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Transfer of sustainable technology in dryland agriculture: Lessons from the Sahel in the 1980's

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ABSTRACT

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Dryland agriculture in the Sahel must become more productive if human conditions in the region are to improve. Constraints impeding increased productivity are examined. The harsh natural environment of the Sahel means that technologies, institutions and economic policies must be tailored to meet the special challenges of that environment.

Introduction

The seven West African countries of the Sahel[1] are among the poorest of the world: per-capita income in 1981 averaged $300 (MacDonald, 1986); average food intake is below minimum requirement, falling as low as 1500 calories per day in some locations (FAO, 1986); and, average life expectancy is about 44 years (MacDonald, 1986). The GNP growth rate for the region during the 1960 – 81 period was essentially zero (MacDonald, 1986).

Despite an extremely harsh natural environment, agriculture is the dominant economic sector supporting 75 – 90% of the population (World Bank,

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[1] Senegal, Gambia, Mauritania, Mali, Burkina Faso, Niger, Chad.

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1985). Yet, less than 4% of the region is classified as arable (FAO, 1984) and dryland production accounts for 99% of all cultivation.

Population growth rates are high. The average in the past decade has been between 2% and 3% annually. For the region as a whole, it is projected at 2.8% per year (World Bank, 1985). Since the late 1960's, per-capita food production has declined steadily by about 1.7% per annum (OTA, 1986). This alarming trend is expected to continue. By the year 2000, for example, the population of the Sahel will approximate 54 million and exceed carrying capacity under traditional rainfed production systems by about 30 million people (World Bank, 1985).

The situation in the Sahel, therefore, is one where agricultural production is below potential, technological changes are occurring slowly and standards of living continue to decline. Given the limited role of irrigation (Biswas, 1986), the dryland sector must become more productive if significant changes are to occur. Major issues arise concerning the need for widespread adoption of technologies for a sustainable agriculture, given the natural environment of the Sahel and the need for institutional and economic changes that will stimulate the transfer of appropriate technology.

In this paper, the constraints to increased productivity in the Sahel are examined and policy-relevant conclusions are presented.

Constraints to increased productivity

Constraints to increased agricultural productivity in the Sahel may be physical, biological, technical, socio-economic, and/or institutional in nature.

Physical constraints

Constraints associated with the physical environment include: a short rainy season, irregular rainfall, high potential evapotranspiration (1600 – 2200 mm), poor soil conditions, and high intensity rains creating severe soil erosion problems (Nicou and Charreau, 1985). In many areas, soil crusting restricts water infiltration and increases runoff (Hoogmoid and Stroosnider, 1984). Much of the present crop area in the Sahel is in fragile and low-fertility soils (Sanders et al., 1985). Micro-variability in soils and rainfall distribution patterns make agricultural technology very site-specific in the Sahel. Therefore, the potential for any particular technological package to be viable throughout the Sahel is slim. Short-run production increases, in response to price incentives, without land and water conservation measures, may result in systematic degradation of the physical environment in the long run.

Biological constraints

Within the agro-ecosystems of the Sahel region, there are a number of significant biological constraints to agricultural productivity, some of which are generally referred to as 'pests'. In particular and most important are weeds, insects, nematodes, diseases, and vertebrates (particularly granivorous birds). These 'key pests' cause continual or recurrent food production shortages and it is estimated (Cramer, 1967) that preharvest crop losses due to pest complexes are in the range of 30 – 40% . Further it has been estimated that a 50% reduction in pest losses can be attained by the implementation of pest control strategies in some developing countries (Smith, 1979).

Crop protection in agricultural production is complex. The farm production process is involved with multiple pests whose potential for damage is usually not independent. Single crop protection methods, therefore, will seldom constitute the least cost means of achieving the level of pest control desired. The best combination of control measures will be specific to particular farming systems in specific agro-ecosystems. The relative costs of the alternative control methods will likewise be site-specific. Identification of a particular group of control measures which will 'best fit' the physical, biologic, economic, social and cultural milieu characteristic of the various farming systems is a difficult task in the varied settings of the Sahel.

A number of key pests have been identified as major biological constraints to agricultural productivity in dryland agriculture of the Sahel, some of which are given here.

Striga hermonthica, a parasitic weed of sorghum and millet, is generally considered to be one of the most important yield-reducing weeds, albeit weeds in general constitute severe problems. Some progress has been made in identifying resistant varieties, although the physiochemical basis of resistance has yet to be determined. Head bugs and stem borers are key pests of sorghum, and the millet head girdler as well as stem borers are the principal insect pests of millet (ICRISAT, 1983; Gahukar et al., 1986; Teetes and Gilstrap, 1987). Diseases such as sorghum long smut and leaf blights are representative key diseases. The effects of nematodes have yet to be adequately determined.

Single crop protection methods seldom will constitute the least cost means of achieving the level of pest control associated with maximum profitability of the farm enterprise. It is far more likely that some combination of control measures will be employed and which will tend to be specific to particular farming systems in specific agro-ecosystems. The relative costs of the alternative control methods will likewise be site-specific. It is the logical optimization of pest control in an economically, socially, and ecologically accepted manner (Paschke, 1980).

Technical constraints

A number of studies over the past several decades, and in particular in the 1980's, have demonstrated the yield-increasing potential of technologies based on animal traction, tied-ridging, fertilization, mulching and high-density intercropping. However, interrelated technical and socio-economic constraints have impeded more rapid adoption of each of the above technologies.

Animal traction. Since the 1930's, 125 animal traction projects have been initiated in Francophone West Africa (Delgado and McIntire, 1982). Rates of adoption of animal traction have been low and decreasing (e.g., even in Mali, the most advanced animal traction 'user' in the Sahel, adoption rates were only 2% per year during the peak years of the 1970's). Technical constraints to animal traction have been identified. First, poor health and high mortality of draft animals limit the capacity of farmers to follow crop/labor calendars recommended by extension services that assume animal traction of maximum efficiency. Second, plowing is almost impossible until the first major rains have softened the soil. At this time, plowing causes delay in planting and may adversely effect yield. Third, animal traction could accelerate soil deterioration and erosion without simultaneous measures to improve soil fertility (Nicou and Charreau, 1985). Fourth, risk-averse subsistence farmers will not risk crops by weeding with animal traction after crops are knee-high in the ground (Delgado and McIntire, 1982). Thus, weeding operations with animal traction have been limited. Weeds compete with crops and reduce the latter's yield. Fifth, training the animals to perform requires time and entails investment costs (Jaeger and Sanders, 1985). Farmers who are unwilling to become better animal traction operators may achieve only marginally better results than with hand tillage and soon give up (Sanders, Nagy and Shapiro, 1985).

Fertilization. Present use of chemical fertilizer is rare, and averages 6.4, 1.0, and 4.7 kg per ha of arable land in Mali, Niger, and Senegal, respectively (Shapouri et al., 1986). The lack of adequate water at critical stages of plant development results in low and variable technical response rates for fertilizer, especially on local crop varieties. Landlocked Sahelian countries experience high marketing costs which constrain the input-output efficiency of fertilizer. Moreover, the use of organic fertilizer, so important for maintaining good soil structure, is not widely practiced by Sahelian farmers. The limited access to animal manure and its improper storage and application that characterize agriculture in West Africa represent a serious long-term problem.

Tied ridging. The technical efficiency of tied ridges depends on: (1) the nature of the soil; (2) the time of construction; and (3) the position in the toposequence. Tied ridging has been shown to significantly improve yields in medium to high quality soils, but less so on poorer bush soils which comprise a large portion of the cultivated land in the Sahel (Roth and Sanders, 1984). With respect to timing, efficiency depends on when the ridges are constructed compared to the distribution of rainfall throughout the season as well as soil type (Nicou and Charreau, 1985). With respect to toposequence, the potential for erosion makes tied ridging less viable on slopes greater than 3 – 4% in humid regions (Lal, 1975).

Mulching. The moisture-retaining effects of mulch are directly related to the volume of material put on top of the soil. The amount of mulching material available may be insufficient to achieve significantly beneficial effects if the crop output of the previous season was poor and/or if there are many competing demands for crop residue (fodder, fuel, and construction materials). Mulching prohibits even semi-deep plowing with turning and makes traditional weeding methods more difficult.

Intercropping. Traditionally, intercropping is the rule rather than the exception in the Sahel. For example, a 1982 survey of 348 farms in south-central Niger showed that 79 per cent of the fields were intercropped. Once the plant density has been determined which will adequately reduce crop competition for nutrients, allow sufficient exposure to sunlight for all crops, and permit efficient harvesting, there are few technical constraints to intercropping. Pest incidence has not increased in Niger as a result of greater intercropping density.

Socio-economic constraints

Constraints associated with the simultaneous adoption of technological 'packages' and the constraints to adoption associated with farmer resources and goals must be considered in addition to technical constraints. With combinations of technologies the interaction effects are usually greater than the sum of the individual effects of particular techniques (Roth and Sanders, 1984). In some situations a single technological change, eg. use of chemical fertilizer, as indicated, may not be economically beneficial at all. However, 'package' adoption contrasts markedly with the sequential adoption that subsistence farmers seem to prefer. It is generally understood that risk-averse subsistence farmers typically are reluctant to invest simultaneously in innovations with which they have little first-hand experience and which require substantial changes in household resource allocation. Such behavior may be entirely rational given the particular farm setting. Therefore, the extent to which sequential adoption patterns can be changed, and the steps to take in order to make 'package' adoption viable, require knowledge of farmers' resources, goals and attitudes.

To a large extent, the resources available to farmers determined the goals they strive to fulfill. Predominant factors that farmers take into consideration when evaluating new technologies are the amount of labor and capital required, the potential return to these scarce resources and the degree of risk associated with food production and capital investments.

Labor factor. A major factor affecting technology adoption is labor scarcity and the opportunity costs of on-farm employment. Evidence suggests that labor availability throughout the Sahel is frequently a greater constraint to increasing agricultural productivity than is land availability. This is true even in areas of high population density such as Burkina Faso's Mossi Plateau (Roth and Sanders, 1984). Relatively high off-farm wages have stimulated local non-farm employment, urban and foreign migration, and school attendance, at the expense of the farm labor pool. The need for significant amounts of time devoted to social/cultural commitments and to rest because of low caloric intake further exacerbates an inelastic farm labor supply situation. At seasonal peaks (usually at planting and weeding times), labor bottlenecks develop and greatly influence the choice of techniques. For example, in a linear programming analysis of intercropped millet and cowpea production in Niger, Krause et al. (1987) discovered that the additional labor requirements for urea applications during the optimal periods for cowpea planting and first weeding may discourage Nigerien farmers from using fertilizers. Thus the ability of new technology to shift labor use from peak to slack periods becomes a particularly important criterion for acceptance.

Capital factor. Another important factor affecting the adoption of new technology is simply whether the farmer possesses, or has access to, the necessary capital to invest in new technologies, and whether the returns to on-farm investment exceed other opportunities. Agriculture in the Sahel is characterized by low commercialization and low surplus production. Farm cash flows are small and uncertain. Thus, without viable rural financial markets that successfully transfer credit to farmers in a timely fashion and with low transaction costs, factor price ratios will be skewed so that labor-intensive inputs will be favored over capital inputs. Capital market inefficiencies in turn exacerbate seasonal labor bottlenecks. For example, Krause et al. (1987) showed that a lower cost of capital in Niger would not only reduce the cost of seed and fertilizer, but also make it profitable to hire more labor in periods when family labor constraints limit family fertilizer use.

Risk factor. One very important objective of subsistence farmers is to minimize the risk of failure. In the highly difficult and unpredictable natural environment of the Sahel, they cannot afford to make mistakes; doing so places their very survival in jeopardy. Such an objective entails production and marketing strategies that attempt to assure an adequate food grain supply for the family during the year.

Risk-averse Sahelian farmers consider not only the financial costs of adoption, but also the costs of getting information about the technique and the costs of taking the risk of using it, as well as the psychic costs that reflect general resistance to change. For example, Delgado and McIntire (1982) stress that farmers' reluctance to use animal traction in the Sahel reflects incongruities between the technology and farmers' risk-averse behavior. New technologies must be compatible with subsistence farmers' markedly risk-minimizing and food self-sufficiency objectives. Hence, techniques that increase average yield or average net farm income over several years, but also increase year-to-year variability, can be expected to suffer poor rates of adoption.

Institutional constraints

Institutional constraints comprise marketing system constraints and macro policy constraints.

Marketing system constraints. Farm-level incentives to invest in new technology are dependent not only on the cost of the inputs, but on expected output prices as well. Highly variable and unpredictable price changes are common in Sahelian commodity markets. This sends confusing signals to producers and increases the risk of investing in food production for the market. Yet this kind of investment is precisely what is needed to overcome the Sahel's chronic food-deficit status. Other marketing system constraints prevailing in the region are: official producer prices too low; government pricing policies which depress private marketing initiatives; underinvestment in physical infrastructure; inadequate input supply scheduling, eg. fertilizer imports, and the existence of private input/output trading monopolies that tend to restrict output and elevate consumer prices.

Macro policy constraints. National macro policies carried out in the Sahelian countries have not always created the proper incentives for farmers to want to try to increase productivity. Some of the policies that have had serious detrimental impact in this regard are: minimum wage rates in the urban sector which act to draw labor away from agriculture; high food aid and food imports which depress farm gate prices; over-valued exchange rates which encourage imports of food supplies and, once again, act to depress the prices farmers receive; and unchecked inflation which negatively affects agricultural exports.

Public policy constraints. To these traditional price and income policy issues, we must add public policy issues of possibly greater importance to the Sahelian countries as they attempt to define, generate, and diffuse sustainable technologies for their environment. Such public policies include those relating to land tenure (including water and user rights), the level of public investment in higher agricultural education, applied agricultural research, extension, public policy analytical capacity, and effective institutional means of providing timely agricultural statistics (e.g., prices paid and received by producers, market outlook information).

Priorities for the future

The future for many millions of people in West Africa depends on actions taken now to improve the productivity of dryland crop and livestock farming systems. Many things need to be done. Some of the needed changes are no different than those required throughout the developing world. Some, however, are perhaps unique to the Sahel. In this section, our views regarding priorities are presented.

Necessary characteristics of sustainable technology for the Sahel

If new agricultural technologies are to be widely adopted in the Sahel, they must be suited to the arid and semi-arid conditions that prevail throughout the region. As indicated, the type of soils, the terrain and the characteristics of the weather become highly important in this setting. While the specific nature of the soils, rainfall and temperature regimes vary widely there is enough similarity from location to location to identify basic features that new crop and livestock production practices must possess if they are to be viable in Sahelian agricultural systems.

First of all, new technologies, and related farm management practices, must improve the agronomic environment for crop production. Without improvement in soil fertility and better means of capturing and storing water in the soil, significant productivity gains cannot occur. Crop-breeding for low-moisture and low-input levels can be a complementary component in this effort, leading to improved agronomic systems based on integrated soil, water and crop management (including crop protection) at the farm level. The second important aspect of new technologies is that they must be capable of significant increases in the productive potential for basic food grain staples. Food grains command a predominant place in the production and consumption plans of all Sahelian farm families. For this reason, new technologies must be applicable to millet and sorghum and, to a degree, maize and rice. Where cash crops such as cotton or groundnut are important, income gains can be achieved with technologies oriented to these crops; however, the emphasis given to home consumption, even by cash-crop producers, is still high.

The third requirement for new technology relates to the extreme variability in weather that affects the outcome of all farming operations in the Sahel. Even with soil and water management practices that improve the farm resource base, late rains, droughts, and severe storms will persist. Land-based rainfed technologies can help the farmer to cope with these phenomena, but they cannot eliminate the basic problem. Technologies, in this context, then must help to stabilize farm returns. More specifically viable technologies will be those that help to minimize the downside losses from poor weather conditions, as well as outperform traditional practices during average or normal seasons.

In addition to these special characteristics, new technologies must satisfy basic conditions relevant to technological transfer in general, i.e., they must be affordable, consistent with available labor, and acceptable on socio-cultural grounds, including risk attitudes. It should be noted that a technology support system of input markets, parts and repairs, and extension services must be in place and maintained if technology diffusion and technology use are to occur and continue.

These basic conditions become irrelevant, however, if the new technologies developed through research and made available to farm-level decision-makers are not capable of causing substantial shifts in technical production functions to compensate for high-risk and risk-aversion production systems and decision-making.

Institutional setting for technology transfer in the Sahel

Our review of socio-economic and institutional constraints to productivity gains in the Sahel revealed that these constraints are very much the same as for developing economies in general. The common problems that impede the adoption and diffusion of sustainable technology in the Sahel include: insecure land tenure and usufructuary rights; inadequate input delivery systems; poorly functioning commodity marketing systems; macro-policies that create disincentive wage-rates, interest rates, and farm gate commodity prices. The lack of effective demand for the commodities Sahelian farmers can produce is a major problem affecting the ability to pay for technological innovations. Policy reform can relieve many of the factors that create constraints to diffusion of new technologies.

In the dryland production systems of the Sahel, the highly variable and uncertain rainfall patterns unfortunately create unique difficulties for the farmers who somehow must cope with the situation year after year. Spatial and temporal variability in weather leads to variability in crop yields and production. Variability in output in turn leads to price and income variability and creates an uncertain and risky economic condition for farmers. In the Sahelian environment, this will be a persistent problem. In such an environment, investment in new and costly equipment and supplies is a difficult decision, even in the good years. Productivity gains must be large enough to create adequate carry-over supplies for both consumption and sale. Investment is not likely to occur, even though 4 years out of 5 the farmer may be better off, if the farm family cannot survive the bad year.

Conclusion

The lessons to be learned from the Sahel in the 1980s are: (1) that physical, biological, technical, socio-economic, and institutional constraints have to be understood and taken into account when designing new agricultural technologies; (2) these new technologies must be sustainable, i.e., they must improve the agronomic environment to allow substantial increases in basic food grain production over the long run while stabilizing farm income in high-risk production systems managed by risk-averse decision-makers; and (3) to be transferrable, sustainable technologies require sound, careful and prolonged agricultural policies that recognize the very uncertain economic setting that characterizes Sahelian agriculture. More rapid technology diffusion may, in fact, require a fundamental restructuring of existing institutions. Needed is a setting whereby public and private institutions can share alike in the risks and in the returns to a more productive agricultural sector. This will not be easy, nor quick, nor painless, and it can only be done by Africans.

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