop production, Improved varieties of wheat, rice, and corn were at the heart of the Green Revolution of the 1960s in Asia and Latin America, and it was assumed that better varieties of millet and sorghum, which represent over 70 percent of Sahelian cereal production (28), would do the same for the Sahel, But despite nearly a decade of effort since 1975 (in addition to over 40 years of previous French research), scientists have failed to come up with varieties that perform significantly better than those already in use by farmers in any but the higher rainfall areas (128).

In retrospect, Sahel experts agree that a lack of understanding and underestimates of the importance of key ecological and socioeconomic factors led to the choice of inappropriate existing or imported technologies and delayed efforts to develop technologies that were more appropriate. To a large extent, the knowledge base on which Sahel programs were built was inadequate. But in many instances, and increasingly so as knowledge grew with experience, there was also a failure to integrate what was known into choices of technical objectives and project designs. The lessons of the past decade regarding technology development involve therefore: 1) the identification of key ecological and socioeconomic factors, 2) the specific knowledge regarding those factors learned from experience, and 3) the implications of what has been learned for future strategies.

An Inadequately Understood Environment

The broad question of environmental degradation in the Sahel, particularly the visible progress of desertification, is seen by Sahel experts as a high priority in the future. Recent patterns of agricultural development are contributing factors to degradation (87,93). Increased care to avoid negative environmental impacts in agricultural project activities and the explicit integration of environmental limitations into long-term strategies are essential to the development of technologies appropriate for the Sahel (22).

The rate of destruction of trees is of particular concern given the importance of the forestry sector both in terms of domestic energy requirements and overall environmental stability. Though policy makers have been slow to respond and past actions have been largely disappointing, authorities insist on the need for high-priority, forestry-related development activities (37). Those failures have led to several important conclusions for future strategies:

- the need for new approaches to replace the large-scale tree plantation efforts using imported species of the 1970s and a better balance between plantation and community-level, small-scale approaches using both better adapted imported species and local species' (55);
- the need for a closer association between forestry and agriculture, to be achieved in part by increasing farmers' perceived interest in forestry (18) and improving institu-

[1]Small-scale community forestry projects, however, have proven to be more costly than originally assumed and management difficulties are not automatically solved by this approach. Very little research has been conducted about the ultimate potential of local varieties in reforestation,

Photo credit: U.S. *Agency for* International Development

Deforestation can have serious environmental consequences, CARE supported this shelterbelt project i n the Maggia Valley of Niger to prevent soil erosion and maintain crop productivity.

tional links between forestry and agriculture departments and programs; and

- the need for a parallel focus on the development and extension of conservation technologies: for example, more efficient charcoal production, continued work on fuel-efficient wood burning stoves,' brush fire control, and the development of alternative energy sources.

The past decade has also taught a much greater appreciation of the importance and resiliency of natural plant and animal communities despite conditions of drought and increasing human pressure, Researchers are beginning to understand that these systems are important sources of food and medicines, particularly during times of drought when cultivated crops fail and domesticated livestock die. Knowledge of natural systems and their regenerative processes needs to be integrated into development strategies, and future programs need to include protection and development of those systems.

The lessons of the past decade point to four key environmental factors relevant to agricultural objectives in the Sahel:

1. the Sahelian climate,
2. its soils,
3. agricultural pests, and
4. diversity,

These lessons also indicate the need for increased attention to general problems of environmental degradation beyond agriculture,

'Although wood stoves were much heralded when introduced in the Sahel in the late 1970s, adoption rates have been slow and the fuel efficiency of early models (claimed to consume up to 40 percent less wood than traditional methods) has been questioned. Improved models are now being developed.

The Sahelian Climate

Sparse and highly variable rainfall are the principle characteristics of the Sahelian climate. And though still poorly understood, geological and historical evidence suggest that annual weather patterns in the Sahel are subject to long- and short-term patterns making recurrent drought a permanent feature of the region (86). Scientists speculate that rainfall patterns of the past two decades could be part of an extended period of low rainfall. Unfortunately, early decisions on the selection of improved crop varieties and tree species for the Sahel were based on the assumption of a return to higher than average rainfall patterns of the 1950s and early 1960s. Therefore, unrealistic assumptions regarding rainfall were a major factor in the poor performance of many of the new varieties of sorghum and millet brought to the Sahel from elsewhere, in their lack of responsiveness to increased fertilizer usage, and in the failure of attempts to introduce new forage crops and exotic fuelwood species (20).

The implications for future strategies are clear, Drought must be accepted as a permanent and highly probable feature of Sahelian life and be included as a major factor in the determination of technical objectives. Given the certainty that even under the most favorable scenarios, at least 90 percent of Sahelian cereal production will continue to be produced under rainfed conditions, a better understanding of Sahelian climatology is essential (22). The 1975 creation of the Sahelian Regional Center for Agrometeorology and Applied Hydrology (AGRHYMET) as a specialized institution under CILSS was a positive step, but the development of AGRHYMET's capacity has been slow and its role is limited to data collection. A more systematic analysis of AGRHYMET data and data from the U.S. National Oceanic and Atmospheric Agency, which has been using remote sensing to improve early warning systems for famine, is needed to increase long-range forecasting capacity. Linking climate and agronomic information has the potential to reduce risks and decrease the variability of agricultural production under varying rainfall (112).

Sahelian Soils

The failure to appreciate adequately the low fertility and other characteristics of Sahelian soils was a further reason for the poor performance of many of the millet and sorghum varieties brought to the Sahel from India and elsewhere (77,98). In some instances, soil and rainfall characteristics have combined to lead to the poor performance of introduced varieties. Runoff rates are extremely high in many areas of the Sahel—up to 40 percent by some estimates (77)—due to the intensity of rainfall and poor absorptive capacity of soils. High runoff not only means inefficient use of what little rain does fall but also further degradation of soils through erosion. Compensating for poor soil quality must bean explicit factor in agricultural development strategies in the Sahel.

Continued research also will be needed to classify soil types as a basis for crop breeding and agronomic research programs, and to increase and apply knowledge regarding the composition and structure of Sahelian soils, The complex relationships between water, soils, and plant physiology under conditions of low rainfall still are understood inadequately, The development of low-cost strategies to increase soil fertility and improve other soil characteristics in low rainfall areas is challenging but critical, Most Sahelian soils are poor in phosphorus and nitrogen, The use of simple rock phosphates found in several regions of the Sahel has potential for relieving the former constraint while techniques relying on organic fertilizers or improved plant-associated nitrogen fixation may provide alternatives to costly chemical fertilizers (98). More research is needed on both alternatives,

Pest Problems

A wide variety of diseases and pests (e.g., insects, weeds, rodents, and birds) —many unique to the Sahel—have also hindered attempts to increase agricultural production, Though several large integrated pest management projects were launched (e. g., the CILSS Integrated Pest Management Project and AID's Regional Food

Crop Protection Project), their effectiveness was limited[3] and pest issues were not adequately addressed in many plant breeding and agronomic programs (89), Several of the new cereal varieties introduced were particularly susceptible to pest damage and changing agronomic practices, such as continuous cultivation, increased weeds. In some instances, pest problems have increased in drought years, further reducing the improvements that had been achieved in several better-yielding varieties.

Although the extent of preharvest and postharvest losses due to pests is debated, insufficient attention has been given to determining their extent or to developing alternatives (2). Again, however, the need is not only to learn more but to better integrate research results into programs. Due to their high cost, lack of availability, and safety considerations, the use of chemical pesticides is impractical for the immediate future except under limited circumstances. Pest resistance as an objective in breeding programs and improved agronomic practices (e.g., physical removal, cropping patterns) hold the most potential for reducing preharvest losses due to pests.

Diversity

The most crucial characteristic of Sahelian ecology that was underestimated in most agricultural development efforts is the number and diversity of Sahelian soils and microclimates. Rainfall variability over time and location is extreme, especially in low rainfall areas. Several kilometers can make the difference between modest yields and total failure. Fertility and other soil characteristics can also vary within short distances. Pest problems, too, are highly location-specific. Improved technical packages were often developed on the basis of assumed "average" rainfall and soil characteristics of a given area—a concept of little practical use when high variability means that the "average" rarely corresponds to the actual conditions faced by farmers and herders. In instances where successful technologies were based on local data, attempts to spread those technologies more broadly have achieved poor results (93).

More appropriate research and development programs require knowledge of the degree of diversity and the frequency or probability of any particular combination of environmental conditions occurring. What are the different soil types? What is the probability of a 20 percent greater or lesser rainfall on a given field? How likely are pest outbreaks? Given the various possibilities, which ones should determine research objectives? These are the type of questions that will need answers in the development of new Sahel strategies. The lesson of the past decade is that the failure to factor in diversity can be as disastrous to development strategies as the failure to accept the persistence of drought.

Poorly Appreciated socioeconomic Systems

A lack of understanding concerning Sahelian social and economic systems was a further reason for the failure to develop technologies appropriate to the Sahel. Over the course of the past decade, the various actors in the Sahel have put different degrees of effort into anthropological, sociological, and economic analysis, The United States is considered to be one of the leaders in this regard. The studies have been of uneven quality and, as the knowledge base has expanded through experience, the problem seems to be one of ineffective integration of socioeconomic analysis into the processes of technology development and exchange. The lessons of the past decade underscore several key characteristics that are essential to future efforts.

The Influences of Poverty

Poverty is the fundamental reality facing the vast majority of Sahelian farmers, Poor farmers whose very survival depends on producing sufficient quantities of food are understandable}

[3]Both projects served to increase attention to pest management issues and improved Sahelian institutional capacities to address them; nonetheless, both suffered management problems that limited their effectiveness.

reluctant to adopt technologies that increase the risk of failure, By conducting a combination of agricultural and nonagricultural activities (including migration of individual family members), farm households spread rather than concentrate risk, Farmers and herders in the Sahel are also particularly cash poor and tend to minimize inputs, especially cash investments. In one example, a 40-percent increase in returns was necessary before farmers would risk adopting new technologies (57).

These high risk-avoidance and the low-input preferences in farmer decisionmaking were not adequately appreciated nor integrated into the search for appropriate technologies for the Sahel. These factors were certainly significant in the poor adoption rates of the technologies that were introduced, In fact, many of the agricultural, livestock, and forestry technologies introduced in the Sahel actually have increased risk (55). There are numerous examples of new seeds, practices, and animal breeds that, while higher yielding, were more susceptible to drought, pests, and diseases than traditional approaches. **The implications of these lessons are that in the future, technologies must be lower risk, lower input, and provide higher returns if the majority of the Sahel's low-resource farmers and herders are to benefit (43).** Particular attention to not increasing risk is, moreover, not only necessary for better adoption rates, but the only defensible position when dealing with the poorest Sahelian farmers.

Labor Supply Factors

Contrary to original assumptions, labor supply has proven to be a major constraint in Sahelian agricultural production systems and in the willingness to adopt new technologies. The seasonal nature of Sahelian agriculture and the lack of alternatives to human labor create labor bottlenecks at periods of peak labor need: planting, weeding, and harvesting, Despite high population growth, these bottlenecks have in many cases increased because of several factors: rural-urban migration, increased school attendance, breakdown of the traditional family production unit, and continuing high levels of debilitating disease. Second, labor availability is influenced by competition for labor from alternative activities. Risk avoidance strategies spread labor among activities rather than concentrating it on increasingly risky agricultural activities. The proportion of nonagricultural income in most rural households is high, Also, drought and desertification have increased the time spent in such essential activities as wood and water collection, usually by women, and has meant less time available for agriculture.

Thus, the limited labor supply has affected the outcomes of development activities. A study to determine why oxen cultivation was not adopted in most of the Sahel showed that the prohibitive cost was the extra labor required to maintain the animals (39). One reason why most irrigation schemes failed to successfully encourage farmers to grow two successive crops of rice was competition for labor from rainfed agriculture or, during the dry season, perceived better alternative income opportunities (e. g., migration to cities, vegetable production) (76). **The lesson learned is that future strategies must either be based on new technologies that do not greatly increase labor demands or on those that provide sufficient returns and can effectively compete for labor.** There is a special need to develop technologies to increase the productivity of labor input (e.g., improved mechanization) and to develop broader approaches to labor supply, including labor-saving technologies in other areas such as food processing, water and fuelwood collection, and fuel-efficient cooking technologies, Complementary programs such as health and nutrition improvement could also help increase the effectiveness of available labor.

The Role of Women

The past decade has also provided important lessons regarding the importance of recognizing gender factors in most food production systems in the Sahel, In the Sahel as elsewhere, poor project performance has often been tied to the lack of careful gender analysis and the failure to integrate the implications of that analysis into the development of production strategies (13,23). Agricultural extension, credit, and other inputs usually have been directed toward

Photo credit: World Bank

Photo credit U S Agency for International Development

Most grain is ground by hand throughout the Sahel. Therefore women, such as these from Burkina Faso, spend hours preparing food Mechanical grinders can cut labor needs and free women's time for other activities.

men (5). Yet women provide a major portion of total labor input for cereal production and also have responsibilities for food processing and storage and household maintenance. In cereal grain improvement projects, women's labor constraints are thus particularly critical (104).

Studies of development efforts in Africa have demonstrated unexpected results caused by the lack of gender focus [7,24,41 ,42,44,1 14). Increased opportunities for cash income, even in activities traditionally reserved for women (e. g., rice in The Gambia and Senegal or vegetable production in Mali) have been usurped by men. In livestock development projects, the emphasis on cattle (controlled by men) over goats and sheep (controlled by women) and within cattle programs on beef as opposed to milk production have benefited men disproportionately and often decreased women's income. The lessons of the decade call for an expanding knowledge about gender roles and also for better methodologies to apply that knowledge.

Economic Realities

Development efforts in the Sahel often were based on faulty assumptions about the economic realities facing the Sahelian households. With few exceptions, Sahelian agricultural production involves low-input, low-productivity systems and they provide low returns. Most experts feel that opportunities for further expansion of such "extensive" production systems are becoming limited and that expansion of current systems has resulted in lower yields and negative environmental effects in some areas. Therefore, many authorities feel that efforts to increase output substantially must rely on changes in production that use a wide variety of inputs more efficiently.

Such strategies face considerable obstacles. Low-input, risk-avoidance strategies and the relatively high cost and marginal production increases of the technologies offered over the past decade have been factors in their poor adoption. Returns to farmers and herders from "improved" technologies often were not worth the investment (93). But the focus on production and inputs has missed the even more significant constraint of low market demand and low prices. This has been particularly the case for grains such as millet and sorghum where, with the exception of drought years when the farmer has little to sell anyway, demand is limited (84).

The "food gap" at the national level has not translated into higher demand or prices for the cereal crops produced by most Sahelian farmers. Rather, demand has grown for imported rice and wheat, which is competitively priced, more easily prepared and, to many urban dwellers, better tasting. The economic rationality of increasing millet and sorghum production under these conditions is questionable. The more successful adoption of new technologies in cotton, and to a lesser degree in peanuts, has been related to their higher economic return, For the latter, falling world prices, the end of input subsidies, and fixed low prices have resulted in significant reductions in areas planted. The current precipitous drop in cotton prices could well have a similar effect. Efforts to increase production must therefore be geared also toward increasing income by increasing productivity (particularly labor productivity), by lowering input costs, and by expanding market demand.

Diversity

The lack of appreciation for the great diversity in production systems in the Sahel, each a response to a specific set of ecological and socioeconomic factors, was a key design weakness of many livestock and crop development activities (24,67,93), Substantial differences exist between households, ethnic groups, and castes in crucial areas such as access to land, labor and capital and services, gender and age group roles, cultural designations of "acceptable" occupations, traditions of communal economic activity, the importance of agriculture as opposed to other income sources, and rights to surpluses produced. Project designs based on simple models of average farm households failed to recognize or integrate the diversity of socioeconomic and cultural contexts represented in any given community—differences that often determined responses to proposed technologies. The implication for the future is that there is a need for far more localized—or targeted—approaches and technologies.

Guidelines for Sahelian Agricultural Technologies

Scientists and planners working in the Sahel speak of the need to reorient the search for agricultural technologies to respond to the lessons learned in the past decade. Most agree that environmental and socioeconomic factors have constrained the efforts of the past. An analysis of these factors gives rise to several broad characteristics that should guide the search for tomorrow's technologies in the Sahel, Though not a revolutionary reversal, these characteristics represent important changes that many agricultural researchers in the Sahel are already adopting (77), These technology characteristics can be grouped into four categories: stability, affordability, improved returns, and long-term environmental sustainability.

Stability

It is the variability of rainfall rather than its generally low levels that provides the greatest challenge to agricultural research in the Sahel. For example, new technologies must be able to perform not only during periods of low rainfall but also when the rains are relatively high. Considering the prevalence of rural poverty and vulnerability, improved technologies for farm-level food security must begin by striving to provide production stability. Several approaches could be used to help increase production stability:

- Use crop breeding programs to develop more quickly maturing varieties that are also resistant to moisture damage in later stages.
- Improve water management, emphasizing techniques for reducing and concentrating run-off and increasing infiltration such as tied ridges, contour ridges, microcatchments, and improved plows.
- Develop a better understanding of Sahel-specific agro-climatology, linking prediction capabilities with agronomy,
- Improve pest control and storage methods,
- Develop appropriate irrigation techniques, Small-scale irrigation traditionally has played an important role in the stability of Sahelian agriculture and efforts are needed to support innovators and study the most effective methods to realize the potential of the Sahel's surface and subsurface water resources,
- Use the Sahel's diversity as an advantage, building on traditional strategies to obtain stability by combining a range of different crops or even noncrop activities. Examples include mixed cropping; intercropping of different varieties of the same crop; introduction of new crops; mixed crop/livestock/tree systems; nonagricultural income-generating projects; inland fisheries development; and technologies for improving the output of natural systems—wildlife ranching, artificial seeding of natural species, and improved harvesting and processing techniques,

Affordability

With few exceptions, Sahelian farmers are low-resource farmers. New technologies generally must respond to their low-input strategies. Inputs such as fertilizer, animal power, other forms of mechanization, improved seed, pesticides, or improved animal health and nutrition measures will only be adopted if their cost is low relative to their probable return. Because probable returns for cereals and most other crops are low, technology development must seek inputs that are correspondingly inexpensive, This pertains not only to inputs purchased with cash but also to labor and to land where it is scarce,

Improved Returns

New technologies must be low risk, affordable, and they must also provide adequate increases in returns, Since it is likely that the value of existing agricultural products will not increase greatly, either new, higher valued commodities will have to be introduced or the technologies used to produce existing commodities will have to be improved to make current practices more profitable, Attempts to find new commodities for the Sahel have been largely unsuccessful. Experimental sunflower production in The Gambia, export production of vegetables and fruits in Senegal and Mali, and increases in cashew and sesame production in several countries provide at best modest prospects. Strategies to increase demand for or enhance the competitiveness of Sahel-produced cereal grains (e. g., improved processing and storage technologies for millet and sorghum, decreased subsidies for imported grains, or more active trade protection measures and subsidies) are also possible.

Technologies need to be developed that provide food stability under low input levels while also responding well to increased inputs and better management. For the particularly challenging case of low-value cereal crops, substantially higher yields are possible if they are grown in rotation with export crops such as cotton, Higher input systems often are associated with improved management and the residual effects of fertilizer used on previous cash crops is significant. For example, average yields of millet and sorghum cultivated in rotation with intensified cotton production in Mali are as much as 40 percent higher than those in the surrounding area (20).

Long-Term Environmental Sustainability

Continued environmental degradation and stagnating or even falling yields have led Sahel experts to view long-term sustainability as a critical criterion for new agricultural technologies. Although the evidence is controversial, many people feel that the impact of development activities inadvertently may have decreased long-term sustainability, For example, development activities may contribute to the loss of soil fertility through continuous cultivation and the expansion of agriculture onto marginal lands; increased pest problems from monocropping; overgrazing and soil compaction from livestock concentration around deep wells; salinization and waterlogging in irrigation projects; and increased aluminum toxicity and acidity levels where commercial fertilizers have been used continuously, Technology development must include long-term environmental sustainability as a key research objective.

The Integration of Traditional Technologies

The poor performance of introduced technologies has given development experts a new appreciation for the environmental and socioeconomic appropriateness of traditional Sahelian technologies. Centuries of experience have led to successful techniques such as mixed cropping patterns; herder migration patterns and water management techniques; seed selection; the use of ash as fertilizer; food storage and processing technologies; the food and medicinal value of indigenous fruits, berries, leaves and barks; the use of natural systems as food reserves during drought; and other adaptations to the environment. While most traditional production systems are well adapted to the Sahelian environment, farming and herding systems are falling behind population growth and environmental change.

It is essential to integrate traditional and new technologies in agricultural research. This integration can suggest low-input innovations to help traditional production systems keep up with changing environmental and socioeconomic conditions. The traditional approaches can act as starting points to develop appropriate new technologies,

Photo credit: George Scharffenberger

Wild plants supplement other foods during shortages. One former Peace Corps Director in the Sahel reports that the fruits being gathered here are boiled for hours, then "taste like bologna. "

More than any individual technology, the dynamic adaptive processes by which African farmers and herders collect information, experiment, and continually adjust their own technologies is considered to be a helpful starting point for research and development efforts **(103).** Charles Weiss, former World Bank Science and Technology Advisor, summarized the future direction needed for technology development and selection for Africa agriculture:

> For Africa's smallholders, the major technological task is the development of improved

technologies which are adapted from and more productive than traditional technologies and which are sustainable socially, ecologically, institutionally, and economically. This means that they must be suited to ecological conditions of Africa, should not disrupt traditional patterns of work, must not require heavy front-end investments or recurrent costs, and must not place too much of a burden on the limited managerial abilities of government officials or African small farmers (143).