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Resource Endowments, Farming Systems and Technology Priorities for Sub-Saharan Africa

by

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RESOURCE ENDOWMENTS, FARMING SYSTEMS AND TECHNOLOGY PRIORITIES FOR SUB-SAHARAN AFRICA

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Introduction

Sub-Saharan Africa contains an immense variety of agro-climates, farming systems, and endowments of land and labor resources. Technology development strategies for the first quarter of the next century, the technology development target period, must take these divergencies into account. While other papers for this project will deal primarily with agro-climatic issues and crop choice, this paper deals primarily with the emphasis different technology groups should receive in research and development programs. The technology groups considered are (1) yield increasing technologies such as high yielding varietes, fertilizers, crop husbandry technologies, etc.; (2) labor-saving technologies such as machines, implements and herbicides; (3) quality-enhancing techniques such as long staple cotton or cocoa curing techniques; (4) fodder management and production techniques; and (5) land investments such as drainage, irrigation and erosion control.

If a new technology or input does not reduce the unit cost of production (including the cost of family labor and the opportunity cost of owned land) the farmer will not adopt it. Using this simple idea this paper shows that at low population densities -- in systems typically characterized by shifting cultivation -- farmers will rarely be interested in

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yield-increasing technologies, unless they can be achieved with truly negligible cost in terms of purchased inputs or labor. No matter how well organized, research and extension efforts are in developing and promoting yield increasing technologies are therefore futile until the scarcity value of land rises to appreciable levels. The same applies to land improvements. On the other hand, new crops and quality-enhancing innovations are much more readily adopted and may provide better opportunities for research. Additional generalization on the allocation of technology development and diffusion resources are derived. Moreover, looking at farmer demand for different types of innovations as done in this paper provides additional insights into the pattern of success and failure of agricultural research in Sub-Saharan Africa.

The second section of the paper discusses population and agricultural labor force trends. Demographic forces imply that virtually all countries of Sub-Saharan Africa will experience rapid growth of agricultural labor forces during the next 40 years. Farming systems will be under immense pressure for changes. A classification of countries in terms of population/labor pressure and predominant agroclimate is provided which shows that, despite rapid growth of population, enormous differences in population and agricultural labor force densities will persist well into the 21st century. Eleven Sub-Saharan countries are already among the most densely populated of the world, if account is taken of their often limited agroclimatic potential, while another 13 countries will remain very land abundant during the second half of the 21st century. The countries are further sub-divided by major agroclimatic zones, and strategic research targeting issues discussed for each group.

The paper closes with a few remarks about the division of labor between the private and public sector in the generation and diffusion of the different technology sub-groups.

I. Determinants of Profitability of Technologies by Farming Systems

Sub-Saharan Africa has a wide range of farming systems, from forest fallow systems where a plot of land is cultivated for one or two years and allowed to revert to fallow for 15-20 years, to annual cultivation systems, where plots of land are cultivated continuously without any fallow intervals. In between these two systems are extensive areas of bush fallow and grass fallow systems which are characterized by progressively shorter fallow periods. The evolutionary movement from shifting cultivation to permanent cultivation of plots of land is driven by population growth and by higher returns to farming which arise when market infrastructure improves and farmgate prices rise (Boserup, 1965; Ruthenberg, 1980; and Binswanger and Pingali, 1984).

In this section we discuss the relevance and profitability of introducing (different types of technologies) into the vastly different farming systems of Sub-Saharan Africa. Agricultural technologies can be classified as yield raising, labor-saving, quality-enhancing and land improving, as in Table 1. Yield increasing innovations reduce the area required to produce one unit of output. Yield increasing technologies fall into four categories: (i) input-using innovations such as fertilizers and pesticies; (ii) stress avoiding innovations based on genetic resistance or tolerance to pests, diseases or water stress; (iii) crop-husbandry techniques such as more intensive weeding, etc; and (iv) fodder management and production techniques.

Table 1: EXPECTED INPUT SAVINGS PER UNIT OF OUTPUT FOR VARIOUS INNOVATIONS

Innovations	Land Area (1)	Inputs Used in Proportion to Area Which is Saved 1/ (2)	Inputs Used on the Remaining Area: Labor (3)	Inputs Used on the Remaining Area: Machines (4)	Inputs Used on the Remaining Area: Purchased Inputs (5)
Yield Increasing					
1. Input Using (fertilizers, pest control chemicals, fertilizer responsive varieties)	–	–	(+)	(+)	+
2. Stress Avoiding (varieties with resistance to pests, diseases or drought)	–	–	0	0	0 or +
3. Crop Husbandry Techniques	–	–	+	+	0
4. Fodder Management Techniques	–	–	+	+	0 or +
Labor Saving					
5. Machines and Implements	(–)	(–)	–	+	0
6. Herbicides	(–)	(–)	–	0	+
7. Quality Improving	0	0	(+)	0	(+)
8. Land Improvements	–	–	+	+	+

1/ This includes primarily the labor and machine inputs for land preparation planting and crop husbandry. It may, however, also include pesticides and herbicides applied to the saved area when such input levels remain unchanged (on a per ha basis) after the adoption of another innovation, such as a moisture stress resistent variety.

Note: + = substantial increase.
– = substantial decrease.
(+) = small increase possible.
(–) = small decrease possible.

The primary benefit of labor-saving innovations is reduced labor or animal draft requirements. Labor-saving innovations do not usually lead to substantial yield increases. Experimental evidence is clear, for example, that improved tillage quality can raise yeilds on many soil types. Nevertheless, a vast number of survey studies suggest that farmers do not experience substantial yield gains when they switch from handhoes to the plow or from animal draft to tractors (Pingali et al., 1986). Instead, labor-saving and area expansion are the primary motivation for such technology switches. Similarly, yields or output levels are not sharply altered when farmers shift from hand threshing to mechnical threshing or hand weeding to herbicides.

Innovations aimed at raising quality of output affect the price of output rather than the yield. They may, however, raise the labor requirements and/or the cost of purchased input as when higher quality requires improved pest and disease control. Land improvements such as irrigation and drainage tend to raise yields. In addition, they are complementary to other yield-raising technologies such as fertilizers. Land improvements require high levels of labor and/or machinery inputs.

A necessary condition for a farmer to find a new technology to be profitable is for him to experience a unit cost reduction. If costs are not reduced he will not adopt the technology or the new input. On the other hand, if the unit cost reduction is large, the enhanced profitability will induce the farmer to expand the output level of the crop. The total benefit from the technology includes both the cost reduction on the existing level of output as well as the extra profit on the expanded output. How much output expansions there will be depends on conditions in the market for outputs and for inputs, but this issue is beyond the scope of this paper. Because the profitability of adoption depends directly on the size of unit cost reduction, what determines unit reduction is all that needs to be understood for targeting research to the broad technology groups just discussed.

For commercial farmers the unit cost reduction can be evaluated using the market costs of inputs. For subsistence farmers evaluation is more difficult. A subsistence farmer will find a technology to be cost-reducing if it enables him to produce more output with less family labor, leaving more time for alternative pursuits or leisure. Moreover, where land is limited, land no longer required to produce a fixed subsistence requirement may be used for an alternative crop, perhaps a cash crop. To measure the benefit to the subsistence producer the land and/or labor-saving is multiplied by the opportunity cost of land or labor. No conceptual problem arises but measuring these opportunity costs may not always be easy.

Let us start our technology evaluation in the very sparsely populated environments of Sub-Saharan Africa which also have poor market access. Cultivation rights are easily available in these environments and can usually be obtained for free or for token payments. For simplicity's sake, assume that the opportunity cost of land is zero. Shifting cultivation systems are the norm in this environment with land and labor being the only inputs used in production. Labor requirements are low since only minimal levels of land preparation weeding and interculture are done and since fallow periods substitute for labor intensive organic fertilizer production. Table 2 provides a breakdown of labor use by farming systems. No machines and other purchased inputs such as chemical fertilizers and pesticides are used.

A. Yield-Increasing Innovations: The four yield-increasing types of innovations reduce the cultivated area required to produce any given level of output. However, they provide no saving in land costs in this environment since the opportunity cost of land is zero or negligible. The only relevant input saving is the labor for land preparation, planting and weeding which was required on that area whch can now be saved because less land is required to produce a unit of output (or the subsistence level of output). The question we face is whether the value of this labor saving is greater than the cost of labor and other inputs required for incorporating the yield-increasing innovations into the shifting cultivation system.

Consider first the profitability of using chemical fertilizers. The traditional system of soil fertility restoration is to abandon plots of land after a few years and to allow them to revert to fallow. Given scarcity of labor and the abundance of land this is the most cost-effective means of regenerating the soil. Under sparse population densities, a switch from this system to the use of chemical fertilizers would result in minimal labor savings and substantial levels of cash expenses. As population densities increase, fallow periods are reduced and farmers start to apply organic fertilizers to maintain soil fertility. By the annual

Table 2: Comparison of Farming Operations in Different Farming Systems

Operation or Situation	Farming System				
	Forest Fallow	Bush Fallow	Short Fallow	Annual Cultivation	Multiple Cropping
Land clearing	Fire	Fire	None	None	None
Land preparation and planting	No land preparation; use of digging stick to plant roots & sow seeds	Use of hoe & 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 chitimene techniques; a household refuse for garden plots	Animal dung or manure; 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
Use of animals	None	Animal-drawn plow begins to appear as length of fallow decreases	Plowing, transport, interculture	Plowing, transport, interculture, post-harvest tasks, & irrigation	Plowing, transport interculture, post-harvest tasks & 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, & post harvest 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.

cultivation stage, soil fertility can be maintained by using labor intensive organic fertilizer techniques. Incorporating chemical fertilizers at this stage into the farming system results in the release of labor from organic fertilizer production. Whether or not farmers switch to chemical fertilizers in annual cultivation systems depends on the wage rate, cost of chemical fertilizers and output price.

Fertilizer responsive seed varieties (high yielding seeds) would therefore not be profitable in areas where the substitution of natural fallows and organic fertilizers by chemical fertilizers is not cost-effective. Where such a substitution is cost-effective, the proficability of introducing high yielding seed varieties is directly proportional to the savings in land costs and the savings in labor on the "saved" land. Consider at the opposite extreme, a land scarce environment in which a farmer can expand area under a crop only by buying or renting extra land, by reducing area under some other crop or by developing marginal land. Rwanda, Burundi, Kenyan Highlands and most areas in Asia are in such a situation. In such environments the value of land saved is very high and overshadows the savings associated with the inputs on saved areas, especially where technology is simple. It is here that yield increasing innovations are most in demand.

For the crop husbandry techniques to be cost-reducing in land abundant areas, the labor saved in preparing and weeding the saved area must be more valuable than the extra labor or machine costs to undertake the crop husbandry operation. But as Table 2 shows, these land preparation and weeding labor inputs are very small under shifting cultivation. The labor costs for land preparation and weeding rise with the intensity of farming. Therefore, the adoption of crop husbandry techniques is much more likely at high farming intensities.

While none of the yield increasing innovations are particularly attractive in land abundant environments, we can see immediately from Table 1 that, among the yield increasing innovations, it is the stress-avoiding ones which are most preferred. This is because they tend to have the lowest incremental cost, which is only the more expensive new seed. The other two types either increase labor costs or have a more significant effect on the cost of purchased inputs.

Crop-residue management techniques and new fodder crops either increase the yield, the effective utilization or the quality of fodder produced from one unit area. Crop-residue management can take the following forms (arranged in terms of labor input requirements), open access to harvested fields for any animals, restricted access to selected animals of the cultivator of the land or his contractual partners, transport to and storage of crop residues at the homestead for use in stall feeding. The transition to more labor intensive fodder management techniques becomes cost-effective where the value of the land saving made possible by more intensive residue management exceeds the cost of the extra labor input. Under high land costs cultivators also start producing fodder crops.

Based on the above discussion we derive the following generalizations on yield increasing technologies:

(1) <u>Under low population density and at low technology levels the benefits</u>

of yield increasing technology is confined exclusively to the reduction in labor use associated with the area savings made possible by the yield increase.

(2) The economic value of yield-increasing crop and fodder production innovations is a direct function of the scarcity value of land as measured by land rental rates or residual farm profits per hectare.

(3) The higher the pre-existing level of purchased input and machinery use (whose per ha input use is not directly affected by the innovation), the more valuable is the yield increasing technology.

B. Labor-Saving Technologies: Machinery and herbicides are the two labor-saving innovations analyzed in this sub-section. Recall our starting point, a land-abundant, labor-scarce area practicing shifting cultivation. Would it be profitable to introduce tractors or animal drawn plows into this environment? Some background information on land preparation practices in shifting cultivation systems needs to be provided before this question can be answered.

In shifting cultivation systems, the tree cover is removed by cutting and by burning the surface vegetation. The tree stumps are, however, left in the ground and ensure speedy regeneration of vegetation when the plot is returned to fallow. Land in between the stumps is prepared using a hoe and is planted with crops. This method of land preparation requires very low amounts of labor. In order to use a plow, not only would land have to be cleared, but stumps and roots would have to be removed, a far more arduous task than clearing of the vegetation above the surface. To justify such a large investment farmers have to use the land permanently and therefore have to spend substantially larger amounts of labor on weeding and soil fertility maintenance. Therefore, introducing the plow and converting shifting cultivation systems to permanent cultivation is not cost-saving but increases labor or cash input per unit of output.

As the fallow periods become shorter, stumps and root density declines and so does the cost of destumping. Labor required for land preparation with a hoe increases because of the increased presence of grass roots in the soil. Moreover, with the decline in fallow periods farmers have to start using organic fertilizers. By the grass fallow stage labor requirements have risen so sharply that switching to the plow for land preparation becomes truly labor-saving. Whether animal or tractor drawn plows are cost-effect depends on the relative cost of using these two technologies, the difficulties of learning how to use them, and the infrastructure cost associated with them (Pingali et al., 1986).

The story with herbicides is very straight forward: they will be adopted where the value of labor savings is greater than the cost of herbicides. For instance, given the low wage rates in semi-arid India, the use of herbicides is uneconomical compared to hand weeding (Binswanger and Shetty, 1977).

4. <u>The benefits of, demand for, and probability of acceptance of labor-savings technologies is a rising function of the wage rate or the opportunity cost of labor but is not strongly dependent on land values.</u>

C. <u>Quality-Enhancing Innovations</u>: For innovations that enhance the quality of output the benefit is the extra value of the crop. This benefit is of course independent of land or labor prices. Whether it pays to adopt it is simply a question of whether the quality premium paid by the market exceeds the cost of producing the enhanced quality. On the cost side, wage rates enter for those quality enchancing innovations which require more labor. We therefore generalize:

5. <u>The benefits of quality-enhancing innovations are independent of the value of land. Those quality-enhancing innovations which require labor are more easily adopted where labor is cheap.</u>

D. <u>Land Improvements</u>: Land improvements affect crop yields in the following three ways: (i) they have direct yield effects as in the case of irrigation, drainage, the application of lime, etc.; (ii) they have a secondary yield effect due to their complementarity to fertilizers, high yielding varieties, etc., which may have a yield advantage over traditional varieties only if the land base is improved; and (iii) investments in erosion control have long-term yield effects by preventing soil degradation. At what stages in the evolution of farming systems are farmers motivated to invest in land improvements?

In the early stages of agricultural intensification, forest and early bush fallow almost no investments are made in land. Tree cover is cleared by felling and fire and the stumps are left in the ground to allow quick regeneration of vegetation when the plots are returned to fallow.

As a plot of land is used more permanently, the first major investment that takes place is to remove all the tree stumps from the fields and to have well-defined plot boundaries. This generally happens around the late bush fallow and early grass fallow stage.

Where farmers can choose among different soil types, they first choose to cultivate the easy-to-work soils of the mid-slopes rather than the deep, clayey soils of the lower slopes and depressions or the marginal lands on hillsides. As the intensity of cultivation rises, farmers expand to more marginal lands susceptible to soil erosion, and developed protective devices against erosion such as ridging and tied-ridging on stone wall terraces. In the more densely populated parts of Sub-Saharan Africa these protective land investments were already in use prior to the colonial period (Allan, 1965, p. 386). The hilltop refuges provided several historic examples of terrace cultivation such as the Jos Plateau in Nigeria, the Mandara Mountains of Cameroon, the Kikuyu Highlands of Kenya, Mt. Kilimanjaro, Tanzania, Kigezi District, Uganda, and Rwanda-Brundi (Okigbo, 1979; Morgan, 1969; and Gleave and White, 1969).

Anti-erosion investments in land are becoming increasingly common in the more recently intensified areas of Africa. Machakos District of Kenya, for example, was a site of increased migration from the highlands between 1955 and 1965, the farmers in the district readily accepted the practice of bench terracing the mid-slopes (Ahn, 1979). However, experience is also clear that as long as the easily cultivable soils of the mid-slopes are abundant farmers are not interested in making anti-erosion investments. Even with coercion, it is very difficult to get the farmers to do it right when land is not scarce.

As population densities increase one also observes a movement from the mid-slopes to the hard-to-work soils of the lower slopes and depressions. The heavy, waterlogged soils of valley bottoms and depressions can often not be brought under cultivation without drainage or flood control investments, such investments are labor intensive and are generally avoided until population pressure makes the cultivation of this land a necessity. These soils are particularly well suited for irrigated rice cultivation, which has become a major source of food supply in Asia, but is not yet widespread in Sub-Saharan Africa. The cultivation of rice in flood plains or depressions has, however, been increasing in Guinea, Sierra Leone, the Senegal and Niger valleys and the basin of Lake Victoria and one would expect this trend to continue throughout Africa. In Sukumaland, Tanzania, for instance, the flood plain land was left for grazing 40 years ago but is now completely cultivated with rice and the demand for this land is extremely high (Rounce, 1949).

In Asia, small scale irrigation and water control techniques that reduce water stress or allow dry season cultivation are very common. In semi-arid India, the gently rolling uplands are intensively used for rain-fed crops, rainfall run-off is being stored in tanks and used for irrigated wet rice cultivation in the depressions. While some of these tank systems have been in operation for hundreds of years, the majority of the investment in these systems was made in the late 19th and early 20th century. Since the 1950s, tank irrigation has been surpassed by investment in wells for cultivating a second crop on the mid- and lower slopes. Water is drawn from the wells with the help of pumps (Englehardt, 1984). The ultimate in water control structures is seen in 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).

As the land frontier becomes exhausted, farmer-initiated irrigation systems have to be complemented by state-supported, large scale irrigation systems for expanding cultivation into dry areas and increasing the intensity of cultivation on currently cultivated land. The building of such large scale systems is induced by high population density and requires adequate labor supply for construction as well as for the much more labor intensive irrigated crop production. The frequent failure of large scale irrigation systems in Sub-Saharan Africa can be partly attributed to the reluctance of cultivators to engage in labor-intensive production as long as they have other alternatives. The office du Niger scheme in Mali is a case in point. The 50,000 hectares that were actually developed by 1964 fall far short of the initial target of several hundred thousand hectares; and even in this area the density of settlement is insufficient to yield an output that would meet all costs of both the settlers and the management of the scheme, provide the settlers with good livelihood and earn some return on the large amount of capital invested (de Wilde, 1967, p. 288).

II. Implications for Research and Technology Strategy in Africa

It is clear from the above discussion that under land abundance, biological researchers have less opportunity to show dramatic breakthroughs such as the yield gains of the green revolution than under land scarcity. Whatever the technical merits of innovations which research makes available, farmers will not be very interested in fertilizers, their precise placement, fertilizer responsive varieties or elaborate crop husbandry techniques such as intensive manuring, or in land conservation techniques. They will welcome stress resistance varieties, labor-saving innovations and quality- enhancing innovations. They also generally welcome new crops which enable them to produce more food or a higher gross return for a lower labor input. Under circumstances of land abundance, it will not be easy to generate effective farmer support for large scale experiment station funding.

However, long before the land frontier closes, infra-marginal land scarcities arise. Some regions may be more densely populated, perhaps because they are close to transport infrastructure or to urban centers because of climate and soil types, or for historic reasons. Land in such locations will acquire substantial value, despite the fact that elsewhere it still is not a constraining factor. Benefits of biological research will be most easily measurable where infra-marginal land scarcity exists. It is also here that farmer support can be more easily generated.

It is therefore not surprising that the limited success stories of agricultural research come primarily from densely populated East African countries, such as maize in Kenya, or from tree crops areas where land is infra-marginally scarce. In other places, such as cotton areas, quality improvements and disease and pest resistance were an important output of the research systems. For example, Carr's (Carr, 1984) excellent description of research efforts in Uganda from 1910 to the mid-1960s shows that in none of the crops were yield gains achieved at the farm level, despite 50 years of strong emphasis of research and extension on yield raising varieties, agronomic techniques and fertilizer inputs. The farmers simply did not adopt many of the proposed innovations. However, farmers readily adopted new crops which provided more food or income per unit of labor, and disease resistant varieties of cotton. The research system is also credited with developing and maintaining high levels of cotton quality.

From the discussion in this section we can suggest the following strategies for targeting agricultural research effort. Concentrating research effort on yield increasing technologies makes little sense in the more land abundant environments. Apart from working on quality and on resistant or tolerant varieties, asking the systems to rapidly come up with yield gains is a recipe for demoralization of the research staff. Their yield raising should concentrate on areas where land is infra-marginally scarce. By allowing them to concentrate on such environments several advantages are gained: The limited research staff and resources can concentrate on a limited number of problems. Their work on yield gains will force them to solve basic problems of adaptation of external genetic material to selected national conditions, work from which other regions will benefit in due course. Research capacity building is a primary output of these early systems, and such capacity building includes this fairly basic work, as well as the training of people. Finally, by generating yield raising strategies for some environments, the system will be prepared to respond to the need to raise yields when land scarcity becomes a more generalized national problem.

But targeting should also take place in terms of the nature of the technical changes sought. The most important targeting in areas where land is relatively abundant is targeting of research towards resistance or tolerance to pests, diseases and water stress, and towards quality enhancement where the market pays a premium for quality, or where taste of the staple foods is a major factor in the farmer's adoption decision. Varietal research of ICRISAT on sorghum and millet in West Africa initially did not concentrate on these topics, but emphasized the adaptation of fertilizer responsive cultivars from India. This research strategy has now been abandoned because the Indian materials simply did not have the resistance characteristics of the local cultivars, and therefore were unable to outyield them at the low levels of fertilizer that farmers are willing to use.

It is also important to sharply curtail work on labor intensive husbandry techniques. Decades of work on incorporating manures or crop residues into land abundant farming systems have met with very limited success. Moreover, seasonality of labor use in the existing farming system must be considered as well. The worst kind of research is research on husbandry techniques which increases peak season labor demand, a point long ago emphasized by Norman and others (Ouedraogo, Newman and Norman, 1982).

Implications for Development Projects: The same points made about research apply to other yield raising strategies. Land abundance implies very low demand for labor intensive irrigation and many irrigation projects which emphasize yield per acre make little sense if introduced into regions where many farmers practice shifting cultivation, or where tree crops production could grow rapidly if the necessary marketing infrastructure was available and prices were high. Attempting rehabilitation of older plantations to raise yield is equally uneconomic where new low intensity planting can easily produce the limited output which can be marketed internationally. The obsession with yield which most agricultural specialists from the developed world or from Asia bring to Africa is as counter-productive in projects as it is in research.

III. Technology Strategies for Different Population Densities and Agroclimatic Zones

The broad conclusion of the first part of this paper was that the profitability of technical change is closely related to the land and labor endowments of an economy. Efficient resource allocation for research and for technology transfer therefore depends on our ability to categorize agricultural environments in terms of their current land and labor endowments and anticipated changes in these endowments over time. In this paper we can only do this for countries as a whole.

Agricultural land endowments are usually measured by arable land per capita. This measure of land availability is not adequate for comparing countries since it does not take into consideration agroclimatic and soil-related differences in land potential. However, FAO provided a measure of land endowments which takes these factors into account in its recently completed project on land resources for populations of the future (Higgins et al., 1982). This project computed the physical potential for food production of land resources for most of the developing countries.

Each country was delineated into a number of agro-ecological cells. For each of these cells, the FAO study evaluates the maximum calorie production which could be produced using either low, intermediate or high input levels. Country totals of potential calorie production by technology level were obtained by aggregating across the cells. While this physical approach is not useful for predicting economic supplies, it can be used to provide a standardized measure-of a country's land endowments.

For each of the countries in Sub-Saharan Africa and for selected countries in Asia and Latin America, we divided total population by FAO's estimates of potential calorie production. We used the intermediate technology level estimates, this is the level most countries either have reached or should be able to reach in the coming decades. The result is a standardized population density in terms of persons per million calories of potential production. We will call this standardization the agroclimatic population density. Of course, even with today's soil maps and climatic data, estimating potential calorie production is a difficult task, and is subject to a wide margin of error, especially if the country data is to be used. Nevertheless, the resulting differences are so striking that it is well worth examining them. More detailed discussion of the measure of potential calorie production is provided in the appendix.

The following examples highlight the differences in the two measures of land resources. When countries are ranked in terms of population per square kilometer of agricultural land, Bangladesh comes first, India ranks seventh, Kenya falls somewhere in the middle and Niger is among the least densely populated countries. In terms of population per million of potential calories, both Niger and Kenya are more densely populated than Bangladesh is today, and India ranks 29th among the most densely populated countries. These differences come about because both Kenya and Niger have large areas of low potential arid zones where extensive livestock production is the only profitable food production activity, while both Bangladesh and India have the potential to increase their areas under intensive rice production through increased area under multiple cropping. In addition, India and Bangladesh have already invested heavily in irrigation which is accounted for in the calculation of potential calorie production.

An alternative measure of the balance between land and labor resources is the agroclimatic labor density, defined here as the number of agricultural workers per million calories of potential production. However, forward projection of total and agricultural labor forces is more problematic than forward projections of population, especially if it goes beyond the next 15 years, the period for which new labor markets entrants are already born.1/ Nevertheless, recent projections imply that for Sub-Saharan Africa, agricultural labor forces will rise at exceptionally rapid rates over the coming decades (Figure 1). A high initial labor share in agriculture and rapid growth in population have the consequence that only extremely rapid growth in the non-agricultural labor force can reduce the absolute number of workers in agriculture. A numerical example clarifies this "development arithmetic." If 70% of the labor force is still in agriculture, and the total labor force is growing at 2% p.a., the

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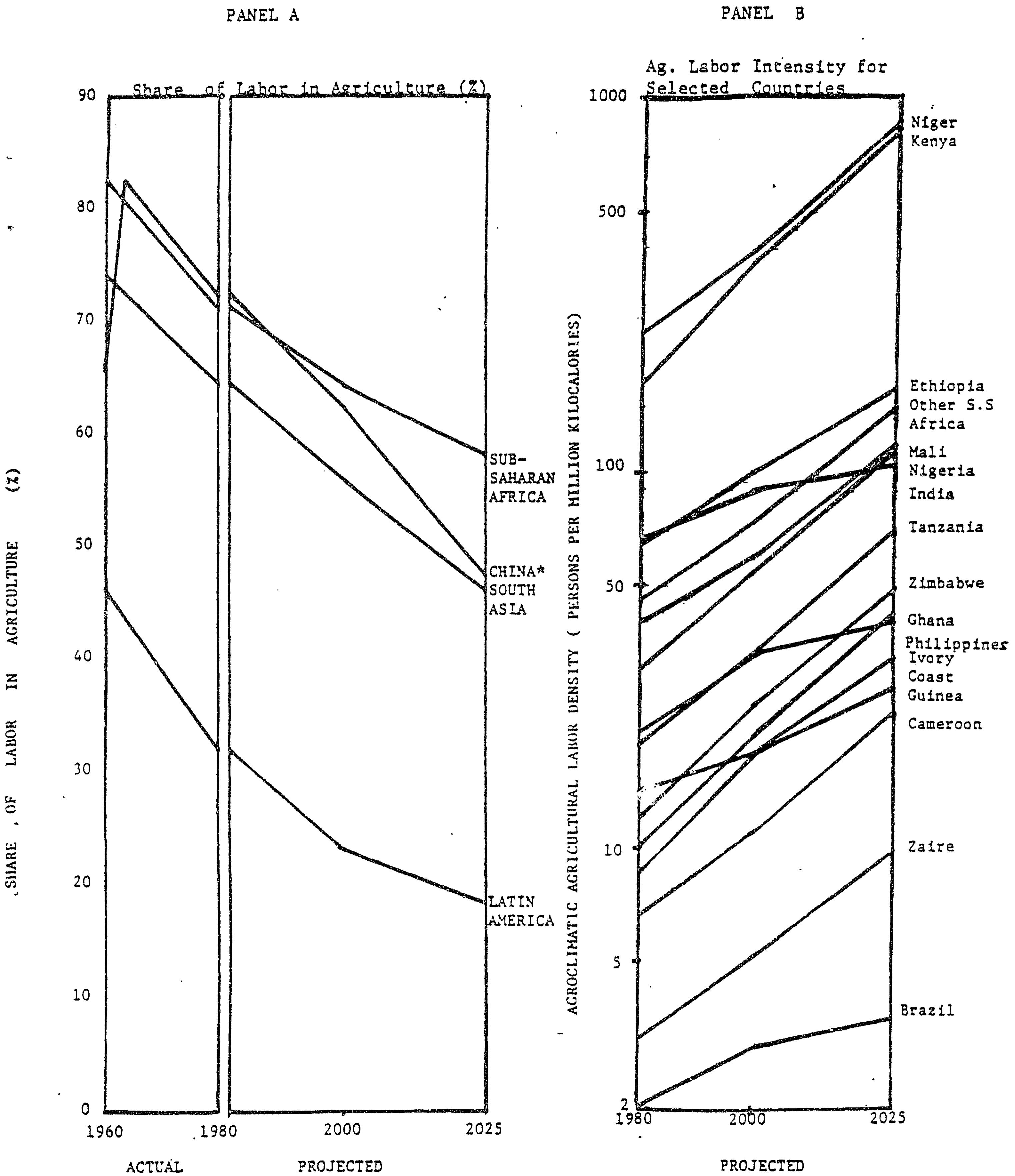
1/ Population projections for the years 2000 and 2025 were obtained from IBRD (1986). Agricultural labor force projections were made as follows. First the expected working age popuation age 15-64 was calculated which will exist at every 5-year interval until 2050. Then projections were made of the non-agricultural labor force based on an econometrically estimated relationship between the growth rate of the non-agricultural labor force as the dependent variable and the growth rate of the population 15-64 and the share of labor in agriculture in the initial period (Zachariah, 1985). The remainder of the working age population was then assigned to agriculture. The agricultural labor force is then projected, assuming the agricultural labor participation rates of the age group 15-64 will remain constant. These demographic projections are admittedly crude, and have to be used with much caution, especially at the individual country level. In addition, favorable economic conditions and policies can alter the actual outcome. Nevertheless, the projections clearly indicate the pressure under which agricultural labor markets will be operating in the future.

FIGURE 1 : ACTUAL AND PROJECTED TRENDS OF THE SHARE OF LABOR IN AGRICULTURE AND AGRICULTURAL LABOR INTENSITY, 1960 - 1980 and 2000 - 2025.



*China's labor force data are anomalous for the period 1957 - 1963, when major economic reorganization was taking place (See Dernberger 1982).

non-agricultural labor force would have to grow at 6.6% p.a. merely to keep the absolute number of workers in agriculture constant. To reduce the agricultural labor force by even 1% p.a., the non-agricultural labor force would need to grow at an extremely rapid 11.3% p.a.

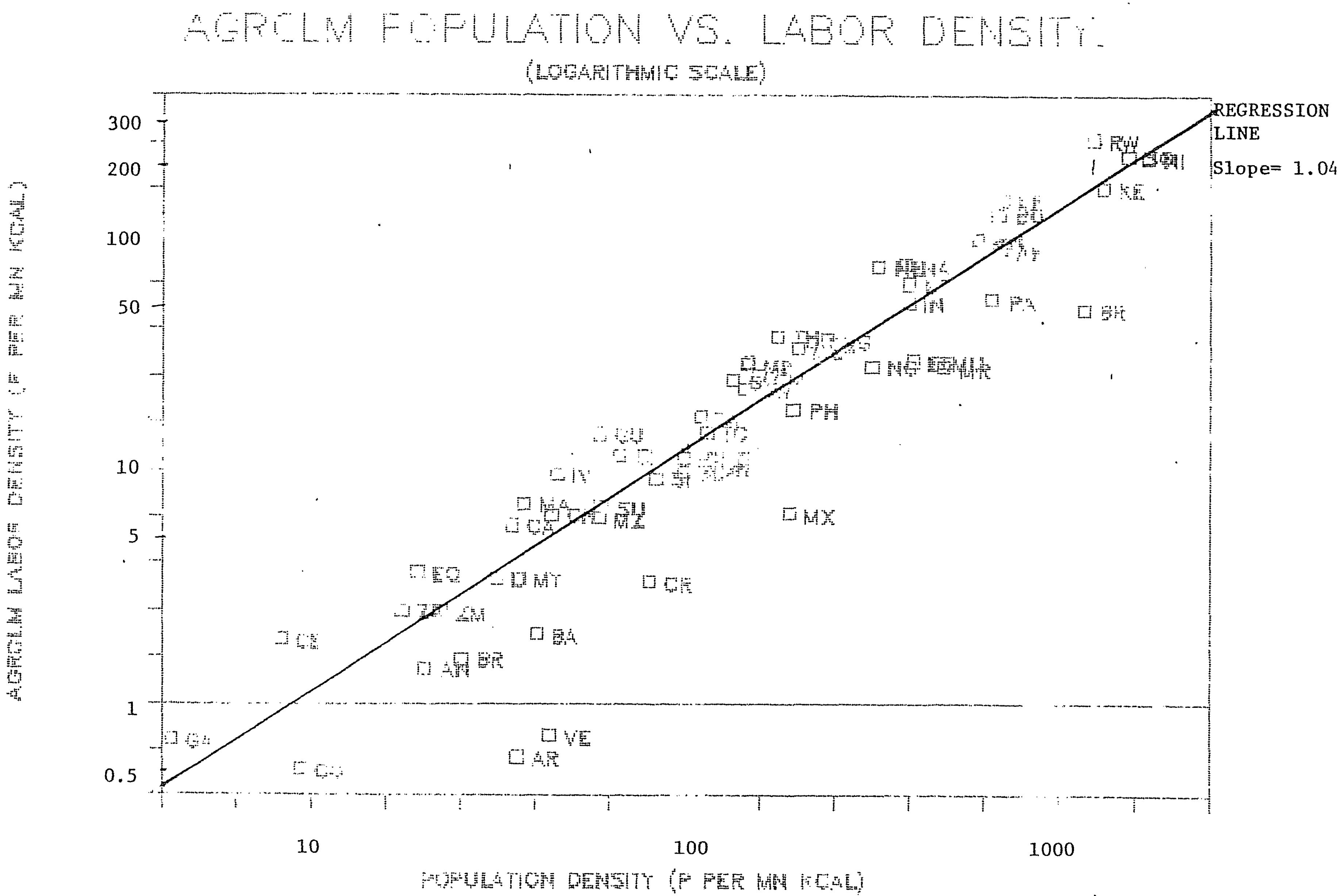
In order for the existing powerful demographic forces not to result in rapidly rising agricultural labor forces in Sub-Saharan Africa, non-agricultural employment would have to rise at rates very much higher than those observed during the 1960s and 1970s. The alarming Sub-Saharan African prospects shown in Figure 1 arise from the following combination of facts: Shares of labor in agriculture still range between 53 and 82 percent. Mortality rates are still declining rapidly and birthrates are projected to decline only slowly from unprecedented high levels. Moreover these trends are not reversible in the medium term, even if fertility started to decline sharply: The labor market entrants for the next 15 to 20 years are already born.

Agricultural employment and wage trends can be improved by favorable macroeconomic policies, by policies leading to improved absorption of labor in the non-agricultural sector and by favorable agricultural trends. And in the long run they can be affected by demographic changes. Nevertheless, these projections show the enormous pressures under which rural labor markets in Sub-Saharan Africa will be operating in the coming decades, and the pressures to rapidly intensify agricultural production.

Because population density shows both pressures in the labor market as well as pressures from the output demand side we will group countries by agroclimatic population density rather than labor density. The two measures are of course highly correlated as Figure 2 shows, which plots the data and a simple log-linear regression for the year 2000. A ten percent increase of the agroclimatic density is associated with a roughly 10% increase in agricultural labor density, with a coefficient of determination of 86%. The five most important countries below the regression line are all countries outside of SSA.

Figure 3 groups countries according to the population densities they will be having during the period 2000 to 2025. We call this period the research planning horizon, because decisions on research and technology priorities which are taken now will bear their fruits at the farm level during this period. The countries are classified with respect to two cutoff points: A density of 100, about one fourth below the density of 127 reached by Thailand in 1980. And a density of 250, slightly below the density reached by India or Egypt in 1980. Countries which will not reach the level of 100 before 2025 are classified as low density (group 1). Countries which will have already reached the level of 250 in 2000 are classified as high density (group 5). Group 3 includes all the countries which will remain between a level of 100 and 250 for the entire planning horizon. Group 2 and 6 are transition groups which are now either at low or medium density but will move to medium or high density between 2000 and 2025. The numbers in parentheses indicate the year in which countries will reach medium density or high density, respectively.

FIGURE 2


AGRCLM POPULATION VS. LABOR DENSITY
(LOGARITHMIC SCALE)
AGRCLM LABOR DENSITY (F PER MN KCAL)
POPULATION DENSITY (P PER MN KCAL)
300
200
100
50
10
5
1
0.5
10
100
1000
REGRESSION LINE
Slope= 1.04
MX
PH
PA
IN
VE
AR
BA
BR
EQ
MY
CR
KE
RW

NOTES TO FIGURE 2

COUNTRY	
AFGHANISTAN	AF
ANGOLA	AN
ARGENTINA	AR
BAHAMAS	BA
BANGLADESH	BN
BARBADOS	BR
BENIN	BE
BOTSWANA	BO
BRAZIL	BR
BURUNDI	BU
CAMEROON	CA
CENT AFR	CE
CHAD	CH
CONGO	CO
COSTA RICA	CR
EGYPT	EG
EQ GUINEA	EQ
ETHIOPIA	ET
GABON	GA
GAMBIA	GM
GHANA	GH
GUIN BISSAU	GU
GUINEA	GI
INDIA	IN
INDONESIA	ID
IVORY COAST	IV
KENYA	KE
LESOTHO	LE
LIBERIA	LI
MADAGASCAR	MA
MALAWI	ML
MALAYSIA	MY
MALI	MI
MARTINIQUE	MR
MAURITIUS	MU
MEXICO	MX
MOZAMBIQUE	MZ
NAMIBIA	NA
NEPAL	NE
NIGER	NI
NIGERIA	NG
PAKISTAN	PA
PHILIPPINES	PH
RWANDA	RW
SENEGAL	SE
SIERRA LEONE	SI
SOMALIA	SO
SUDAN	SU
SWAZILAND	SW
TANZANIA	TA
THAILAND	TH
TOGO	TO
UGANDA	UG
UPPER VOLTA	UP
VENEZUELA	VE
ZAIRE	ZA
ZAMBIA	ZM
ZIMBABWE	ZI

Regression Output: LOG VERSION

Constant	-1.03236
Std Err of Y Est	0.261822
R Squared	0.857251
No. of Observations	58
Degrees of Freedom	56

X Coefficient(s)	1.042457
Std Err of Coef.	0.056845
T-VALUES	18.33842
	LOG OF AGRCLM. POP.

FIGURE 3 : AGROCLIMATIC POPULATION DENSITIES FOR THE RESEARCH PLANNING HORIZON, 2000 - 2025.

DENSITY CATEGORIES / CLIMATE CATEGORIES	(1) LOW DENSITY: less than 100 for the entire planning period, 2000 - 2025.	(2) TRANSITION TO MEDIUM DENSITY: will reach 100 during the planning period, 2000 - 2025.	(3) MEDIUM DENSITY: between 100 and 250 for the entire planning period, 2000 - 2025.	(4) TRANSITION TO HIGH DENSITY: will reach 250 during the planning period, 2000 - 2025.	(5) HIGH DENSITY: are above 250 for the entire planning period, 2000 -2025.
DOMINANTLY HUMID LOWLANDS	Guin Bissau (2028) Malaysia (2091) Liberia (2051) Equatorial Guinea(2088) Zaire (2080) Congo (2109)	Sierra Leone (2054)	Indonesia (2080)	Philippines (2020)	Bangladesh Martinique Mauritius
MIXED CLIMATES OR MOSTLY INTERMEDIATE RAINFALL	Ivory Coast (2038) Chad (2041) Venezuela (2062) Bahamas (2086) Madagascar (2041) Argentina (2123) Camerocn (2045) Brazil (2119) Zambia (2066) Angola (2071) Central Africa (2114) Gabon (2147)	Benin (2040) Costa Rica (2097) Guinea (2072) Sudan (2065) Mozambique (2062)	Thailand (2033) Gambia (2031) Zimbabwe (2032) Togo (2033) Ghana (2036) Tanzania (2033)	Uganda (2002) Malawi (2009)	Kenya Rwanda Barbados Burundi Ethiopia India Nepal Nigeria
ARID OR SEMI-ARID			Mali (2027)	Senegal (2006) Mexico (2019) Botswana (2023) Upper Volta (2024) Swaziland (2024)	Niger Somalia Lesotho Afghanistan Pakistan Egypt Namibia

Note: The year enclosed in parenthesis for countries in Column 1 denote when they will reach a density of 100. While the year enclosed in parenthesis for countries in Columns 2, 3 and 4 denote when they will reach a density of 250.
Within each density/agroclimate cell countries are ranked by their projected agroclimatic population density in 2000.
Source: Appendix, Table 1.

High Density Countries: These are the countries where "green revolution" strategies employed for the past two decades in Asia are clearly most appropriate even now. These strategies emphasize yield as the source of growth and have already shown some success in Kenya, for example. Where technology is available investments in agricultural extension can have a high payoff. In Sub-Saharan Africa this group includes primarily semi-arid or arid countries but also a number of countries with a variety of agroclimates such as Nigeria and Kenya and the highland countries Rwanda, Burundi, and Ethiopia.

The green revolution strategies have been most successful in irrigated areas. It is well known that even in South Asia, yield growth in drylands has been quite limited. For arid and semi-arid countries or regions the question of irrigation investments therefore becomes a pressing issue. The problems with an irrigation-based strategy are the notoriously high costs of major irrigation schemes in Sub-Saharan Africa. Unless these costs can be dramatically reduced in the near future, irrigation investment will be confined to private well or lift irrigation, and to minor diversion and impounding schemes. One factor which is favorable to irrigation, if not to human welfare, is that labor costs are unlikely to rise and may even decline in the coming decades. Moreover, the willingness of agricultural populations to engage in labor-intensive irrigation will undoubtedly increase. Nevertheless, without major change in construction and contracting practices, irrigated agriculture appears unlikely to provide a basis for an internationally competitive agricultural sector, even in the high density semi-arid zones where it is most required.

The countries with higher rainfall and high quality soils (Rwanda, Burundi) or with mixed agroclimates (Kenya, Nigeria, Ethiopia) are better placed to achieve yield growth via agricultural research and increasing purchased input levels. Farmers will increasingly be interested in land improvements, many of which they will undertake spontaneously if the sector is offered nondiscriminatory output prices.

Irrespective of the agroclimatic conditions, labor saving innovations deserve lower priority in the high density countries. As in Asia, power requirements of an increasingly intensive agriculture will be met by a mixture of stationary machines for milling, pumping and threshing, and by expansion on animal draft and tractors which are all likely to operate within the same farming systems, with tractors concentrating primarily on tillage and transport. (For details see Agricultural Mechanization: Issues and Policies.) Policy should accommodate this process of mechanization by providing a distortion-free environment with maximum freedom of choice for farmers to find the most cost-effective ways of meeting their power requirements, but refrain from subsidizing or otherwise pushing advanced forms of mechanization. As elsewhere, public sector research in this area is likely to have minimal payoff, and research systems should instead concentrate on testing and information dissemination.

<u>Low Density Countries</u>: This large group of countries includes 12 of the 39 SSA countries considered, i.e. over 30%. <u>Many of these countries lie entirely in the humid tropics</u> e.g. the Congo or have a large proportion of their territory in the humid lowlands. Some countries have sub-regions with high population densities such as the Muda region of Malaysia, the highlands of Madagascar or Kivu province of Zaire. But in the humid lowland portions of their territories tropical rain forests or shifting cultivation systems are the norm rather than the exception. Population concentrations occur in highlands with more moderate and healthier climates, on pockets of good soils, and/or where infrastructure is well

developed. While the Latin America countries in this group have large livestock sectors based on extensive ranching, trypanosomiasis has prevented the emergence of this farming system in the tropical lowlands of Sub-Saharan Africa.

A central question facing many of these countries is what agricultural strategy to pursue for the humid lowlands. Much of these areas are characterized by chemically and structurally fragile soils (low CAC soils). Intensive cultivation of most upland soils of this zone leads to rapid leaching, soil acidification and/or erosion. It therefore requires high levels of chemical, mechanical and/or labor inputs to maintain yields, soil fertility and structure, and to control weeds. [Sanchez (1976), Ruthenberg (1980), Lal (1983), Kang and Juo (1981)]. Under low population density tree crop production and subsistence food production have been the most successful adaptations. The high costs of intensive field crop production has prevented humid lowlands with low population density from becoming internationally competitive in other commodities, despite their immense technical production potential. When population densities rise, irrigated and flooded rice production emerges in the lower ranges of the toposequence and has become the predominant source of food supply in the high density Asian countries. Under extremely high population densities, labor-intensive home gardens with several levels of vegetation also emerge. But the low density countries of SSA are a long way from the population densities required to make intensive rice cultivation or home gardens attractive to the local populations.

Yield raising development and research strategies which require high levels of purchased or labor inputs are doomed to failure in these environments. For genetic research, pest and disease resistance and quality issues are the key avenues to success for the low density zones. For the countries as a whole most of the research effort should be concentrating on areas of inframarginal land scarcity. But where the populations have the option of migrating from high density to low density areas, they will not be willing, even in the high density zones, to use techniques which are very intensive in terms of labor and cash inputs.

For the low density zones research in the farming systems and soils area faces the major challenge of coming up with systems which can produce crops at overall unit costs which are competitive with other agroclimatic zones. The limited past record of success suggests that this may not be possible for a number of soil types, and careful concentration of research resources on the more promising environments will be required. The temptation to attempt to work for all regions where poor people reside must be strongly resisted.

Infrastructure development deserves a high priority in low density zones, despite the fact that it is relatively costly per person served. Land far from infrastructure is only suitable for subsistence crop production. But just like research resources need to be concentrated on the more promising sub-regions of the zone, so does infrastructure development. In addition, finding low cost ways of accommodating migrants from areas with high population densities is a priority.

Irrigation should be considered in these countries only for their arid and semi-arid zones, and even there only if exceptional sites allow construction of irrigation works at very low cost. Arid and semi-arid regions have to compete in national output markets and equipping them with high cost irrigation does not improve their competitive position with better endowed regions, as the high failure rate of irrigation in Northeast

Thailand or Northeastern Brazil clearly demonstrates. Where humid zones become more densely populated, drainage investments to allow access to high quality alluvial lands may become an option.

Can one use mechanization to "modernize" shifting cultivation systems in the subhumid and humid lowlands? The low population density of Sub-Saharan Africa has often seduced colonial as well as independent African governments into schemes for rapid tractorization, one of which was the ill-fated Tanzania groundnut scheme. The common assumption was that, once land was cleared and tractors were provided to shifting cultivators, they would then adopt a permanent system of cultivation. But as discussed before, the total unit cost of production is higher when using the plow than when using shifting cultivation. And a consistent record of failure shows that this common assumption is false.

A review of thirty projects between 1945 and 1977 that attempted to speed up the process of tractorization revealed that twenty of them failed to achieve their objective and that no tractors can be found in the project area today (Pingali, et al 1986). Of the failed projects, fourteen were attempts at a direct transition from handhoes to tractors. As discussed in the text, where this transition does not take place it is because from the farmer's point of view production costs, using shifting cultivation and handhoe, are lower than using the plow.

Areas in which the transition to tractors has been sustained are either regions in which animal draft power is well-established, or lowland areas used for rice cultivation, or the grassy savanna zones in parts of semi-arid Africa. In the first case, the farmer is faced with choosing the most effective combination of hand labor, animal draft and tractors. The economic costs of using tractors versus animals is determined by the relative costs of labor and capital, the costs of area expansion, the potential capacity utilization, fodder availability and maintenance costs.

Plows can be used in valley bottom lands where irrigated or flooded rice is cultivated, or in the grassy savanna areas, without incurring high destumping costs since the natural vegetation is primarily a grass cover and does not include trees and bushes. Animal drawn plows and tractors have been sustainable under these conditions even where population densities are low. In these situations, case-by-case analysis is required to determine whether animals or tractors are more cost-effective or whether to use both.

The Medium Density Group: Yield growth will be high on the research agenda for regions where land has or will become inframarginally scarce in the near future, such as the communal sector of Zimbabwe, or the double cropped rice growing area of Central Thailand. But in other areas, such as Northern and Central Ghana or substantial areas of Mali there is still considerable scope for a strategy based on area expansion for one or several decades. Accommodating the area expansion by infrastructural investments will deserve higher priority there than improving yields by investing heavily in extension systems and fertilizer subsidies. Moreover, many of these areas may be at the late bush fallow or grass fallow stages, where the introduction of the plow becomes truly labor saving.

All countries in the transition group to medium density have important portions of their territory in the humid and subhumid lowlands. As in the case of Sierra Leone, their population densities may have reached levels where the shifting cultivation system is no longer sustainable as fallow periods have been reduced sharply. The transition group to high density, on the other hand is dominated by semi-arid countries, a dominance which would even increase if Mali were included - which is estimated to join this group just two years after the end of the planning horizon. The balance in these countries must shift towards yield and irrigation, but again the high cost of irrigation investments presents a difficult barrier. In the more favorably endowed regions or countries such as Southwestern Upper Volta or the Volta Noire, much of Uganda and vast areas of the Sudan, the potential for area expansion nevertheless continues to be important and accommodating it with infrastructural investments, and with support to migration and to mechanization deserves high priority.

IV. Private and Public Initiatives in Technology Generation

The technology groups discussed so far are generated by one of the following: farmers, the agricultural machinery industry, the agro-chemical industry, the agricultural research institutes, and private sector seed companies. In environments where private industries are allowed to grow free of government intervention one observes a systematic division of responsibilities between the public and private sectors. The private sector concentrated on the generation of mechanical and chemical technology while the public sector concentrated on biological technology.

Mechanical technology is sensitive to (i) agroclimatic factors such as soils, terrain, rainfall regimes and (ii) to economic factors such as the farming system, capital availability, farm size and materials available. Where there is a divergence in either environmental or in economic conditions direct transfer of mechanical technology is limited. Accordingly, one observes a great deal of invention and/or adaptation of mechanical technology to meet local conditions. In the early phases of mechanical adaptation such work is usually done by small private manufacturers or workshops in close association with farmers. This process provides direct solutions by mechanically minded individuals to problems perceived by farmers. For instance, in 1880 there were 800 distinct models of plows advertised for sale in the U.S. Early machinery innovation in the developing world reveal similar reliance on small workshops and direct farmer contact. The emergence of a vibrant machinery industry out of small shops in the Indian and Pakistani Punjabs, the power tiller industry in

Thailand and in the Philippines all followed similar patterns. In the early phases small workshops have a distinct advantage over large corporations because of: (i) the location specificity of the innovations, and (ii) the manufacturer's ability to capture the gains of their innovative effort through sales.

The contribution of large corporations increases over time but continues to be most important in the area of engineering optimization. It is at this stage that engineering staff of corporations are most effective. For instance, it was only around the start of the 20th century that the plow industry in the U.S. consolidated with the large firms such as John Deere purchasing the patents and assets of small firms as they expanded.

Given this dominant role of individual initiative in the development of agricultural machinery, what are the appropriate government policy interventions towards mechanization? Innovation and adoption can be engouraged through: (i) patent laws for the enforcement of innovator's rights; (ii) testing, standardization and information dissemination; (iii) support of agricultural engineering education and some university-based research, and (iv) absence of discrimination against small firms in access to foreign exchange, materials and supplies. Efforts to protect the domestic agricultural machinery industry through import controls have not generally been successful. This is because the small innovators no longer have access to models or a wide range of engines to design locally adapted machines.

Unlike in the case of mechanical technology, small entrepreneurs do not play a major role in the generation of chemical innovations. This is because the innovators require special skills acquired through university training and specialized facilities which are too expensive to provide for an individual researcher. Accordingly, most research and development of agricultural chemicals is conducted by large corporations. These corporations can capture the returns to their investment in research through the sale of the final product which is protected by patents. Chemical innovations have to be adapted to agroclimatic differences such as soils and rainfall regimes but here again adaptive research on mixtures, application rates and application schedules is more easily done by the parent corporation. The parent company may set up experimental fields in different environments as part of its sales effort.

As in the case of mechanical technology, private corporations have a comparative advantage in the research, development and production of chemical technology. Here again the role of government should be restricted to enforcing patent laws, testing and supporting university education and basic scientific research.

There are several areas of research where incentives for private sector research have not been adequate to induce an optimum level of investment. In these areas the social rate of return exceeds the private rate of return because a large share of the gains from research are captured by other firms and by consumers rather than by the innovating firm (Ruttan, 1982). The most obvious case is basic or supporting research in genetics, plant pathology and physiology, soil science, etc., which has implications for the development of chemical and biological innovations. Applied research by private corporations uses the results of basic scientific enquiry without having to fully compensate the basic researcher who produced the results.

The second case is where the search for solutions is very expensive and very risky but once the solutions are obtained they can be easily reproduced by the users or other firms. For instance, research and development of new crop varieties is extremely complex having to consider a wide variety of parameters ranging from agroclimates and soil types to consumer tastes. Yet once a suitable variety is developed it can be reproduced by individual farmers. Seed companies, therefore, have not been able to capture more than a small share of the gains from the development of new crop varieties. Hybrid varieties are an exception to this generalization because their genetic potential decays rapidly. Only in recent years have efforts to generate patent protection for new varieties borne fruit in the developed world, where the role of private seed companies is rapidly expanding.

Public sector agriculture research institutes are thus an essential part of a strategy for rapid growth in agricultural output through science and industry based inputs. Public research effort in agriculture is most productive if it concentrates mainly on the provision basic research and on research leading to advances in biological technology. Public research on mechanical and chemical technology can be minimal and mainly university based since the private sector has greater initiative to conduct research in this area. Developing countries have often been hostile to private seed companies. But the example of India shows that private seed companies can flourish. Ignoring their potential contribution in planning research systems in Sub-Saharan Africa will be wasteful of scarce human and financial resources.

Appendix 1

The Methodology of the FAO Carrying Capacity Study*

"The methodology of the study was extremely complex. The detailed FAO/UNESCO World Soil Map (scale 1:5,000,000) provided localized data on soil types, the slop of the land, and other physical characteristics that affect productivity. A separate climate map was prepared, based on patterns of rainfall, temperature and solar radiation, which divided the developing world into major climates and into many hundreds of 'length of growing period zones' - areas within which conditions were suitable for plant growth for a given number of days in the year (for example, 0-75 days, 75-90, 90-100 and so on).

"The crucial step was to superimpose the climate map over the soil map, thus producing a fine mosaic of tens of thousands of land units with distinctive land and climate characteristics. For each cell in this mosaic, a complicated computer programme (designed and run by the International Institute for Applied Systems Analysis in Vienna) calculated the potential yields for every one of the major food crops that could be grown there.

"The one crop that gave the optimum yield was selected for each area, and the yield in terms of calories calculated. These finely detailed results were then clumped together, by country, by climate and by length of growing period zone. The calorie production of each area was converted into a figure for population carrying capacity simply by dividing by the average recommended calorie intake for each country.

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*Reproduced from Paul Harrison's "Land and People, The Growing Pressure", EARTHWATCH, No. 13, 1983: p. 1.

"Comparison with the 1975 populations enabled the project to pinpoint which areas could not support their populations, while comparison with populations expected on the UN medium variant in the year 2000 made it possible to predict which countries and regions would be critical in the future.

"Because farming practices such as fertilizer use have a strong effect on yields, all the calculations were done for three levels of farming: a low level of inputs - roughly what you might find in a rural area of a Least Developed Country - using no fertilizer or chemicals, traditional seed varieties and cropping patterns, and no conservation measures; an intermediate level, using a basic package of fertilizers and chemicals, with some improved varieties, simple conservation measures, and the most productive crop mix on half the land - this level might correspond to that found among medium and small farmers in development project areas in Asia. And a high level of farming, corresponding roughly to North America, with high doses of fertilizer, full use of chemicals, improved varieties and conservation practices, and the ideal mix of crops on all the land.

"There was no attempt in the first phase of the project to decide where individual countries or regions came on this scale. But most farmers in Africa would be at the low level of input use; in Asia and Latin America commercial farmers might be at the intermediate level, but the majority of small farmers would be somewhere between low and intermediate.

"There was also no attempt to assess whether countries unable to produce sufficient food from their own land possessed - or could develop - secure sources of foreign exchange with which to buy imported food. For those that have such sources, inability to feed their population from their own land is less of a problem."

APPENDIX TABLE 1 : AGROCLIMATIC POPULATION DENSITIES FOR SELECTED COUNTRIES, 1980 - 2025.

COUNTRY*	TOTAL POP.1980 (thous.)	TOTAL POP.2000 (thous.)	TOTAL POP.2025 (thous.)	POPUL. GR. RATE '80-2025	POTEN. CAL.PROD. (MILLKC)	AGRCLM. PDEN1980 (P/C M)	AGRCLM. PDEN2000 (P/C M)	AGRCLM. PDEN2025 (P/C M)	RANK** OF COUN. BY 2000	YEAR*** REACHED 100or250
NIGER	5532	10518	20094	0.028663	6110	905.4009	1721.440	3288.707	5	A.R.
SOMALIA	4674	8460	15784	0.027044	5544	843.0735	1525.974	2847.041	5	A.R.
KENYA	16643	36463	69332	0.031709	28072	592.8683	1298.909	2469.791	5	A.R.
RWANDA	5139	10239	20100	0.030308	8352	615.3017	1225.933	2406.609	5	A.R.
BARBADOS	249	280	338	0.006790	242	1028.925	1157.024	1396.694	5	A.R.
LESOTHO	1341	2240	3702	0.022565	3192	420.1127	701.7543	1159.774	5	A.R.
AFGHANISTAN	15950	25403	40870	0.020909	36600	435.7923	694.0710	1116.666	5	A.R.
BURUNDI	4114	7367	13248	0.025987	10718	383.8402	687.3483	1236.051	5	A.R.
PAKISTAN	82061	133053	208535	0.020725	201432	407.3881	660.5355	1035.262	5	A.R.
BANGLADESH	88513	141077	209929	0.019191	232386	380.8878	607.0804	903.[illegible]	5	A.R.
MARTINIQUE	312	358	437	0.007487	726	429.7520	493.1129	601.9283	5	A.R.
MAURITIUS	957	1293	1651	0.012118	2724	351.3215	474.6696	606.0939	5	A.R.
EGYPT	42289	62842	85798	0.015721	154616	273.5098	406.4391	554.9102	5	A.R.
ETHIOPIA	37717	63660	105843	0.022929	159605	236.3146	398.8596	663.1559	5	A.R.
INDIA	687332	994356	1308588	0.014308	2497742	275.1813	398.1019	523.9083	5	A.R.
NAMIBIA	980	1863	3132	0.025819	4788	204.6783	389.0977	654.1353	5	A.R.
NEPAL	14640	24486	41080	0.022928	74140	197.4642	330.2670	554.0868	5	A.R.
NIGERIA	84732	162718	295116	0.027730	514952	164.5434	315.9867	573.0941	5	A.R.
UGANDA	12630	24604	45579	0.028519	102520	123.1954	239.9921	444.5864	4	2002
SENEGAL	5696	10116	17175	0.024526	46172	123.3648	219.0938	371.9786	4	2006
MALAWI	6046	11352	20635	0.027279	56376	107.2442	201.3622	366.0245	4	2009
PHILIPPINES	48300	73299	100153	0.016205	376064	128.4355	194.9109	266.3190	4	2020
MEXICO	69393	109411	154015	0.017716	569918	121.7596	191.9767	270.2406	4	2019
THAILAND	46455	65111	84281	0.013237	367188	126.5155	177.3233	229.5309	3	2033
BOTSWANA	893	1758	2902	0.026190	11136	80.19037	157.8663	260.5962	4	2023
MALI	6699	12233	19971	0.024273	82485	81.21476	148.3057	242.1167	3	2027
UPPER VOLTA	6161	9221	16243	0.0215[illegible]2	62805	98.09728	146.8195	258.6259	4	2024
SWAZILAND	633	1218	2119	0.026849	8352	75.79022	145.8333	253.7116	4	2024
GAMBIA	652	1089	1787	0.022405	8092	80.57340	134.5773	220.8353	3	2031
ZIMBABWE	6976	14283	24692	0.028088	116393	59.93487	122.7135	212.1433	3	2032
TOGO	2578	4859	8716	0.027069	42320	60.91582	114.8156	205.9546	3	2033
GHANA	11500	23139	39930	0.027661	203550	56.49717	113.6772	196.1680	3	2036
TANZANIA	18757	36916	68451	0.028777	334776	56.02850	110.2707	204.5576	3	2033
INDONESIA	146345	211994	282620	0.014625	2128032	68.77011	99.61974	132.8081	3	2080
BENIN	3464	6472	11562	0.026734	65320	53.03123	99.08144	177.0055	2	2040
SIERRA LEONE	3358	5360	8891	0.021637	63940	52.51798	83.82858	139.0522	2	2054
COSTA RICA	2245	3439	4605	0.015965	42784	52.47288	80.38051	107.6336	2	2097
GUINEA	5488	8313	13197	0.019498	124740	43.99551	66.68270	105.7960	2	2072
SUDAN	18945	33391	57810	0.024791	560945	33.77336	59.52633	103.0582	2	2065
MOZAMBIQUE	12103	21722	38718	0.025841	366673	33.00716	59.24[illegible]	105.5912	2	2062
GUIN BISSAU	809	1226	1964	0.019709	20790	38.91293	58.97065	94.46849	1	2028
IVORY COAST	8358	17308	29200	0.027778	380457	21.96831	45.49265	76.74930	1	2038
CHAD	4477	7271	12108	0.022109	166124	26.94974	43.76851	72.88531	1	2041
VENEZUELA	15620	26151	36618	0.018973	603174	25.89634	43.35564	60.70885	1	2062
BAHAMAS	210	310	405	0.014595	7744	27.11776	40.03099	52.29855	1	2086
MADAGASCAR	8714	16189	29830	0.027346	436067	19.98316	37.12502	68.40671	1	2041
MALAYSIA	13870	20540	27263	0.015017	573556	24.18246	35.81167	47.53328	1	2091
ARGENTINA	28237	36535	45099	0.010405	1029065	27.43947	35.50310	43.82521	1	2123
CAMEROON	8701	16648	30177	0.027636	485344	17.92749	34.30144	62.17651	1	2045
LIBERIA	1871	3463	6126	0.026357	110418	16.94470	31.36264	55.48006	1	2051
BRAZIL	121286	178802	239019	0.015075	7077985	17.13566	25.26170	33.76935	1	2119
ZAMBIA	5647	11044	19609	0.027663	498729	11.32278	22.14429	39.31794	1	2066
ANGOLA	7582	13221	23170	0.024824	656120	11.55581	20.15027	35.31366	1	2071

APPENDIX TABLE 1: (Con't).

COUNTRY*	TOTAL POP.1980 (thous.)	TOTAL POP.2000 (thous.)	TOTAL POP.2025 (thous.)	POPUL. GR. RATE '80-2025	POTEN. CAL.PROD. (MILLKC)	AGRCLM. PDEN1980 (P/C M)	AGRCLM. PDEN2000 (P/C M)	AGRCLM. PDEN2025 (P/C M)	RANK** OF COUN. BY 2000	YEAR*** REACHED 100or250
EQ GUINEA	341	536	856	0.020453	27530	12.25296	19.25979	30.75817	1	2088
ZAIRE	27094	49920	86011	0.025670	2843820	9.527325	17.55385	30.24488	1	2080
CONGO	1605	3366	5788	0.028503	350528	4.451804	9.336306	16.05423	1	2109
CENT AFR	2286	3972	6854	0.024400	478668	4.775752	8.298027	14.31890	1	2114
GABON	755	1243	2131	0.025058	296712	2.544554	4.189247	7.182048	1	2147

*Ranked by Agroclimatic Population Density in 2000.

**Countries were categorized and ranked according to the following criteria:

1 = countries with an agroclimatic population density between 0 - 100 during the period 2000 - 2025.

2 = countries with an agroclimatic population density between 0 - 100 in 2000 and rose to between 100 - 250 in the period 2000 - 2025.

3 = countries with an agroclimatic population density between 100 - 250 in 2000 in the period 2000 - 2025.

4 = countries with an agroclimatic population density between 100 - 250 in 2000 and rose to 250 and above in the period 2000 - 2025.

5 = countries with an agroclimatic population density of 250 and above in the period 2000 - 2025.

***Notes on years reported:

1) if rank is 2,3 or 4 then year reported is when these countries will reach anagroclimatic population density of 250.

2) if rank is 1, then year reported is when these countries will reach an agroclimatic population density of 100.

APPENDIX TABLE 2 : AGROCLIMATIC AGRICULTURAL LABOR DENSITY, 1980 - 2025.
(in Million Kilocalories)

COUNTRY*	AGR.LAB. DENS1980 (P/MKC)	COUNTRY*	AGR.LAB. DENS2000 (P/MKC)	COUNTRY*	AGR.LAB. DENS2025 (P/MKC)
RWANDA	287.7155	RWANDA	499.9475	RWANDA	1156.508
SOMALIA	255.5916	SOMALIA	399.0471	NIGER	848.2443
NIGER	237.3158	NIGER	398.3809	KENYA	816.7286
LESOTHO	184.2105	KENYA	376.0002	SOMALIA	805.5892
KENYA	175.1567	LESOTHO	270.2618	LESOTHO	481.4975
BURUNDI	149.7480	BURUNDI	236.7241	BURUNDI	467.9777
ETHIOPIA	65.41148	ETHIOPIA	102.5978	ETHIOPIA	179.0725
NAMIBIA	43.65079	UGANDA	77.15687	UGANDA	162.6636
UGANDA	42.65509	NAMIBIA	76.20832	NAMIBIA	149.7947
BURKINA FASO	42.49661	MALAWI	69.00775	MALAWI	137.8760
MALI	39.69206	MALI	62.06910	MALI	124.9703
MALAWI	39.50262	SENEGAL	59.77016	BOTSWANA	116.1819
SENEGAL	38.07502	BOTSWANA	59.29470	NIGERIA	115.3692
MAURITIUS	35.24229	NIGERIA	54.81707	SENEGAL	107.5183
NIGERIA	31.40681	BURKINA FASO	54.59237	BURKINA FASO	103.9800
BOTSWANA	30.44181	MAURITIUS	49.00347	SWAZILAND	75.50204
GAMBIA	27.43450	GAMBIA	40.91347	TANZANIA	70.37143
SWAZILAND	22.03065	SWAZILAND	39.90959	GAMBIA	67.18729
TANZANIA	18.62738	TANZANIA	33.48426	TOGO	56.63104
TOGO	16.68241	TOGO	28.23071	MAURITIUS	51.14336
GUINEA	13.85281	ZIMBABWE	24.37387	ZIMBABWE	49.56775
SIERRA LEONE	12.52736	GHANA	20.94947	GHANA	42.73255
ZIMBABWE	12.17427	BENIN	19.89063	BENIN	42.34645
BENIN	11.20636	IVORY COAST	18.17718	IVORY COAST	32.03759
GHANA	10.58707	GUINEA	18.01425	MADAGASCAR	27.78890
GUIN BISSAU	9.812409	SIERRA LEONE	16.77934	GUINEA	27.44740
CHAD	8.632106	GUIN BISSAU	14.29785	SIERRA LEONE	26.85947
IVORY COAST	8.592298	MADAGASCAR	13.51331	MOZAMBIQUE	23.53099
MADAGASCAR	8.106552	SUDAN	12.59927	CAMEROON	23.19350
MOZAMBIQUE	8.017933	MOZAMBIQUE	12.14187	SUDAN	23.18217
SUDAN	7.934824	CHAD	11.92165	GUIN BISSAU	22.60342
CAMEROON	6.599442	CAMEROON	11.07779	CHAD	20.14604
LIBERIA	4.329004	LIBERIA	6.537841	LIBERIA	12.55193
ZAIRE	3.140142	ZAIRE	5.129799	ZAMBIA	10.09814
EQ GUINEA	2.[illegible]	ZAMBIA	4.[illegible]	ZAIRE	9.718713
ZAMBIA	2.738962	EQ GUINEA	3.604859	CENT AFR	6.546451
CENT AFR	2.254171	CENT AFR	3.399457	EQ GUINEA	5.813071
ANGOLA	1.790830	ANGOLA	2.708650	ANGOLA	4.971014
GABON	1.314405	GABON	1.710493	GABON	3.104662
CONGO	0.496494	CONGO	0.997136	CONGO	2.589737

*Ranked by Agroclimatic labor density for respective years.

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