Increasing Food Production in Sub-Saharan Africa: Environmental Problems and Inadequate Technological Solutions

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Recent reviews analyzing the poor performance of agriculture in Sub-Saharan Africa have placed primary emphasis on the constraints posed by inappropriate fiscal and pricing policies, inadequate extension and marketing systems, and mismanagement (World Bank, USDA). An underlying assumption of these reviews has been that once such institutional barriers were removed, technical conditions would permit major and sustainable growth in aggregate supply. Corollaries to this latter assumption are that there are surplus resources (particularly land) which can be drawn into production, and/or that current on-shelf technologies, once in farmers' hands, can indeed bring about a long-term increase in farm productivity.

While not denying the importance of disincentives and other institutional and infrastructural constraints to African agriculture, we believe that the most common interpretation of the land surplus argument and the adequacy of the current set of "improved" technologies are both in need of a serious reassessment. This paper briefly surveys the evolving technical and social conditions of African agriculture and evaluates the current stock of technological innovations. We conclude that, with the exception of relatively limited high-potential zones, the set of new technologies is most often inappropriate, poorly responding to farmers' changing needs, and cannot bring about a sustainable response in aggregate supply. Improving this situation demands a reorientation of the objectives and methods of technical agricultural research.

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The Land Surplus Question

Most models of African agricultural development have tended to take the assumption of a generalized land surplus situation as a starting point (Helleiner, Hansen), but it is necessary to qualify this perspective.

First, substantial proportions of land are economically unsuitable for agriculture because of desert conditions, rock outcroppings, and periodic flooding or are unsuitable for human and animal populations because of diseases such as bilharzia, trypanosomiasis, and onchocerciasis. Second, there is a high degree of microvariability in land quality, such that the better soils are often already under cultivation. Third, soils in much of Africa are unstable with productivity declining rapidly under continuous cultivation, thereby requiring a high ratio of fallow to cultivated land. Overlayed on these technical factors, the rapid growth of African rural populations during the last thirty years has pushed many regions of Africa toward intensified cultivation marked by stagnant or declining crop yields and a degradation of the land base.

To examine the effects of these demographic changes on African farming systems and the resultant implications for technological change, it is necessary to review briefly the natural resource base with which African farmers work.

Environmental Constraints to Agriculture

The variability in climate, soils, and population densities across Sub-Saharan Africa requires a delineation of zones to define technical potential, constraints, and needs for technological change. At the most general level we distinguish between the humid and semiarid zones. Within the former the quantity, distribution, and reliability of rainfall are not limiting factors, but the agricultural potential is less than in the semiarid zones because of factors ironically linked to the high rainfall (ter Kuile). Solar radiation is limited and because of leaching soils are low in natural fertility and tend to be acid. Moreover, with clearing of the vegetative cover, soil degradation can be readily induced, posing the most important constraint to sustained increases in food production. Finally, continuously humid conditions and high temperatures cause very rapid spread of pests and diseases constraining the introduction of exotic genetic materials.

In the semiarid regions of Sub-Saharan Africa, low and variable rainfall and a short growing season are the primary limiting constraints to production (Matlon). In addition, although high temperatures and solar radiation during the rainy season encourage rapid plant growth, the resulting high evapotranspiration rates importantly increase crop water demands and reduce available soil water (Charreau). Extremely high rainfall intensities also cause serious erosion. Frequent intra-annual and prolonged interannual droughts add to the endemic instability of agriculture in the semiarid zones. The dominant soils of the semiarid tropics also suffer from important chemical and physical deficiencies and are highly fragile (Pichot et al.).

Traditional Farming Systems and Evolving Technical Needs

The farming systems which evolved in response to these environmental conditions were logically highly extensive (Norman, Newman, and Ouedraogo; Ruthenberg). But rapid demographic and economic changes within the last several decades have irreversibly changed the ecological balance upon which these extensive systems depended. Cultivated area has expanded onto marginal soil types, and fallow periods are being systematically reduced. Local farming systems are adjusting slowly; as a result, major areas of land in Africa are being systematically mined and degraded. Moreover, the pressure on traditional farming systems caused by evolving demographic and economic changes have been greatly exacerbated by the persistent drought experienced in much of the semiarid zones of Sub-Saharan Africa since 1968. Arable and grazing lands are being lost to desertification, and water is becoming scarcer. There is thus much need to develop intensive land-conserving and land-augmenting technologies.

Unfortunately, because the rate of demographic change is higher and the physical conditions which determine technical potential are often more difficult in Africa compared to other continents, the extent to which technical solutions developed elsewhere can be imported into Africa is quite limited. Comparing the semiarid tropics of West Africa and India, for example, it has been observed that although total annual rainfall is similar, the growing season in Africa tends to be shorter, with greater risk of drought (Charreau, Matlon). Moreover African soils tend to be shallower, have poorer texture, are more inert, and have lower water-holding capacities than comparable Indian soils (Stoop et al.). Pests and pathogens are also different.

Such differences help explain the lack of success to date in the direct introduction of exotic high-yielding cultivars, except for irrigated rice where the environment can be modified to suit the crop. For example, ICRISAT has had little success with direct introductions of Indian sorghum and millet variéties to West Africa (Matlon). And after seven years of variety trials in which over 2,000 varieties were imported for trials in the mangrove swamps of West Africa, the West Africa Rice Development Association (WARDA) found only two varieties that perform as well as the best local varieties.

New Technological Options

In this section we examine some of the current stock of technological interventions in five principal areas: irrigation, other forms of land/water management, mechanization, soil fertility management, and crop improvement.

Irrigation

The potential leverage of irrigation on aggregate production in Africa is greatest in the semiarid regions where water is an important limiting factor. Despite major investments in large-scale irrigation schemes in West Africa, only about 3% of total farmed area is under irrigation.

Limited *ex post* assessments of the economics of large-scale irrigation projects have usually revealed economic losses or noncompetitive returns (Sparling). Major problems include high investment costs from the very high proportion of foreign capital and imported manpower used in the construction of such projects, high recurrent costs, and poor management which result in inadequate maintenance of structures and equipment. In addition annual yields tend to be low because of the general absence of double cropping, poor water control, inappropriate agronomic packages, and the lack of complementary inputs.

The evidence strongly suggests that in the absence of large, long-term, and highly subsidized donor assistance, complemented with substantial investment in training of local manpower, it is unlikely that large-scale irrigation schemes will play an important role in meeting Africa's food needs in the foreseeable future. However, there is evidence of attractive returns to investment in small-scale labor-intensive projects managed and operated by family and/or community groups (Eicher and Baker).

Land/Water Management

The objectives of improved land/water management methods are to protect the soil base over the long-term while at the same time providing an immediate boost to yields. Research on the humid zones has shown that the process of soil degradation under high rainfall conditions usually begins with inappropriate partially mechanized clearing methods subsequently exacerbated by insufficient soil cover. Improved systems, building on traditional farming practices, are being developed by the International Institute of Tropical Agriculture (IITA). These involve light clearing, *in situ* burning, and intensive use of surface mulch in combination with herbicides and minimum or zero tillage. How these packages perform under small farmers' management and fit into their systems, however, is only now being determined in on-farm testing. Moreover, the development of economic chemical weed control methods and small-scale equipment for use in low tillage systems pose immediate research problems (ter Kuile).

Within the semiarid zones, a set of interventions is being examined including tied ridges, mulching, contour bunding, and various watershed-based management systems. Although tied ridges have been shown to dramatically reduce runoff and increase yields in on-station trials in both East and West Africa (Ruthenberg, ICRISAT 1981), substantial labor costs and yield gaps observed under farmers' conditions throw doubt on the extensive use of this approach. The development of low-cost, farmer-adapted means to mechanize the tying of ridges should be an important research priority. Because of increasing demands for crop residues as livestock feed, fuel, and in alternative uses, the potential for extensive use of mulches in sorghum and millet production is even more limited.

On the other hand, farmers' tests conducted in Burkina Faso over several years have found highly significant short-term yield increases from the introduction of dirt anti-erosion dikes constructed on the contours of farmers' fields (ICRISAT 1983). Small-scale rock-based water harvesting systems have also been shown to be attractive to farmers as a means of reclaiming highly eroded fields in high population pressure regions of that country. These latter approaches, which invest labor in semipermanent structures to make more efficient use of rainfall, are among the promising technologies available for semiarid zones with moderate to high population pressure.

Mechanization

Improved equipment (internal combustion, animal, or human powered) have not yet made an important contribution to agricultural production except in a limited number of cash-cropping areas in the semiarid tropics of Africa. Within the humid-tropics, tse-tse fly infestation prohibits the development of animal-based systems. Mechanization schemes based on the use of tractors (two- or four-wheeled) have met with limited success in the humid tropics because of high capital costs relative to the capital resources and scale of operation of farmers, as well as the lack of know-how in equipment use and maintenance. Work in the humid tropics is now concentrating on light manual-powered equipment for use in minimum tillage and alley-cropping systems (ter Kuile). Whether these tools are economic under farmers' conditions has yet to be demonstrated.

Despite efforts to introduce animal traction in the semiarid tropics dating to the early 1900s, the current use of animal traction systems is limited to less than 15% of cultivated area. The potential yield and labor savings benefits of animal-powered cultivation practices, repeatedly measured under experiment station conditions (Sargeant et al.), have rarely been confirmed under farmers' management.

A set of common institutional and technical constraints, acting both on the demand and supply sides of animal traction systems, have limited the attainment of the potential benefits. On the supply side, poorly developed extension and support systems result in the lack of medium-term credit for equipment and animals, as well as inadequate training, veterinary, and equipment maintenance systems, and the absence of assured channels for complementary inputs and products.[1]

Several limiting factors are present on the demand side. First, because of the limited range of operations mechanized, power constraints are often simply shifted between operations resulting in a gross underutilization of animals and little area expansion. Second, except for the Guinean zones where the rainy season is longer, there is a conflict between plowing and timely planting which limits the area plowed and restricts the emergence of rental markets (Jaegar). Similarly, due to the rapid drying and hardening of soils following the rains, farmers face a conflict between harvest and end-of-season plowing which means that crop residues are almost never completely incorporated. Finally, numerous studies suggest that at least six to eight years are required to achieve full economic benefits, causing net incremental benefits to be negative during the early years of adoption.

Soil Fertility Improvement

Despite the generally poor chemical status of most African soils and its rapid depletion under continuous cultivation, the consumption of chemical fertilizers is very low in Sub-Saharan Africa. This is caused in part by the absence of well-developed petrochemical industries in most African states, so that fertilizer use entails substantial foreign exchange costs exacerbated by high transport costs to and within landlocked countries. Furthermore, technical response rates are low and highly variable, particularly on local varieties of rainfed food crops and in the more arid areas, resulting in marginal or negative economic returns (IFDC, ICRISAT 1983). Finally, complementary applications of large quantities of organic matter are required to achieve and maintain the potential response to chemical fertilizers over the long run (Pichot et al.).

For all of these reasons, greater basic and applied research needs to be directed to developing and using locally available sources of chemical fertilizers, such as rock phosphate as well as organic sources of soil nutrients. A particularly promising area is a more efficient integration of crops and livestock. The inter- or relay-cropping of leguminous fodder crops with food or cash crops holds some promise. For the longer term, nitrogen fixation by nonleguminous crops and blue green algae may also become feasible. Finally, the integration of tree and crop production may hold future potential, not only as windbreaks and as a source of organic matter, but also as a means of recovering nutrients from soil depths below crop rooting zones.

Crop Improvement

Crop improvement programs during the pre-independence period generally emphasized export crops (Collinson). With few exceptions, e.g., hybrid maize in Zimbabwe and Kenya, major programs for the genetic improvement of food staples are relatively recent and have had little success. Despite frequently promising on-station results, yield gaps of up to 60% are consistently observed when most new varieties are cultivated by farmers (ICRISAT 1980/83). Unacceptable taste as well as processing and storage problems are also commonly encountered. As a result, probably less than 2% of total sorghum, millet, and upland rice area in West Africa is sown to cultivars developed through modern genetic research.

Experience suggests that this poor record is caused by a complex of factors including excessive emphasis given to the development of high-yielding but input-dependent crop varieties in view of the regions' soils, level of infrastructural development, and limited farm-level capital. New materials are also generally developed and selected exclusively under research station conditions which are generally atypical of prevailing farmers' conditions. The situation is often made worse by the lack of early, systematic, and critical feedback from the farmer to the breeder (Matlon).

Several corrective prescriptions can be suggested. In the semiarid tropics, for example, moderate yield increases but substantially greater stability could be achieved through breeding for improved seedling vigor, drought resistance, and resistance to the most common

[1] In part, these factors help explain the successful extension of animal traction systems in the Sine-Saloum area in Senegal, in southern Mali, and in southwestern Upper Volta, where vertically integrated cash crop marketing organizations have actively promoted adoption through comprehensive support (Matlon).

pests and diseases. The development of varieties with different agronomic characteristics, such as shorter crop cycle or modified plant structure, could also increase farmers' management options, e.g., intercropping or permitting late planting without yield loss (Stoop et al.).

Conclusions

The current set of new production technologies responds inadequately to the continent's evolving needs. In areas of lowest population pressure in the semiarid tropics, marginally profitable animal-powered mechanized systems permit some expansion of cultivated area. But methods by which these systems can evolve to more intensive, ecologically sustainable systems are generally lacking. Improved labor-augmenting mechanized systems are even less well developed in the humid tropics.

Research to develop yield-increasing, land-augmenting technologies has received increasing emphasis recently, but gains have been modest. Contrasted with often impressive on-station yields, new technologies usually perform poorly under farmers' conditions and demand a level of management small farmers are usually unable to provide. These failures stem to a large extent from an inadequate understanding of small farmer goals and resources used in formulating research objectives. Finally, African research systems have been slow to diagnose and respond to these problems because of the absence of systematic monitoring and feedback of technology transfer problems encountered at the farm level.

We recommend three broad changes in current technical research programs to address these problems.

First, specific research objectives should be based on greater understanding of farmers' objectives and resources and greater regional and farm-type disaggregation. This change requires a more explicit *ex ante* assessment of farmers' situations and more finely defined recommendation domains.

Second, there should be greater on-farm testing of new technology components as an early and integral part of the technology development process. On-farm research is particularly needed to identify the factors responsible for yield gaps at the farmer level for feedback into a reassessment of on-station objectives and methods.

Finally, technical research programs should reflect greater balance between long-term (land base conservation) and short-term (production) objectives. This implies not only a broader set of objectives for technology development, but also a multiyear time frame for technology evaluation.

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