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Chapter 10

Sustainability, New Intensive Technologies, and Institutional Change

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Introduction

One of the principal attacks on new technology introduction in the eighties and nineties has been on the soil degradation and water pollution resulting from intensive agricultural production systems. In developed countries, an anti-chemical input orientation has frequently been an integral part of environmental movements. In contrast with the high levels of chemicals in developed countries, natural and man-made causes have increased the level of degradation and destruction of the environmental systems and natural resource base in semi-arid Sub-Saharan Africa. Soil fertility is low before cropping and is mined as the fallow system breaks down. This long-term fertility maintenance system of fallow rotation is not being replaced with purchased inputs in most regions; purchased input use on most crops is minimal with some significant exceptions. Nevertheless, even without using chemical (or industrial) inputs, soils are being eroded, forests eliminated and grasslands overgrazed, thereby threatening long-term sustainable agriculture.

As the resource base deteriorates, the ability of these countries to feed themselves is reduced. Meanwhile, there is already substantial malnutrition in Sub-Saharan Africa and the continuing rapid population growth will result in large increases in the domestic demand for food. Hence, an important aspect of the sustainability debate in Sub-Saharan Africa is first maintaining and improving the quality of human life through adequate nutrition (von Braun, 1991; Webb et al., 1991). Given the large number of households dependent on farming and thus on natural resources, water and land, there is an urgent need for policymakers and researchers to focus on the adoption of sustainable agricultural technologies.

The first section presents various methods of considering sustainability. Then the interaction of technological change and sustainability is considered, with farm modeling in the next three sections. The fifth section focuses on the interaction between population pressure, agricultural intensification and evolution of indigenous land rights systems. The sixth section looks at specific sustainability problems and suggests policy implications for different agro-climatic zones. Finally, some concluding observations are made.

Sustainable Agriculture and Societies

The concept of sustainable agriculture has gone through a bewildering array of definitions. Ruttan (1991) provides an excellent overview of how notions of sustainability have changed. He emphasizes the following five issues: (1) enhancing the capacity for improving the contribution of natural components to agricultural production, (2) improving the institutions to reduce environmental stress associated with residual wastes generated through agricultural intensification, (3) increasing the role of technology in widening the substitutability among natural resources and reproducible capital, (4) improving intergenerational equity, and (5) designing institutions that can internalize the costs of the spillover effects of environmental stress. Chopra and Rao (1991) underline the existence of a complementarity between environmental conservation and economic development. Sustainable agriculture is defined here as a successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment.

If sustainable agriculture is concerned with stabilizing output along an increasing trend and maintaining a balance in environmental resources, then there is a substantial role for economic analysis and multidisciplinary collaboration. The economist can obtain help from the different agricultural and biological scientists about the appropriate constraints and their minimum or maximum levels, or at least their ranges. The economic analysis can then consider the tradeoffs in costs and benefits of various levels of environmental constraints.

The conceptual difficulty comes with a more limiting form of sustainable development as a minimization of the use of natural resources. This concept implies that exceeding some level of use of natural resources could lead to a catastrophe. Thus, resource utilization needs to be minimized until this danger is understood, causal relations are identified, and resource use can be adjusted so as to avoid the catastrophe. Such a concept of sustainable development emphasizes the limits of the assimilative capacity of the environment and of the capability of technology to enhance human welfare (Mellor, 1988; Batie, 1989, pp. 1084, 5). This second form of sustainability is associated with much of the ecology literature (also see Lynam and Herdt, 1989, pp. 385, 386). There is useful analysis that can be done here, but minimization of environmental damage, the avoidance of the use of chemical inputs, or even most disaster theories probably overstate the weights most developing countries would put on environmental goals.

Sustainability becomes more problematic at low income levels where many of the country's inhabitants are not receiving minimum nutritional levels or other basic requirements. From a societal perspective, a country's residents must be adequately fed and provided with other basic social services to fulfill their potential as human beings.[1] Sustainable societies provide these basic social services for their populations. In Sub-Saharan Africa, the most important goal of sustainability needs to be the improvement of the quality of life of the population. From an agricultural perspective, this means a more rapid growth in agricultural production. Thus, in Sub-Saharan Africa, "sustainable" means reversing crop yield declines in some of the low-input systems and increasing yield gains in the high-input systems. The first concern of the next three sections is to explain why the shift to more yield-intensive technologies has not as yet taken place in many of these semi-arid, Sub-Saharan regions such as the Sahel.

Technology Development: Beyond the Boserup Effect[2]

A few decades ago, Ester Boserup challenged the classical Malthusian perspective of population increasing faster than food production, arguing that as a result of increasing population pressure, a traditional agrarian community moves from slash-and-burn fallow to a bush-fallow, to annual cropping, and finally to multiple cropping. Each sequence represents a growing intensification of the farming system. Technological change comes as a response to adversity, which in the Boserup scenario results from increasing population pressure (Boserup, 1965). Several attempts have been made to formalize and test the Boserup hypothesis (Stryker, 1976; Darity, 1980; Pryor & Maurer, 1982; Robinson & Schutjer, 1984; Binswanger & McIntire, 1987; Bilsborrow, 1987).

In the Sahel, Boserup's hypothesis is relevant in explaining the historical evolution of farming systems. Initially, settlement took place on the lighter soils since these soils were easier to work and land was abundant relative to labor. Population pressure then began to push farmers on to the higher quality, heavier soils.

Frequently, animal traction was used on the low-lying, heavy soils to facilitate preparation and to extend the cultivated area (Pingali, et al., 1987; Jaeger and Matlon, 1990).

However, as population density has continued to increase, negative consequences have occurred. With accelerating population growth, the fallow system has broken down, yields have declined, and farmers have extended crop area onto more marginal land previously utilized for communal grazing (Broekhuyse and Allen, 1988). Increased population pressure thus leads to over-exploitation and degradation of the natural resource base of agriculture. The problem is exacerbated in low-productivity, high-risk environments such as the Sahel, for not only is nature's bio-mass diversity low, but recovery speed of once damaged land and vegetative resources is slow (UNCOD, 1977). In some regions of the Sahel, population densities have reached very high levels (around 48 people/sq. km. in the Central Plateau of Burkina Faso).[3] Here substantial wind and water erosion, crusting, and soil-fertility mining have taken place on soils that had been characterized as low in fertility and fragile before the degradation process (Matlon, 1987). Crop yields have reached low-level equilibriums declining by a third to a half of those levels of an earlier period with an adequate fallow system (Broekhuyse & Allen, 1988). Extensification by animal traction pushes cultivation into even more marginal land, further decreasing yields (Vierich and Stoop, 1990, p. 123). Intensive or yield-increasing technological change is necessary to reverse the land degradation and to increase crop yields. However, this shift to more intensive technologies has not been occurring. Food imports have been increasing into most Sub-Saharan countries. Agriculture has been stagnating. Policymakers have been more concerned with keeping food prices low in urban areas than with increasing the profitability of agricultural production. In these circumstances the Boserup case of population pressure leading to more intensive agricultural systems has not been occurring. Rather, continuing high population growth has resulted in a breakdown of the fallow system, declining crop yields, and an acceleration of resource degradation.

The Shift to Yield-Increasing Technologies in the Sahel

When land is abundant, there is an economic incentive to further expand the cultivated area with extensive technologies substituting for labor. Extensive or labor-productivity-increasing technologies refer here to the use of animal traction to perform on-farm operations, such as plowing and weeding. Moreover, as the fallow is eliminated, more labor is required for weeding, increasing soil-fertility, and for additional operations associated with higher planting densities. Animal traction can alleviate the labor shortages faced by the farmer in performing these timely operations associated with the increased intensity of land use (Pingali, et al., 1987). Nevertheless, in the West African semi-arid tropics, less than 10% of the farmers employ animals for power; approximately 15% of the crop area is cultivated with animal traction (Jaeger, 1986; Matlon, 1987).

One critical problem of the Sahel is that continuing high population growth has led to severe environmental degradation in some regions without the introduction of intensive or land-substituting technologies. In most of the Sahel, more intensive technologies are not being adopted. Without fertilization or soil-fertility improvement of some type, soil fertility will not be completely replenished once the fallow system breaks down. Even with the addition of more animals, the amount of manure and compost produced on the farm in the traditional or even extensive technology system with animal traction will not be sufficient to replace the major nutrients mined from the soil by crop production[4] (Nagy, et al., 1988). Thus, there will be a long-run yield decline and eventually land abandonment unless more intensive technologies are introduced (Broekhuyse and Allen, 1988). Moreover, the declines in soil fertility force farmers to extend the crop area into more marginal communal grazing areas reducing the potential to raise large animals.

To understand what factors would induce farmers to adopt more intensive technologies, the following two hypotheses are evaluated:

- The continuing pressure from decreasing land supply availability will encourage this shift to more intensive technologies.
- A more profitable economic environment will have a similar effect.

Technology Adoption Responses to Decreased Land Availability and to Improved Agricultural Profitability

To test these hypotheses, a farm model[5] was developed for the Mossi Plateau in Burkina Faso (see Chapter 6 for some analysis with this same model and the Appendix to this chapter for model details). The principal concern with the modeling is to evaluate the profitabilities and the constraints associated with various combinations of intensive technologies in the presence of changes in the land market and in the economic environment.[6] To capture the effects of decreasing availability of land on a typical farming household, the following three cases are considered:

- Bush-fallow land is completely elastic and freely available to the farm.
- Bush-fallow land is moderately elastic and this is modeled by using a time cost of travel of one hour of additional time to get to outlying fields.
- Bush-fallow land is perfectly inelastic. Only 3.5 ha of bush-fallow land are available.

The farm income as a result of adopting either the traditional technologies or the intensive combination under different land-elasticity scenarios is shown in Figure 1. As land supply becomes more constraining, the household is able to profit by adopting new technologies over the traditional ones (compare points A and A', B and B', and C and C'. Also see Tables 5 and 6 in Chapter 6). On the Central Plateau and in other heavily populated regions of the Sahel, such as the peanut zone of Senegal, the land is already severely degraded. Thus, population pressure leads to a breakdown in the fallow system and declining yields, as in the famous Java case of farm fragmentation, resulting in chronic poverty (Geertz, 1963). This is represented in the more land-supply inelastic cases as in the Central Plateau with further yield declines ranging from a third to a half over the non-degraded case (Points I and II in Fig. 1). Nevertheless, the more intensive technologies are still able to increase farm income by 36% to $530/year (shift from Point II to I). But even with these new technologies, farm incomes are lower than the original position of bush-fallow land-supply elasticity without new technologies (Fig. 1, Point A). Thus, the soil degradation substantially reduces the potential of the new technologies.

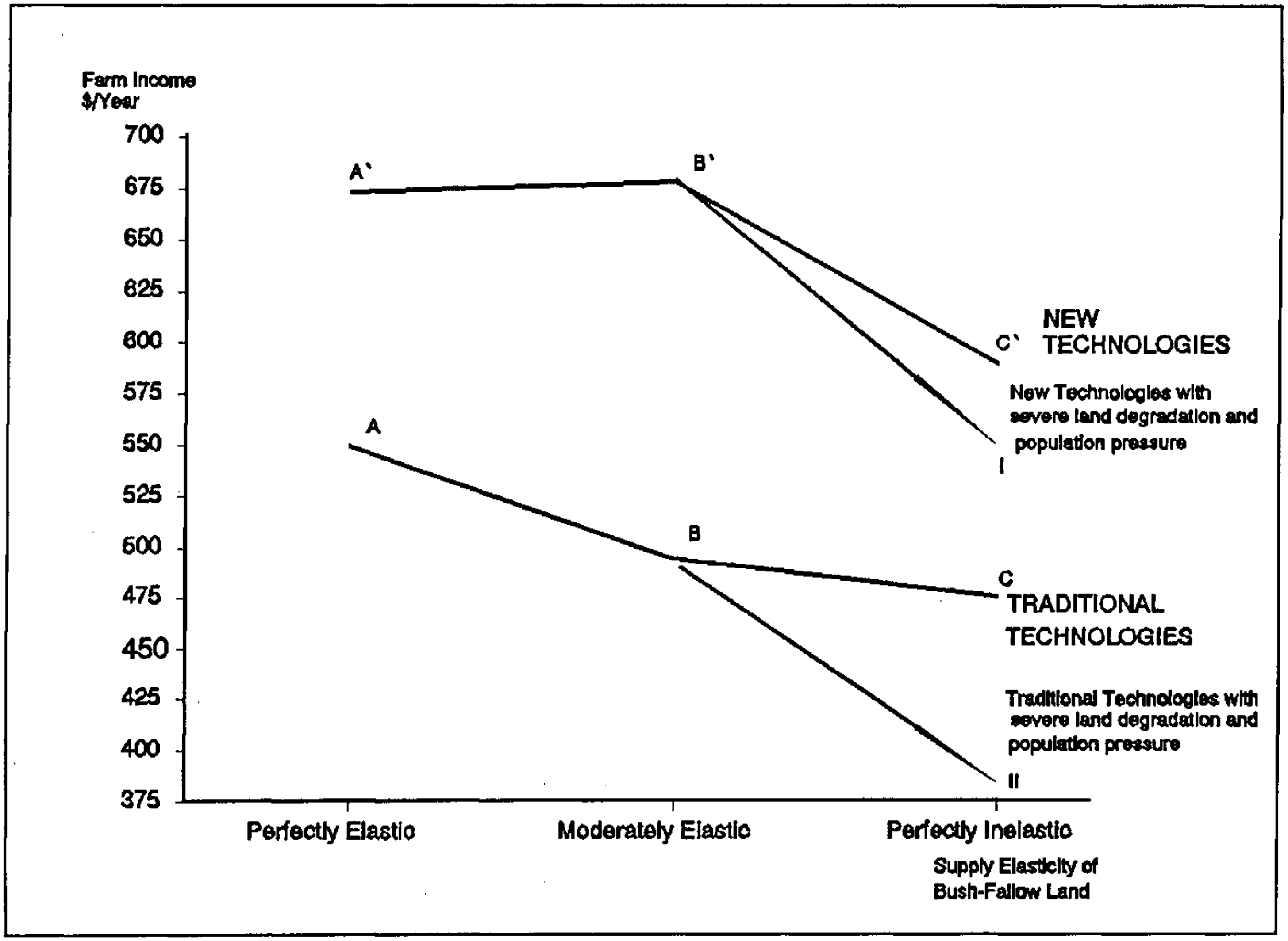

Figure 1. Farm Incomes with Traditional and New Technologies as the Supply of Bush Fallow Becomes More Inelastic.
Notes:
- Farm income includes the value home consumption.
- The moderately inelastic land supply was modeled by introducing a time cost of travel.
- The perfectly inelastic land supply was modeled by fixing the supply of bush fallow land at 3.5 ha/farm.
- The exchange rate in 1990 was 273 FCFA = 1 U.S.$ (IMF, 1990).

Source: Ramaswamy, S. and J.H. Sanders, 1992.

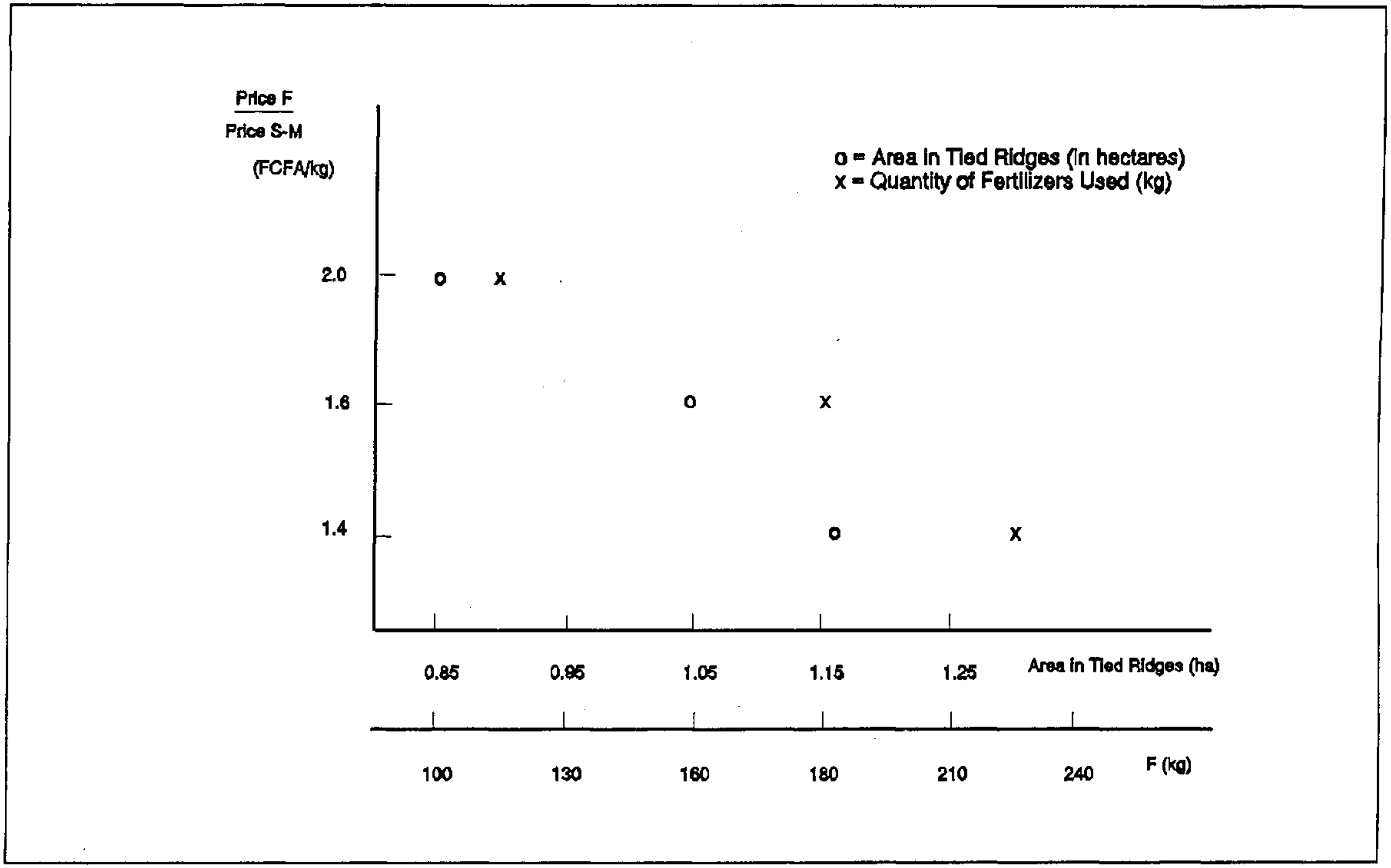

Figure 2. Effects of Improved Market Access on Utilization of Intensive (Yield-Increasing) Technologies.

NOTE: The weighted price of fertilizer (Price F) was constant, with Urea at 72 FCFA/kg and cotton fertilizer at 100 FCFA/kg (1988 prices). The average price of sorghum/millet (Price S-M) was 45 FCFA/kg and then increased 22% to 55 FCFA/kg and 44% to 65 FCFA/kg. Prices of other crops were increased proportionately. Tied ridges and fertilizers were used as complementary inputs on higher-quality sorghum land. On the compound area (maize land), only tied ridges were used. The exchange rate in 1988 was 298 FCFA/US$ (IMF, 1988).

Source: Ramaswamy, S. and J.H. Sanders, 1992.

To test the other hypothesis of the impact of an improved economic environment on intensification, a sensitivity analysis was performed on output prices. With improved transportation and communication, there would be more competition. Thus, farmers would receive increased output prices through reduced marketing margins and would face reduced input costs. This better linkage to the market is hypothesized to encourage intensification of agricultural production. For farmers in the intermediate land-supply case with only 0.7 ha of higher-quality land being intensively cultivated with sorghum, cereal prices were increased by 22% and 44% (corresponding to increases in the price of sorghum/millet from $0.16/kg to $0.20/kg and then to $0.24/kg). With increasing output prices and constant fertilizer prices, farmers shift to more intensive technologies, extending the area in tied ridges and increasing fertilization, according to the model results (Fig. 2). The creation of a profitable economic environment for farmers is one area in which policy intervention would have a direct impact. For example, if the government were to encourage the development of a feed industry for goat and sheep fattening for years of good rainfall and consequent cereal price collapses, farmers' prices for these types of years would increase. Thus, farmers' expected prices would increase.

According to the model, both the increasing inelasticity of lower-quality land and the improved economic environment result in the introduction of yield-increasing technologies. The income gains are small in absolute terms[7] but it is still possible to raise incomes moderately by introducing intensive technologies. Once these income increases are begun, there are opportunities for further income gains with new cultivars and increasing input use. Moreover, in regions of poor soil resources and prone to soil degradation, the sustainability aspect of new technologies will be increasingly important (Gorse and Steeds, 1985).

Since the above shifts are all model results, one obvious question is the accuracy of their predictions. On the more degraded soils of the Central Plateau, there recently has been a rapid diffusion of intensive technologies, including both water-retention and soil-fertility improvements. Dirt and stone diking are water-retention measures being rapidly introduced in the more severely degraded regions (for more detail, see Chapter 6). Moreover, the ICRISAT village studies of the 1980s in Burkina Faso have been recording shifts over time to more intensive techniques (Vierich & Stoop, 1990). The increased use of chemical fertilizer and the growth of a cash market for the Fulani cattle manure have both been observed in different Central Plateau villages. Increased out-of-crop-season production of fruits and vegetables for sale on the lowlands with labor-intensive watering methods is yet another shift to more intensive production occurring in this region (Vierich & Stoop, 1990).

Sustainable Agriculture and Indigenous Land Tenure Systems in the Sahel

An implicit argument in the sustainability debate is that it is primarily technology that is destabilizing to the environment. In many regions of Sub-Saharan Africa and especially the Sahel, there is an ongoing deterioration of the environment resulting from cultural practices, policies and institutional arrangements evolved for low population pressures and shifting agricultural systems. Institutional change, such as the modification of land tenure systems, is expected to be a function of agricultural development similar to the induced innovation concept of technological change (Binswanger and Ruttan, 1978, pp. 327-357; Pingali, 1990, p. 249).

Feder and Noronha (1987) assert that land rights can be seen as a bundle of distinct functional privileges that can be grouped into those concerned with <u>use</u> (cultivation, planting of trees, construction) and those tied to the notion of <u>alienation</u> (the right to sell or rent). The system of land rights in the Sahelian villages vested use rights at the level of the individual household and alienation rights at the level of the community or group (Matlon, 1991). The communal nature of property rights is derived from quasi-religious beliefs which serve to guarantee use rights for future generations. The practical implication of these beliefs is that while an individual may have rights to cultivate a particular plot, the land itself remains communal property, irrespective of the period of cultivation. In particular, the individual does not have the right to alienate such land from the community through sale or lease.

Given the rapidly rising population in the Sahel and the subsequently greater need for higher land productivity and food output, there is a growing debate within the literature about whether the indigenous communal land tenure systems are a constraint on adoption of new agricultural technologies. Dorner (1972), World Bank (1974), Harrison (1987), Southgate et al. (1990) see the communal land tenure system as static constraints on agricultural development. This system performs well at low population densities, but provides insufficient security of tenure to induce farmers to make necessary long-term land improving investments.[8] These investments can be interpreted as hostile attempts to take over land.

In contrast, Uchendu (1970), Cohen (1980), Noronha (1985), Bruce (1988), and Matlon (1991) assert that indigenous tenure regimes are in fact dynamic in nature and evolve in response to changes in factor prices. As population pressure and agricultural commercialization proceed, there has been a greater individualization of property rights and a similar evolution is expected over time in other regions (Matlon, 1991; Migot-Adholla, et al., 1991). If there were evidence that the indigenous land tenure systems were in fact constraining the adoption of new agricultural technologies, then there would be a need for large scale land titling arrangements which could be costly at this stage of economic development in the Sahel.

Figure 3 outlines in detail the proposed links between population pressure, communal land systems and agricultural technological change. As population pressure increases over time, it has a negative effect as well as a positive effect. The adverse impact, which is already visible in parts of the Sahel, results in shortening fallows, declining yields, land degradation and ultimately in depopulation as people move out of the region. Boserup (1964), Ruttan and Binswanger (1978) and Pingali, et al. (1987) emphasize the other possible effect that increasing value of land relative to labor has on the evolution of traditional farming systems. As factor prices change, there is a greater tendency for yield increasing technologies to be adopted. There is also a weak force moving the traditional communally-owned land system to become individualistic even in the absence of technological change.

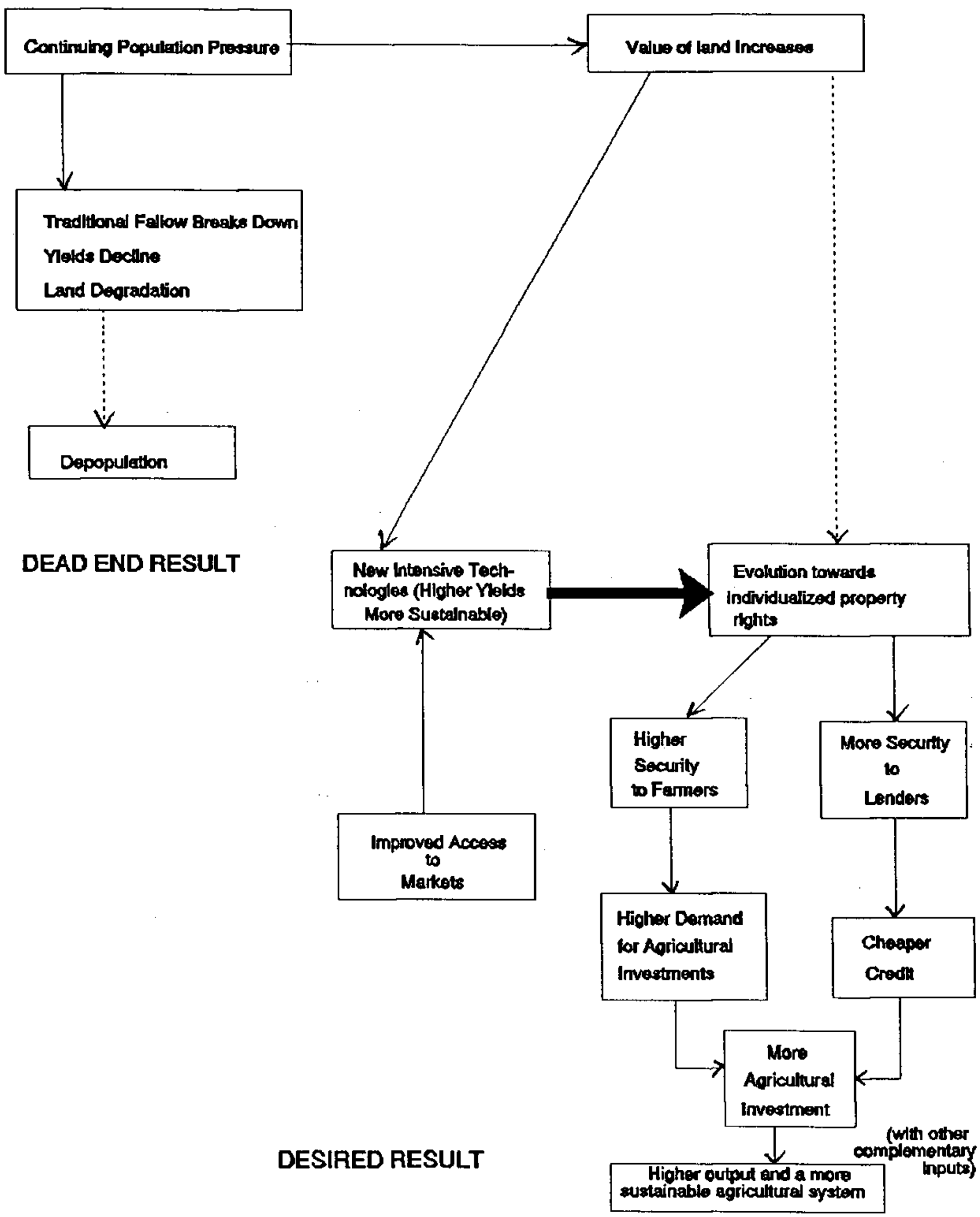

Figure 3: Links between Population Pressure, Technological Change and Institutional Change.

However, the combination of improved access to markets--that makes the adoption of new technologies more profitable--and land becoming scarce has a significant impact on the adoption of new intensive technologies. According to our model results, a favorable economic environment does act on a powerful inducement for farmers to adopt intensive technologies (see Figure 2). This technological change is then hypothesized to have a substantial effect on the evolution of indigenous land rights systems. The system becomes more individualistic. This enables land to be increasingly used as collateral against credit. The credit leads to farmers investing more in land improving investment, thus making the farming system more sustainable.

The extensive literature on land tenure systems from other parts of the world identify the following four benefits to justify the costs of reforming indigenous land rights regime (see Matlon, 1991, pp. 28-29):

a) Promotes greater efficiency in production by eliminating inefficiencies associated with plot fragmentation;

b) Ensures equitable access to land as a production unit and promotes interpersonal income equity;

c) Promotes long-term investments in land;

d) Land could be used as collateral to get term-credit for other purposes.

Historically, in parts of Sub-Saharan Africa and especially the Sahel, population pressure has been low. For the available technologies and the low levels of market activity, existing systems have performed adequately with respect to the first three aforementioned goals. There is not enough evidence presently to evaluate whether the lack of credit due to the absence of land being used as collateral poses a serious threat to agricultural productivity increases (Matlon, 1991; Migot-Adholla, 1991).

Nevertheless, farming systems across the Sahel are in a transitionary phase with rapid levels of population growth and many regions (Sahelo-Sudanian and Sudanian regions, for example) facing ecological degradation. On the basis of trends from other parts of Sub-Saharan Africa, and also the Sahel, further individualization of land holdings and the evolution of use rights into permanent proprietary rights are expected with a successful introduction of new technologies The synergistic interaction between agricultural technological change and evolution of traditional institutions is hypothesized to be a key element for making the production systems more sustainable in the future.

Sustainability Problems: Design and Implementation of Appropriate Technologies and Policies Across Agro-Ecological Zones

The natural pressures of declining land availability and policies to increase the profitability of agriculture have both been shown with programming models to encourage the adoption of intensive technologies. These intensive technologies also improve or at least maintain soil quality characteristics. Thus, this is a more sustainable agricultural system with higher chemical inputs. At the extremely low levels of purchased chemical inputs in most of semi-arid Sub-Saharan African agriculture, these chemical inputs are complements to the other, more management- or labor-demanding techniques to increase soil fertility such as increased manure, inoculation, or cereal-legume rotations (see Chapter 4 for further discussion of these concepts).

This is a fortuitous development that introducing intensive agricultural technologies at this stage of agricultural development in Sub-Saharan Africa will lead to more sustainable agricultural systems. To increase yields and to attain a more sustainable system, higher levels of agricultural chemicals, fertilizers and insecticides will be required. It would be unfortunate for the development in these countries if the political pressures from the environmental movement to reduce chemical inputs in the developed countries and in some of the irrigated regions of developing countries, such as South Korea, were pushed upon these low input agricultural systems.

However, adaptive research needs to be undertaken in this region to obtain viable integrated systems of soil-fertility management and of pest management. This research would be aimed at reducing but not eliminating the requirements for chemical-input use through improved scientific applications and better farmer management. In Table 1 some of the predominant soil and pest problems in the region are identified. Declining organic matter, erosion, crusting, and decreasing soil fertility cannot all be handled with increasing chemical inputs. Similarly, management changes and biological controls will be necessary for some of the pest problems. However, the scientific knowledge and management skills for handling some of these problems with purchased chemical inputs are presently available. Hence, it is important to utilize this knowledge and to improve crop yields now rather than to wait for the scientific-adaptation and management improvements

Table 1. Some Specific Sustainability Problems in the Major Agro-Climatic Zones[a] in Semi-Arid West Africa.

Agro-Climatic Definition	Rainfall Levels (mm) (90% Probability)	Population Density	Crop Technology Development Potential	Soil Sustainability Problems	Some Principal Pest Problems[b]
Sudano-Guinean	800-1100	Moderate. High human and animal disease risks.	High	Declining organic matter.	High levels of pesticides on cotton, storage insects, Striga.
Sudanian	600-800	High	Moderate	Water and wind erosion, soil-crusting, low organic matter, low soil fertility	Headbugs & stemborer in sorghum, Cowpeas (see below), Striga.
Sahelo-Sudanian	350-600	High in southern section, but declining farther north.	Lower than Sudanian for sorghum system. Low for millet/ cowpea system.	Water and wind erosion; low soil fertility and organic matter; poor water and nutrient retention in sandy, dune soil.	Headgirdler and stemborer on millet; thrips and maruca on cowpeas in field and bruchids in storage; Striga

Sources: Rainfall divisions are from J.E. Gourse and D.R. Steeds, *Desertification in the Sahelian and Sudanian Zones of West Africa*, Washington, DC: World Bank, 1985, p. 2. For more detail on cropping systems, technology adoption, and potential technology introduction, see J.H. Sanders, "Agricultural Research and Cereal Technology Introduction in Burkina Faso and Niger," *Agricultural Systems* 30(1989):139-154. Also see J.L. Posner and E. Gilbert, "Sustainable Agriculture and FSR in Semi-Arid West Africa: Keeping the Elephant out of the Rowboat," mimeo presented at Farming Systems Association meeting, Michigan State University, East Lansing, MI, U.S.A., Oct. 1990.

[a] The other agro-climatic zone in semi-arid West Africa is the Sahel with less than 350 mm of rainfall (90% probability). This region was not included as rainfall is too low for crop production, except in oases or with irrigation.

[b] For the last two agro-ecological zones, Dr. D. Paschke, Professor of Entomology at Purdue, provided useful inputs from his fieldwork in the Sahel.

from the future technical development of integrated soil and pest-management programs[9] (for more discussion of integrated techniques of fertility and pest management, see Lal, 1991, and Edwards et al., 1991).

The discussion of sustainability has been generalized for the region and now needs to be looked at in more detail for specific agro-climatic zones with a further emphasis on policy alternatives.

Resource Allocation and Sustainability Issues in High-Input Regions

Allocation of research investment between regions will need to concentrate on where the returns are potentially the highest within the constraints defined for sustainability. In many cases, the more prosperous regions (higher rainfall or greater water availability, better soil fertility) will also be the regions with the highest potential returns (see Plucknett, 1990; Hudgens and Harwood, 1990).

In semi-arid West Africa, the most rapid technological change in agriculture has occurred in the highest rainfall region, the Sudano-Guinean zone. This also appears to be the region with the greatest future potential for continuing output increases. Rainfall is sufficiently high so that water-retention techniques are not necessary in most crop years. Crop yields are still low by international standards. Moreover, the population densities are lower here than in the other two regions. Areas of higher rainfall have greater potential for output increases but in West Africa these areas are often associated with higher disease risks (see Chapter 12). The incidence of trypanomiasis, malaria, and river blindness are all higher in the Sudano-Guinean zone than in the other two zones. The returns to investment in agricultural research and development are probably linked to simultaneous investments to improve health conditions. These are not expected to be small investments or short-run strategies.

<u>Maintenance research and sustainability issues</u>. In the Sudano-Guinean zone of Burkina Faso, chemical fertilizer use is moderately high on cotton and corn and there is an impact from fertilization on sorghum through rotation. In this zone there is a complicated technical problem of reversing the decline of organic matter on farms where plant residues are grazed, harvested for building materials, and/or burned. Inorganic fertilizers are applied but there is little application of organic fertilizers. Chemical fertilizer does not help

build up this organic-matter level and in some circumstances can aggravate this decline. Introduction of a legume into the rotation, incorporation of plant residues, and other measures to raise organic matter are increasingly of concern to applied agricultural researchers here.

As the yield gaps between developed countries and the high-input systems in Sub-Saharan Africa are reduced, implementing systems of maintenance research to respond to emerging problems will become increasingly important. The closing of the yield gap is probably a decade away but the national agricultural research systems in Sub-Saharan Africa need to be creating now the scientific manpower and institutions to respond to new problems experienced over this decade.

Case of the Low-Input Regions

Reversing cereal-yield declines. In the Sudanian and Sahelo-Sudanian zones, the principal economic and sustainability problem is to increase cereal production. Cereals are the basic staples and yields are declining with population pressure, reduced fallow periods, and soil degradation. The principal constraints to crop-yield increases are water availability at critical times and soil fertility (Sanders et al., 1990; Matlon and Adesina, 1991). New technologies responding to both constraints are being rapidly introduced into the more degraded regions of Burkina Faso, i.e., contour dikes combined with animal manure. Moreover, there are a series of similar technologies from other regions of the world that could be adopted here, such as the furrow dikes (tied ridges) of the Texas high plains. Field and farm-level research results are available on the successful agronomic and economic performance of several of these water-retention and soil-fertility innovations for the Sahel (Sanders et al., 1990). These land-intensive technologies would not only increase yields but also handle many of the soil problems. Once combined strategies for water retention and chemical fertilizers are implemented, new cultivars can have a substantial impact in this agronomically-improved environment. Soil fertility has to be improved. Organic fertilizers are in limited supply and most other alternatives to chemical fertilizer have either technical or economic problems (Nagy et al., 1988). Hence, increasing levels of chemical fertilizer appear to be necessary to improve cereal yields. These purchased inputs need to be combined with labor-intensive water-retention methods to increase the returns to chemical fertilizer and reduce the risks.

No "magic" alternatives (low farmer expenditure, zero foreign-exchange cost) are presently available to resolve the soil-fertility constraints in these low-input systems. At the very low purchased-input levels of much of semi-arid Sub-Saharan Africa, inorganic and organic fertilizers are complements not substitutes (Sanders, 1989; Deuson and Sanders, 1990). Chemical fertilizer has been shown to be profitable on sorghum in the Sudanian and the higher-rainfall Sahelo-Sudanian zones when combined with water-retention techniques (Sanders et al., 1990). Research for a technically feasible, economically profitable substitutes for chemical fertilizer can be an important priority but should not delay increasing cereal yields now. Foreign exchange is an apparent constraint to increasing fertilization levels in many countries. Policymakers can be deluded by the illusive prospect of a local solution not requiring imports or farmer expenditures. Manure, rotation, local rock phosphate, inoculation, and other alternatives have been suggested. Field-testing and economic analysis have indicated that these alternatives are either not available in sufficient supply (such as manure and crop residues), do not have the expected technical impacts, or are not profitable (such as local rock phosphate) (Nagy et al, 1988). It continues to be important to do basic and adaptive research on these soils and on the multiple alternatives to reduce fertilizer costs. Meanwhile, the available technologies of water retention and chemical fertilizers need to be employed since crop yields need to be increased now.

Specific soil problems. Low organic matter and low soil nutrients are common problems in the Sudanian and Sahelo-Sudanian zones. Once cereal yields are stabilized and increased, there will be more organic matter for incorporation into the soil. Increased cereal production also enables a withdrawal from more marginal lands where grazing can then be increased. Increased livestock also means increased manure. As in the high-input regions, better rotations -- especially including a high-yielding grain legume in the rotation -- and incorporating more crop residues would also help resolve the above soil problems.

Movement of crops out of marginal production zones. The sandy, dune soils in much of the Sahelo-Sudanian region support subsistence levels of millet and cowpeas. In some countries, such as Niger, these are very important cropping systems with a major sector of the farm population. However, with scanty rainfall and very low soil fertility, designing technologies to increase crop production in a sustainable way appears to be a very inefficient manner to spend public resources. In farm modeling in one low-rainfall crop region in Niger (see Chapter 7), there is no reasonable scenario about new technologies or policy changes in which even a low-level fertilizer use comes into the model (Shapiro, 1990, p. 128). Without fertilizer use, this degraded system does not become sustainable. In these more marginal rainfall regions, crop production probably needs to be replaced with trees and grazing. Since developing technological change in crop production for these more marginal regions appears to have very low potential returns, this presents a difficult adjustment for farmers on these low-rainfall, fragile, sandy, dune soils and for policymakers concerned with their welfare (Shapiro, 1990). Technological change is not expected to be an efficient instrument to resolve all human welfare problems. Alternatives to crop production and increased out-migration seem to be more appropriate so that crops can be replaced with forestry and grazing.

Conclusions

In semi-arid Sub-Saharan African agriculture with its low fertility and often degraded soils, sustainable-development priorities need to focus on increasing purchased inputs rather than on some of the more complicated management concepts stressed in the ecology literature, such as nutrient cycles or integrated pest management (Lal, 1991; Edwards et al., 1991). In many of the low-input regions, the combination of technologies to improve soil fertility and increase water retention have shown reasonable gains in yields and profitability. Some of the soil problems, such as low initial and declining organic matter, will probably require not only changes in farmers' practices but also continuing applied and even basic research. Some of the low-input crop production regions with more unfavorable rainfall and soil conditions will need to shift into forests and grazing.

In many countries the principal emphasis may need to be on the high-input regions since the returns to investment and research are expected to be the highest in the regions with sufficient water available to insure high returns to other inputs. Technology development needs to be concentrated on those regions with the highest returns rather than to be overly oriented to equity concerns to resolve all farmers' income problems, wherever they may be. The equity objectives within agriculture need to be balanced with the objectives of higher nutritional levels for consumers in urban areas. Technological change is not a very efficient instrument for the attainment of income-distribution objectives.

Furthermore, the responsiveness of technological change in attaining high rates of cereal production should not be seen as a justification for the continuing failure of governments and donors to act effectively on the staggering rates of growth of population in the Sahelian countries. The potential effects of the yield increasing technologies were shown to be reduced by the land degradation resulting from high population densities.

Appendix: The Linear Programming Model

A representative farm model was constructed for the Central Plateau. The decision-making unit maximizes a linearized profit-function subject to a consumption constraint for maize and constraints on land, labor, donkeys, and capital. (For further details, see Roth, et al., 1986, and Sanders, et al., 1990.) The farm produces five commodities: sorghum, maize, millet, cowpeas, and peanuts.[10] The farm household maximizes the gross value of production (sales plus value of home consumption) less expenditures for inputs. There are two power technologies, hand and animal traction.

For hand-tillage technologies, land and labor are the only inputs. Their costs are derived implicitly from land and labor constraints incorporated in the model. When animal power or fertilizers are introduced, purchased input costs are incurred. For each type of traction system (hand/animal), 27 different activities are possible on the farm. The derived demand and supply of land resources is defined by

$$\Sigma X_{ij}^{M} + \Sigma X_{ij}^{A} <= T_{i} \qquad j=1...27$$

Demand for land type '1' is derived from cultivation enterprises X_{ij}^{M} and X_{ij}^{A}. Supply of land, T_i, represents endowments of the particular land type owned or controlled by the household. Three land types are included: (1) high-quality land next to the farm household (also called compound land) on which maize is customarily planted (0.15 ha); (2) intrinsically more fertile land lying farther down the toposequence on which sorghum or sorghum/cowpeas are traditionally planted (1.4 ha); and (3) sandy, infertile, poor-quality bush fields on which primarily millet and peanuts are planted (Vierich & Stoop, 1987; Stoop, 1987). Initially, the farm household has fixed levels of the first two land types but bush land availability is unlimited. This assumption about bush-fallow land is then modified to reflect increased population pressure.

The representative farm household here has 11 residents, including six active workers and five children. Among the active workers are two adult males and four adult females (Roth, et al., 1986). The model does not allow for hiring labor. In normal and good rainfall years, farmers on the Central Plateau have difficulty finding seasonal labor because most farmers want to cultivate their own plots (Binswanger and McIntire, 1987; Sanders, et al., 1990).

Labor constraints: There are 10 rows denoting the sequential nature of agricultural operations from land preparation to harvesting. The technical coefficients, A_{ij}, represent the number of hours required per hectare in period 'i' for crop enterprise X_j. For each period 'i' the derived demand and supply of labor can be represented by the equation

$$\Sigma A_{ij}^{M} X_j^{M} + \Sigma A_{ij}^{MA} X_j^{A} <= MHR_i * MA + FHR_i * FA$$

Each term on the LHS of the inequality represents the demand for human labor in conjunction with the different technology regimes. The supply of labor is derived from the number of male adults (MA) and female adults (FA) "actives" in the household. Male adults work MHR_i in period 'i' and correspondingly for female adults. The dual prices associated with RHS labor resources, $MHR_i * MA + FHR_i * FA$, are the marginal values of an additional hour of labor in period 'i'. The demand and supply of animal traction are treated in a similar manner.

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Notes

1. For the basic entitlement concept, see J. Dreze and A.K. Sen (1989). Also see Batie, S. (1989) for this division of the conceptual approach to societal goals of environmentalists and economists.

2. The following three sections are taken from S. Ramaswamy and J.H. Sanders, "Population Pressure, Land Degradation and Sustainable Agricultural Technologies for the Sahel," *Agricultural Systems*, forthcoming. It is reprinted with permission of Elsevier Science Publishers. (We will request this permission when we have the go-ahead from a publisher.)

3. In the Senegalese Groundnut Basin, Gambia and the Central (Mossi) Plateau of Burkina Faso, 24% of the population lives on 2% of the area at an average rural population density of 45 persons/km^2. For the entire Sudanian and Sahelo-Sudanian zones across the Sahel, the population density is 19 to 20 persons/km^2 (Gorse and Steads, 1985, pp. 2 and 8).

4. There is a minor exception to this assertion. Fulani systems with large herds and small crop areas produce enough manure to maintain soil fertility. Moreover, the Fulani often sell some of their manure.

5. Several recent articles (Binswanger and McIntire, 1987; Bromley and Chavas, 1989; Krause, et al., 1990) have stressed the importance of risk sharing and institutional change in facilitating technological change and output increases in Sub-Saharan Africa. A next step would be to more comprehensive household modeling including some of these factors. The more limited objectives here focused on the introduction of these technologies in the absence of risk. The principal concern was the long-run comparative statics of the increasing costs for land and of increasing profitability of output. Introduction of stochastic factors affecting yields, prices, and other inputs and more complex objective functions was not expected to affect the long-run direction of these shifts. The authors hypothesize that this crop-mix, technology-adoption choice would be less affected by risk than by the overall family decisions about relatives staying in agriculture in the region. Having relatives working in nonfarm activities and in agriculture in different climatic zones has a much greater potential effect on income variability than the adoption of new technologies, which include the yield risk-reducing feature of assuring greater water availability between seasons. More research incorporating risk is needed on these broader issues of household decision-making.

6. The intensive technologies are the tied ridges on the compound land (0.15 ha) and the combination of tied ridges/fertilization on the high-quality bush-fallow land (1.4 ha).

7. On an adult-male equivalent basis, the hourly wage rate increases from 12 cents to 17 cents (see footnotes in Tables 5 and 6 of Chapter 6 for details on calculation of these hourly wage rates). With the new technologies, these hourly incomes are approximately equal to the average wage of agricultural labor in this region of 17 cents/hour. It is not surprising that farmers would be earning the average wage or below because hired labor would not be employed full time and this hired labor would incur search costs to find employment.

8. Boserup (1981), Pingali and others (1987) provide evidence suggesting that without accompanying improvements in infrastructure, rural health and education, and price incentives, the rate of intensification in agriculture would be constrained under *any* tenure regime.

9. The Office of Technology Assessment (1990) defines integrated pest managements, as "the optimization of pest control measures in an economically and ecologically sound manner accomplished by the coordinated use of multiple tactics to assure stable crop production and to maintain pest damage below the economic injury level while minimizing hazards to animals, plants, and the environment."

10. The yields used in the model were based on SAFGRAD reports, 1982-84; Roth, et al., 1986; and Jaeger, 1988. Initially, the yields were taken to be constant at different land supply elasticities. However, population pressure implies soil degradation, reducing potential cereal yields. Thus, the model explicitly considers two situations: the undegraded and the degraded cases (see Fig. I).