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TECHNOLOGICAL PRIORITIES FOR FARMING IN SUB-SAHARAN AFRICA

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Advanced agricultural technologies have not achieved much success in Sub-Saharan Africa. Attempts to match Asia's Green Revolution in food grains have often failed. The use of tractors has produced disappointing results and has been abandoned in many areas. Many irrigation projects have yielded low or negative returns.

One reason for this unsatisfactory record is that the wrong technology priorities have been followed in several countries. Other reasons include faulty pricing policies, inadequate infrastructure, and poor institutional development. This article focuses on technology priorities and is intended to provide an analytical framework for making choices about technology.

Sub-Saharan Africa has a wide range of climates, soils, and labor, which leads to a variety of farming systems. Technology strategies have often failed to take proper account of these local differences, so have not been cost-effective.

Farmers change their techniques in two ways: (a) they may decide to increase the use of an input with which they are already familiar (factor substitution), as when they decide to weed more intensively, to apply organic fertilizer, or to make simple improvements to their land, or (b) they may adopt techniques that are new to them, in which case they have to go through a learning process. In either case farmers will make only those changes that they think will reduce unit costs of production (including the implicit cost of family labor and the opportunity cost of land). That a technique is highly advanced does not necessarily mean that it will reduce production costs in African conditions.

Techniques that are new to local farmers may have been used elsewhere and can be applied virtually unchanged: one example is the adoption of machinery. However, the technology often needs to be changed, which requires some research and development to adapt it to local conditions.

It takes a long time for agricultural research to bear fruit in increased production. The research and technology strategies adopted today will have their full impact in the first quarter of the next century, which is the planning horizon we employ in this article. In most cases, the chosen techniques and therefore the technology priorities will have to be tailored to local conditions. In a few cases, however, local conditions can be changed by investing in infrastructure and encouraging migration, making it cost-effective to use more advanced techniques.

The Evolution of Farming Systems

Large parts of Africa are still farmed by traditional methods of shifting cultivation. Farmers slash and burn patches of forest, farming the land for a few years until its fertility diminishes. The farmers then move on to another forest patch, leaving the land for twenty years or so to recover its natural fertility. Little tillage is necessary, and digging sticks are enough for the purpose. Draft animals are not needed (and in any case cannot survive in African forests, because tsetse flies spread trypanosomiasis). This phase of forest fallow farming lies at one end of a spectrum of agricultural techniques, with multiple cropping at the other end (see table 1). The evolution from shifting cultivation to multiple cropping is driven by population growth and by the higher returns to farming which arise when market infrastructure improves and farmgate prices increase (Boserup 1965, Ruthenberg 1980, and Pingali, Bigot, and Binswanger 1987). Farmers first move to a bush fallow system: they cultivate their patches for longer periods (six to eight years) and leave them fallow for a similar period. Because they have to weed and till the land, they start making regular use of hoes.

As population density grows, bush gives way to grass cover. The fallow period is reduced, perhaps to no more than a year. Plowing and intensive weeding are needed, so the use of draft animals becomes economic (and possible, since the disappearance of forests reduces the tsetse fly menace). Animal manure helps to fertilize the soil. Since there is abundant grazing on pastures and grass fallows, the cost of keeping cattle is low.

As population density increases still further, annual cropping and later multiple cropping become the rule. This stage has been reached in much of Asia, but is still uncommon in large parts of Africa. Land is now scarce, and its value rises. Farmers find it cost-effective to shift from manual techniques to labor-saving devices such as milling ma-

Table 1. Farming Operations in Different Farming Systems

<i>Operation or situation</i>	<i>Forest fallow system</i>	<i>Bush fallow system</i>	<i>Short fallow system</i>	<i>Annual cultivation system</i>	<i>Multiple cropping system</i>
Land clearing	Fire	Fire	None	None	None
Land preparation and planting	No land preparation; use of digging stick to plant roots and sow seeds	Use of hoe and digging stick to loosen soil	Plow	Animal-drawn plow and tractor	Animal-drawn plow and tractor
Fertilization	Ash, perhaps household refuse for garden plots	Ash, sometimes chit-mene techniques, ^a household refuse for garden plots	Manure, sometimes human waste, sometimes composting	Manure, sometimes human waste, composting, cultivation of green manure crops, chemical fertilizers	Manure, sometimes human waste, composting, cultivation of green manure crops, chemical fertilizers
Weeding	Minimal	Required as the length of fallow decreases	Intensive weeding required	Intensive weeding required	Intensive weeding required
Use of animals	None	Animal-drawn plow begins to appear as length of fallow decreases	Plowing, transport interculture	Plowing, transport interculture, post-harvest tasks, and irrigation	Plowing, transport interculture, post-harvest tasks, and irrigation
Seasonality of demand for labor	Minimal	Weeding	Land preparation, weeding, and harvesting	Land preparation, weeding, and harvesting	Acute peak in demand around land preparation, harvest, and postharvest tasks
Supply of fodder	None	Emergence of grazing land	Abundant open grazing	Open grazing restricted to marginal lands and stubble grazing	Intensive fodder management and production of fodder crops

a. To augment the ashes from the bush cover, branches are cut from surrounding trees, carried to the plot of land to be cultivated, and burned to provide extra nutrients for the soil.

chines, mechanical pumps, and tractors. They have to use manure or chemical fertilizers to maintain soil fertility. Low-cost irrigation can become economic. The transition to these new technologies depends on many factors—the relative cost of labor, capital, and fertilizers; the cost and availability of credit; the reliability of markets for inputs and output; the access to spare parts and repair facilities; and the adequacy of information and training systems.

Population growth is only one influence on farming systems. Other powerful forces include access to urban or foreign markets, which depends on improvements in transport infrastructure and marketing facilities. When farmers are able to sell a surplus, they want to grow more by using more lands—so farming becomes more intensive as surely as it does when populations grow. However, the pattern is often fairly patchy, because good market access may be confined to small areas, and farmers may migrate to areas with high-quality soils and infrastructure.

Classifying Countries

The conventional way of measuring the abundance of land in a particular country is arable land per capita. This measure is unsatisfactory, since it does not take account of differences in soil quality and climate. The Food and Agriculture Organization (FAO) has come up with a new measure that does so. Its project on Land Resources for Populations of the Future (Higgins and others 1982) estimated, for most developing countries, the physical potential for food production at different levels of technology.

Each country was divided into a number of agroecological cells. For each cell, the FAO estimated the maximum number of calories of food production that could be sustained at three levels of technology—low input, intermediate input, and high input. It then added up these cell figures to give total potential calorie production for each country. Although this physical approach is no guide to future agricultural production, it does provide a standardized measure of a country's land endowments.

For all countries in Sub-Saharan Africa and for selected ones in Asia and Latin America, we look first at the population projections of the World Bank for the years 2000 and 2025. We divide the country populations by the FAO's estimates of potential calorie production—at intermediate input technology, as this is the level most African countries should reach between 2000 and 2025. The result is a standardized population density: the number of people per million kilocalories of production potential. We call this the *agroclimatic population density*. Even given the uncertainties and margins of error inherent in such an exercise, the picture that emerges is striking and useful.

When countries are ranked conventionally by population per square

kilometer of agricultural land, Bangladesh comes first, India comes seventh, Kenya falls somewhere in the middle, and Niger is near the bottom. When ranked by agroclimatic population density, the rankings change dramatically: Niger and Kenya are more densely populated than Bangladesh is today, and India ranks only twenty-ninth on the list. Kenya and Niger have large, semiarid areas of low calorie potential, where extensive livestock production is the only profitable form of farming. Bangladesh and India, in contrast, have invested in irrigation and have considerably increased their scope for multiple cropping. (The FAO's estimates for potential calorie production include the impact of irrigation investments already made or planned up to the year 2000.)

An alternative measure of the balance between land and labor endowments is the *agroclimatic labor density*, defined as the number of agricultural workers per million calories of production potential. Recent projections (Zachariah 1986) imply that the agricultural labor force in Sub-Saharan Africa will rise rapidly in future decades. Since the proportion of the labor force in agriculture is still very high and overall population growth is expected to be very rapid, pressure on land will grow even if the rest of the economy provides buoyant job opportunities. Figure 1 gives a picture of the likely outcome. The left panel shows that the proportion of the labor force in agriculture will decline in Sub-Saharan Africa, as in Asia and Latin America. Nonetheless, as the right panel shows, the agroclimatic labor density will shoot up in almost all African countries, at a much faster rate than in India or Brazil.

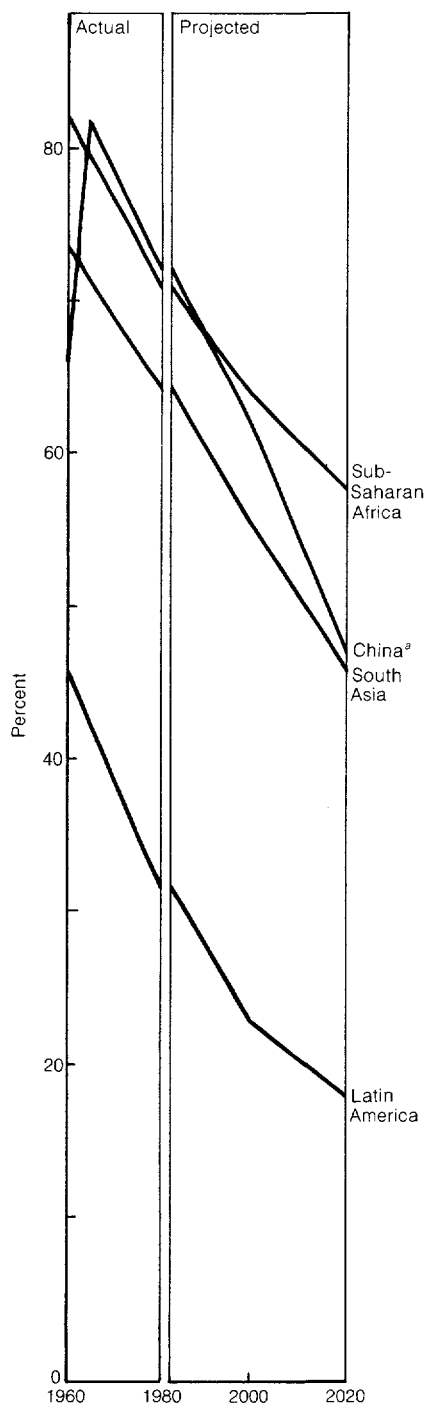
Population growth in Sub-Saharan Africa will average 3.2 percent a year in the 1980s, the fastest in recorded history. Even under favorable assumptions it will slow only marginally in the 1990s, to 3.1 percent. In the medium run the trend is not reversible, even if fertility falls sharply. Entrants to the labor market for the next fifteen years have already been born, and mortality is still falling steeply.

The rest of this article uses agroclimatic population density rather than agroclimatic labor density as a measure of land abundance. The former shows pressures on the demand side, as well as on the rural labor market, and is therefore a better indicator of the farming systems that will emerge in the years ahead. For African countries the two measures are, in any case, highly correlated.

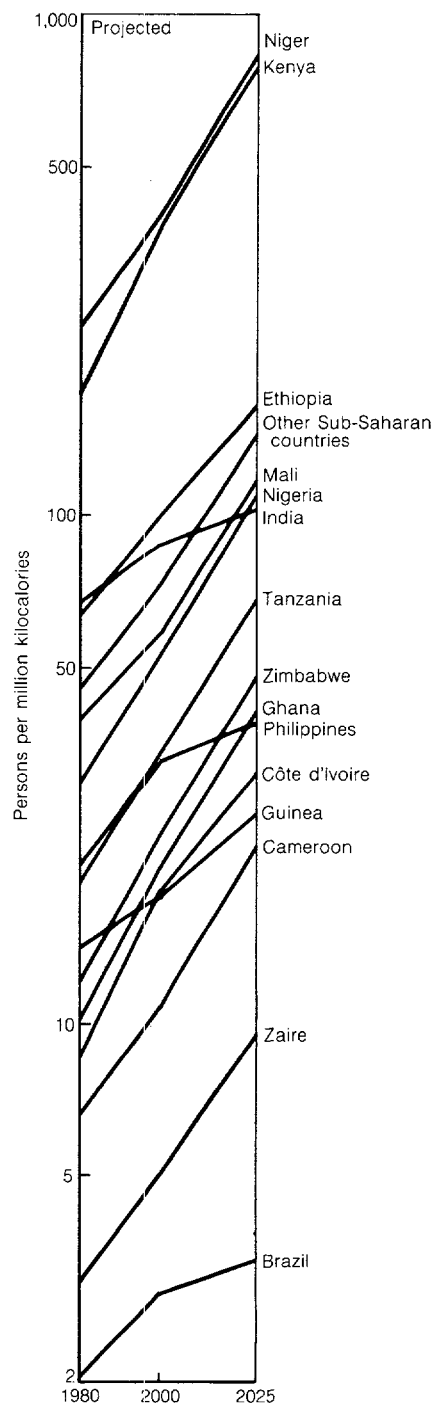
Table 2 divides countries in Sub-Saharan Africa (and a few others) into three groups which will have low, medium, and high density in 2025. Low density is defined as fewer than 100 people per million kilocalories of potential production (and is roughly a quarter less than the density of 127 reached by Thailand in 1980). High density is defined as more than 250 people per million kilocalories of potential production, slightly below the density reached by India or Egypt in

Figure 1

A. Share of Labor in Agriculture



B. Agroclimatic Agricultural Labor Density



a. China's labor force data are anomalous for the period 1957-63, when major economic reorganization was taking place.
Source: World Bank data.

Table 2. Population Density by Climate, Selected Countries, 1987–2025

<i>Climatic category</i>	<i>Low density^a</i>	<i>Medium density^b</i>	<i>High density^c</i>
<i>Humid lowlands</i>			
Country	Guinea Bissau (2028) <i>Malaysia</i> (2091) Liberia (2051) Equatorial Guinea (2088) Zaire (2080) Congo (2109)	São Tome and Principe (2041) Sierra Leone (2054)	<i>Bangladesh</i> Mauritius
Share of Sub-Saharan countries in total Sub-Saharan population	8.7 percent	0.9 percent	0.3 percent
<i>Mixed climates^d</i>			
Country	Côte d'Ivoire (2038) Chad (2041) <i>Bahamas</i> (2086) Madagascar (2041) <i>Argentina</i> (2123) Cameroon (2045) <i>Brazil</i> (2119) Zambia (2066) Angola (2071) Central African Republic (2114) Gabon (2147)	Gambia (2031) Zimbabwe (2032) Togo (2033) Ghana (2036) Tanzania (2033) Benin (2040) <i>Costa Rica</i> (2097) Guinea (2072) Sudan (2065) Mozambique (2062)	Kenya Rwanda <i>Barbados</i> Burundi Comoros Mauritania Ethiopia <i>India</i> <i>Nepal</i> Nigeria Uganda Malawi
Share of Sub-Saharan countries in total Sub-Saharan population	12.8 percent	22.1 percent	46.3 percent
<i>Arid or semiarid climates</i>			
Country	None	Mali (2027)	Niger Somalia Lesotho <i>Afghanistan</i> <i>Pakistan</i> <i>Egypt</i> Namibia (1988) Senegal (2006) <i>Mexico</i> (2019) Botswana (2023) Burkina Faso (2024) Swaziland (2024)
Share of Sub-Saharan countries in total Sub-Saharan population	0 percent	1.8 percent	7.1 percent

Note: In each climatic category, countries are ranked by projected population density in 2000. Data are unavailable for the Sub-Saharan countries of Cape Verde, Djibouti, and Seychelles. Countries not in Sub-Saharan Africa are in italics.

a. Having less than 100 people per million kilocalories of potential production by 2025. Figures in parentheses denote the year a country is expected to reach a density of 100.

b. Having 100 people per million kilocalories of potential production currently or by 2025. Figures in parentheses denote the year a country is expected to reach a density of 250.

c. Having 250 people per million kilocalories of potential production currently or by 2025. Figures in parentheses denote the year a country that has not yet reached a density of 250 is expected to do so.

d. Includes climates with mostly intermediate rainfall and countries with both high- and low-rainfall zones.

Source: Binswanger and Pingali 1987.

1980. Medium density is the range 100 to 250 people per million kilocalories of potential production. In each group, countries are then subdivided into three climatic categories.

- *Mainly humid lowlands.* These countries range from Zaire in the low-density group to Bangladesh in the high-density group.
- *Countries with mixed climates or intermediate rainfall.* The bulk of Sub-Saharan African countries belong to this category. The countries are equally divided between low, medium, and high density. The medium-density countries have substantial pockets of infra-marginally scarce land.
- *Arid and semiarid countries.* In our planning horizon, all but one of these countries will have high density or be on the way to doing so.

This methodology highlights the fact that semiarid zones are under much greater population pressure relative to their land endowments than are the humid areas. Migration from arid to wetter areas therefore makes sense, and is already happening on a substantial scale (sometimes across international borders).

The table shows that one-third of all Sub-Saharan countries—thirteen out of thirty-nine—will still have a low density in 2025, despite rapid population growth: Africa is a huge continent. Shifting cultivation will still be the most common system of farming in low-density African countries, particularly those with humid lowlands (the Republic of the Congo, Equatorial Guinea, Guinea Bissau, Liberia, and Zaire). However, in highlands with more moderate and healthy climates, population density will be greater. The highlands of Madagascar and Kivu province in Zaire are already densely populated, and annual cropping is the norm.

The medium-density group contains twelve countries. Of these, Sierra Leone is the only one dominated by humid lowlands, and Mali the only one in the semiarid tropics. In our planning horizon, shifting cultivation will gradually be phased out from this group, though it will still occur in regions with low population density.

Some twenty-one Sub-Saharan countries already have high density or will reach it by 2025. Eleven of them are in the semiarid zone. Nine have mixed climates and areas with good soil and intermediate rainfall. By 2025, the majority of Africans will live in high-density countries. Shifting cultivation will disappear completely. These are the countries where intensive agricultural techniques will have the greatest chance of success.

Agriculture Technologies

We will consider six kinds of agricultural techniques and see how useful they are in different regions and farming systems.

Input-Intensive Techniques

In sparsely populated areas of Sub-Saharan Africa, cultivation rights can usually be obtained free or for token payment. Land and labor are the only two inputs used in production. Such regions are dominated by subsistence farming, partly because market access is poor. In these areas, input-intensive techniques (such as the use of chemical fertilizers, pesticides, and high-yielding varieties) are not attractive to farmers. The cost of buying inputs is greater than any saving in labor costs that may result, and the farmer has no incentive to save on land costs.

Input-intensive techniques become cost-effective as population grows. Initially it becomes cost-effective to fertilize the soil with manure. Market access also tends to improve, especially if the transport system is developed; it becomes feasible for farmers to specialize in some crops and sell their surpluses. Land becomes relatively scarce, so land-saving technologies become more attractive.

New Crops and Higher-Quality Varieties

History shows that African farmers are willing to switch from subsistence crops to cash crops when marketing outlets are available. Even in thinly populated areas, farmers have often found it economic to shift to tree crops such as cocoa and oil palm. In many other areas they have diversified into cotton and groundnuts. They are also willing to move to new subsistence crops that expand their dietary choice or reduce the labor needed for subsistence production.

In areas dominated by shifting cultivation, the introduction of tree crops is attractive. When land is abundant it is cost-effective to plant more trees badly rather than improve the quality of trees already planted. As population density increases and infrastructure improves, land becomes more valuable, so it becomes economic for farmers to upgrade the quality of their plantations.

For existing crops, farmers are willing to adopt higher-quality varieties. For instance, they will switch from short-staple to long-staple cotton wherever the higher price of the latter compensates for the higher labor and other input costs. In the short run, such a shift is independent of land value. However, if the better crops turn out to be very profitable they will draw in immigrants, so land prices will rise. Cultivation techniques will then shift from extensive to intensive.

Stress-Resistant Varieties

The benefit of seeds that are resistant to drought, disease, and pests is independent of land and labor costs, so farmers are eager to adopt

them whether land is scarce or abundant. And they can benefit from such varieties even if it is not profitable to use fertilizers and pesticides. Resistant varieties do not require any extra labor. The only cost involved is for new seeds, and even that is often a one-shot cost when farmers can multiply the seeds locally. The importance of resistance to pests and disease is increasing in areas of high-yielding monoculture, as such areas are the most prone to attacks.

Research to improve stress resistance can have a high payoff. But the appropriate kind of stress-resistant varieties will depend on the agroclimate and ecology of each area. Drought tolerance may be important in semiarid areas but will be pointless for crops grown under irrigation. Pests and diseases vary from one area to the next, so research has to be carefully focused.

Labor-Saving Techniques

Generally speaking, tractors have been cost-effective where land is abundant and labor scarce (as in North America). Following that logic, many agricultural experts once thought tractors would be appropriate for Africa, too. But many tractorization projects failed, and Africa today is less mechanized than even the land-scarce, labor-abundant countries of South Asia.

The reason is that different farming systems require very different amounts of labor. There is no point in trying to introduce a labor-saving tractor in a system needing little labor. In shifting cultivation, tree cover is removed by cutting and burning; the tree stumps are simply left in the ground. The soil is soft and can be prepared with hoes or digging sticks. Since land is abundant, farmers can choose only the light, easy-to-work soils. Such realities help to explain why a labor-saving device like the plow is not used in labor-scarce forests, yet starts to be adopted in grass fallows where labor is more abundant. The number and intensity of operations are too low in forest fallow systems to justify plows. In addition, a plow can be used effectively only when farmers have removed some or all of the tree stumps on their plots. This arduous task is not worthwhile if plots are abandoned after a few seasons.

When infrastructure develops and farming becomes more intensive, mechanization starts to be cost-effective. Typically, the most power-intensive activities (like milling and water pumping) will be mechanized first. Then may come a shift from draft animals to tractors, provided various questions can be answered satisfactorily: (a) Will the savings in wages compensate for the high cost of a tractor? (b) Is credit available at an economic rate of interest? (c) What are the relative costs of fodder and diesel? (d) Is there reliable access to spare parts and servicing facilities?

In much of Sub-Saharan Africa, the answers to these questions lead farmers to prefer animals to tractors. Of seventeen projects attempting to leapfrog from hoes to tractors without the intermediate stage of draft animals, all but three failed (Pingali, Bigot, and Binswanger 1987). Most of the failures were in bush and semibush country, where the land is full of tree stumps and damages tractor-drawn implements. A jump from hoes to tractors has worked only in depression and valley bottoms that are periodically inundated with water, and in grassy savannas. Under these conditions there are no tree stumps. Soils in valley bottoms are often heavy, making them suitable for growing rice, provided plenty of power is available to prepare the land. If, in addition, labor is scarce and the infrastructure well developed, tractors can be a success. This has happened in Sudan and Zimbabwe and in pockets in other countries, but has usually been aided by heavy subsidies for mechanization. Whatever the conditions, tractors do little to boost yields. One study found that tractors failed to increase yields in ten out of fourteen cases of tractorization in Sub-Saharan Africa (Pingali, Bigot, and Binswanger 1987). Farmers who do mechanize do so mainly to save labor and extend their land, not to raise yields.

The use of other labor-saving devices such as herbicides will be economic only if the saving in labor outweighs their cost. Such innovations will succeed where wages are high and the cost of herbicides is low—neither of which applies in most of Africa.

Crop-Husbanding Techniques

Weeding is a simple technology that boosts yields and saves land. In forest and bush fallow systems, however, weeding is not needed in the first year of cultivation; once weeds start to proliferate, the plot is abandoned for a new one.

As farming systems develop into short fallows and permanent cultivation, weed problems increase sharply. Weeding becomes necessary, especially where organic fertilizers are used. It is most profitable where chemical fertilizers are involved, as it ensures that expensive nutrients are not wasted on fertilizing weeds. A similar pattern occurs with other types of husbandry, such as incorporating crop residues in the soil. As long as yields can be maintained simply by moving to another plot, farmers will not be interested in these techniques. But as land becomes scarce and valuable such techniques become important.

The cost-effectiveness of fodder management depends on the values of fodder, land, and labor. Where land is abundant, fodder has little value. Farmers will leave their harvested fields to be grazed by any animals, as it is not worth their while to harvest the residue for their own livestock. Where land values have risen and grazing land is

scarcer, farmers may allow in only their own animals and those of people who pay for grazing rights. As land and fodder values rise still more, farmers may find it cost-effective to store their residue and use it over the year for stall feeding. When fodder values rise even higher, farmers often find it cost-effective to grow fodder crops.

Land Improvements

Land improvements affect crop yields in three ways: (a) directly, as in the case of irrigation, drainage, and the application of lime; (b) as an essential component to fertilizers and high-yielding varieties; and (c) over the long term, by controlling erosion.

As with other yield-raising techniques, land improvements become economic only when land becomes relatively scarce. In forest and early bush fallows, farmers invest virtually nothing in land. When they use land more intensively, their first investments are to remove tree stumps and build well-defined boundaries. This generally happens in early grass fallows.

Where farmers can choose among different soils, they first cultivate the light, easy-to-work soils of the midslopes. As cultivation grows more intensive, farmers expand uphill to marginal lands, which they protect against erosion by ridging, tied ridging, and terracing. In the more densely populated parts of Sub-Saharan Africa such protective structures existed in precolonial times: examples include the Jos Plateau in Nigeria, the Mandara Mountains of Cameroon, the Kikuyu Highlands of Kenya, Mt. Kilimanjaro in Tanzania, Kigezi District in Uganda, Rwanda, and Burundi (Okigbo 1977, Morgan 1969, and Gleave and White 1969).

Antierosion investments are becoming increasingly common in intensively farmed areas of Africa. Machakos District of Kenya, for example, attracted many immigrants from the highlands between 1955 and 1965, and the farmers readily adopted bench terracing (Ahn 1977). However, where the easily cultivable soils of the midslopes are abundant, farmers are not interested in preventing erosion. And even when land is very scarce they fail to protect very marginal soils, where returns to antierosion investments are low, and widespread erosion damage occurs.

As population densities increase, farmers also move to the hard-to-work soils of the lower slopes and depressions. The heavy, water-logged soils of valley bottoms and depressions often cannot be farmed until they have been drained and flooding has been controlled or irrigation has been provided. Thus, while land is lost in the marginal areas, high-quality land is being formed in previously unused areas. These heavier soils are particularly suitable for irrigated rice, which has become a major crop in Asia but not yet in Africa.

In Asia, small-scale irrigation and water control techniques are common. In large parts of semiarid India, gently rolling uplands are used intensively for rainfed crops. The runoff is stored in tanks and used for wet rice cultivation in the valleys and depressions. Although some of the tank systems have been in operation for hundreds of years, most were built in the late nineteenth and early twentieth centuries. In addition, many wells have been sunk, and the water pumped up to irrigate a second crop on the middle and lower slopes (Englehardt 1984). The ultimate form of water control is to be found on the meticulously terraced hillsides of Java and the Philippines, where in each rice field the required depth of water is stored and the excess drained into the field immediately below (Ruthenberg 1980). Sub-Saharan Africa is a long way from this, but parts of it are ripe for tanks and wells.

Beyond a point, the small irrigation schemes developed by farmers have to be complemented by state-supported, large-scale systems for expanding acreage and allowing land to be farmed more intensively. Such systems are worthwhile only where population is dense, since irrigated farming is labor-intensive. The frequent failure of large irrigation systems in Sub-Saharan Africa can be attributed partly to the reluctance of farmers to engage in labor-intensive production when they have other alternatives.

The Office du Niger scheme in Mali is a case in point. Coercive methods had to be used to bring in settlers. The 50,000 hectares that were developed by 1964 fell far short of the initial target of several hundred thousand hectares. Even in this limited area, the land was not farmed intensively enough to yield an output that would meet the costs of both settlers and the management of the scheme, provide farmers with a decent livelihood, and earn a return on the heavy capital investment (de Wilde 1967). Now that population density is increasing, the prospects are better.

The previous section showed that Green Revolution techniques that have succeeded in the densely populated regions of Asia are unlikely to be adopted by farmers in large parts of Africa, where land is still abundant and market access poor. No matter how good research and extension is in such places, farmers will not be interested in fertilizers, irrigation, fertilizer-responsive seeds, elaborate crop husbanding, or land improvement and conservation. In such conditions, asking research and extension workers to propagate high yields is a recipe for demoralizing them.

Instead, farmers are more likely to be attracted by stress-avoiding technologies, new crops, and higher-quality varieties. These are the areas on which research should focus. Scientists should also try to

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develop varieties that will boost yields without requiring fertilizers or irrigation. Such varieties will not produce dramatic breakthroughs, but are more likely to be adopted by farmers.

Past research efforts for land-abundant areas have often failed because the researchers did not understand shifting cultivation systems. Rather than trying to focus on a few specific issues such as product quality, and stress resistance, they often aimed at making the leap to high-yield, high-input farming long before such a system was cost-competitive with shifting cultivation.

These failures are well demonstrated by what happened to Uganda's research and extension efforts from 1910 to the mid-1960s (Carr 1984). The program was intended to develop and promote high-yielding varieties in conjunction with fertilizers, new techniques of crop husbandry, and better land management. Yet not one of the crops achieved any significant increase in yield at the farm level. Farmers simply did not adopt most of the proposed innovations. Nonetheless, they readily adopted new crops and a sequence of new varieties that improved and later maintained the quality of the cotton.

In the next century, Uganda's growing population will ensure that land becomes scarce and valuable. Then it will make sense to focus on yield-raising, land-saving strategies. Much of the research effort between 1910 and 1960 was almost a century too early. Such mistakes must be avoided elsewhere.

Another (though less serious) example of misdirected research came more recently, from the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) in West Africa. Its work on varieties of sorghum and millet initially emphasized the adaptation of fertilizer-responsive cultivars from India and did not focus on stress resistance. However, the Indian varieties did not have the resistance qualities of local varieties. Moreover, they were unable to outperform the traditional varieties with the small amounts of fertilizer that farmers were willing to use in dryland agriculture. ICRISAT's research strategy has now been changed toward stress resistance.

It is also important to curtail work on labor-intensive husbandry techniques for land-abundant farming. Decades of effort to introduce manures and crop residues have met with very limited success. Moreover, researchers must take into account the fact that the demand for labor is highly seasonal. The worst kind of husbandry techniques are those that increase labor demand in peak seasons (Ouedraogo, Newman, and Norman 1982).

The Strategy Evolves

Long before population growth makes land scarce throughout a country, some areas do become densely populated. They may be close to transport and marketing facilities, or have pockets of exceptional

soil or climatic advantages. For them, high-yielding research strategies are more appropriate. It is not surprising, therefore, that the big success stories of agricultural research come primarily from densely populated East African countries such as Kenya, or from tree crop areas where land is inframarginally scarce.

By concentrating research on such environments, several advantages are gained. The relevance of research is maximized. Limited research staff and resources are focused on a limited range of issues, and hence are more effective. Researchers have to solve some basic problems in adapting genetic material to local conditions, which will benefit more regions as land grows scarcer.

Just as Asia's Green Revolution has been most successful in irrigated areas or where rainfall is reliable, so irrigation will be necessary in much of Africa too if that continent is to have its own Green Revolution. However, irrigation projects in Sub-Saharan Africa are notoriously expensive (see below).

By contrast, areas with reliable rain and good soil are well placed to absorb high-yielding technologies without irrigation: many parts of Rwanda, Burundi, Kenya, and Nigeria fit this description. If agricultural prices are remunerative and not depressed by discriminatory government policies, farmers will be interested in buying inputs and developing their crop husbandry. Many will spontaneously improve their land and dig wells. The process can be accelerated by providing extension services and credit.

Another case for regional targeting involves the humid lowlands, which often have chemically and structurally fragile soils. If such soils are cultivated intensively, the results can be rapid leaching, soil acidification, and erosion. Large amounts of fertilizer and lime are needed to maintain soil structure and fertility, while large amounts of labor or machinery are needed for weeding and other husbandry (Ruthenberg 1980, Lal 1983, Kang and Juo 1981). Since all these activities are expensive, it is hard for those farming these poor soils to produce goods at competitive prices. Subsistence cultivation is therefore the rule, except where infrastructure makes tree crops economic.

The big challenge for researchers is to devise systems that can produce crops at a price competitive with other agroclimatic zones. The paucity of past successes suggests that this may not be possible for some of the soils in Africa, so it is essential to concentrate research on the more promising environments. Other areas can still be helped, but not necessarily by research. In several low- and medium-density countries, for example, the provision of infrastructure can help expand acreage and facilitate a switch to tree crops.

In high-density countries labor-saving innovations are much less relevant than yield-raising ones. Mechanization will generally be cost-effective for such power-intensive operations as milling and pumping.

For control-intensive operations (such as harvesting), however, mechanization will be economic only when wages rise substantially (Binswanger 1986). Until then, it will often be appropriate for farmers to use tractors for tillage, animals for weeding, and labor for harvesting. Man, animal, and machine will be complements, not substitutes.

The policy message from this analysis is clear. Governments should try to create a distortion-free environment that allows farmers to choose the most cost-effective combinations. Governments should refrain from subsidizing or otherwise pushing any particular form of mechanization.

Implications for Projects and Infrastructure

The same logic that governs the relevance of research also applies to infrastructure projects. Where land is abundant and cultivation shifting, it is a mistake to invest heavily in projects attempting to raise the productivity of land. Even if irrigation is provided cheaply, farmers will make little use of it, as irrigation involves a lot of labor. For low-density areas with good land, roads are by far the most relevant form of infrastructure. They provide access to markets and allow people to migrate to places where farming is most remunerative.

However, infrastructure does not always lead to a greater concentration of population. Farmers may prefer to move from densely populated to thinly populated areas, to overcome local shortages of land. It is a mistake to try to force people to congregate in certain areas and take up intensive farming (as was attempted in the Ujaama experiment in Tanzania). Where land is abundant, it can be more cost-effective to undertake extensive cultivation.

Given the high cost of irrigation and land improvement in Sub-Saharan Africa, such projects should be undertaken only where land is scarce, population densities are relatively high, and good infrastructure and marketing facilities exist. The obsession with high yields that many specialists from industrial countries and Asia bring to Africa can be as counterproductive in projects as in research.

Large-scale irrigation projects in Africa typically cost several times more than their equivalents in Asia. One reason is that Sub-Saharan Africa lacks the ample, skilled labor and low-cost technical and managerial staff of Asia, which means that cheap, labor-intensive construction is not feasible. Expensive labor-saving equipment has to be brought all the way from Europe, North America, or East Asia. The projects are usually staffed by expensive expatriate managers and technicians. Until project costs are reduced dramatically, irrigation in Sub-Saharan Africa will be cost-effective only for private wells, lift irrigation, and minor impoundment and diversion schemes.

One factor that could be favorable to irrigation (though not to human welfare) is that labor costs are unlikely to rise much and may

even decline in many parts of Africa in the coming decades. A rapidly growing population means that farmers become willing to engage in labor-intensive irrigated agriculture. If education and training also expand to create skills in construction, engineering, and management, African countries can adopt cheap Asian construction techniques. Meanwhile, other engineering solutions must be explored to bring costs down. The technical potential for irrigation in Sub-Saharan Africa is large. Even the Sahel has large river systems, such as the Senegal and Niger, which can be used to irrigate substantial areas.

In flood plains and valleys in humid areas where the soil is good, drainage can be cost-effective. Such areas are often suitable for growing rice, which has already begun in Guinea, Sierra Leone, Senegal, the Niger valley, and the basin of Lake Victoria. In Sukumaland, Tanzania, the flood plain was used only for grazing forty years ago (Rounce 1949); today it is sown completely with rice. Investment in drainage increases the amount of land available for cultivation, and so becomes cost-effective when land values rise. It also reduces health hazards and attracts labor—essential, in large numbers, for rice farming.

Investments in infrastructure are vital. But they must be selective, to make the best use of limited funds and staff. It is tempting for African governments to try to spread infrastructure uniformly over every district. However, building roads in areas with poor soil does little to help agriculture: farmers in such areas cannot grow cash crops or tree crops at competitive prices and will tend to continue with subsistence cultivation. By contrast, the areas with the best land and climate offer the quickest returns on infrastructure. They are the places where farming will be most profitable, immigration will take place most rapidly, advanced agricultural technologies will most readily be adopted, and where the linkages between farming, services, and industry will develop best. In such areas, agricultural research and infrastructural investment will reinforce each other, and the results will be striking.

The article examines the suitability of different agricultural research strategies in African countries with varying endowments of land, labor, and climate. Differences in such endowments lead to a wide spectrum of farming systems. Agricultural technologies that are cost-effective in some farming systems are not in others. Many past failures are due to a mismatch between technological strategies and farming systems. The article classifies countries of Sub-Saharan Africa on the basis of agroclimatic density and suggests appropriate technological strategies for each class of countries.

Abstract

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