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INFRASTRUCTURE AND TECHNOLOGY CONSTRAINTS TO AGRICULTURAL DEVELOPMENT IN THE HUMID AND SUBHUMID TROPICS OF AFRICA

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ABSTRACT

Green Revolution technologies have not been widely adopted in Africa. What are the chances that they will play a major role in the near future? This paper shows that the enabling infrastructure, especially rural roads and irrigation systems are not likely to be in place in the humid and sub-humid tropics of Africa in the next 20-30 years. Consequently a typology of the more appropriate set of technology that is input and infrastructure efficient, has high returns to seasonal labor and is sustainable is presented. Research institutions should be geared up now to produce them for use in 10-20 years.

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INFRASTRUCTURE AND TECHNOLOGY BOTTLENECKS ON AGRICULTURAL DEVELOPMENT IN AFRICA[*]

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I. INTRODUCTION

Economic stagnation, even decline, has characterized most African countries over the last two decades. Poor performance in the main economic sectors, particularly agriculture which in most cases grew much slower than population, has led to a decline of per capita income. Efforts to bring the countries' economies back to the growth path have led to renewed interest in the role that the agricultural sector can play in the economic recovery of African countries.

Available evidence lends strong support to the close relationship between agricultural development and overall economic growth. Recent results obtained by Delgado et al. (1994), show that an initial increase in rural incomes in a set of African countries is amplified through growth multipliers averaging 2.0 and higher.[1] Furthermore, agricultural

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[1] A rural growth multiplier is the addition to total rural income from adding a dollar of new (exogenous, tradable) income as a result of structural changes such as technological progress, improvement in export prices, etc.. Thus, a multiplier of 2.0 suggests an addition of $1.00 on extra income for each $1.00 of new agricultural income, through a re-spending on non-tradable consumer items and intermediate inputs.

multiplier estimates obtained by other authors (for example, Haggblade et. al. 1989) range from 1.5 to 2.7 and are comparable to estimates for Asian countries which range from 1.5 to 2.4.

Because of the high marginal expenditure shares for food, consumption linkages play the main role in agricultural growth multiplier effects (Haggblade et al., 1989; Haggblade et al., 1991). This implies that increments to income have to be widely-spread for the growth multiplier process to assume importance. At the current level of development of African economies, only agriculture-based activities can bring about broad-based increases in per capita income. In addition, sustaining the process of growth will call for improved competitiveness and greater responsiveness in the domestic consumer goods sector, as expenditure patterns shift in favor of the latter. This puts promotion of appropriate technology in agriculture and the creation of an enabling environment at the center of the challenge facing African countries. Government's role is critical for the creation of basic infrastructure such as roads, rural electrification and water supply, human capital formation and creation of research and extension systems.

The purpose of this paper is to examine recent experiences in trying to introduce intensified agricultural production systems in the humid and sub-humid tropics of Africa (HST), and the difficulties caused by inadequate infrastructure and inappropriate nature of most of the improved technologies offered to farmers in the past.

The paper first examines the record of economic growth of HST countries and their experience with intensified agricultural development, in particular the level of development of the rural infrastructure needed to support use of intensified agricultural systems, and the level of adoption of improved agricultural technologies. Then it looks forward two to three decades, examining the prospects for creating the enabling conditions for intensified agricultural development using new "green revolution" technologies currently being produced by research institutions. In the final section conclusions are drawn regarding the types of technologies needed to fuel agricultural development in the future, and the steps that should be taken to develop such technologies.

The forward look in this paper at agricultural technology needs in the next two to three decades, and the focus on one or two agro-ecological zones marks a growing recognition of the importance of differences between ecological zones, and the need for greater attention to research at the sub-regional level.

2. INTENSIFIED AGRICULTURAL DEVELOPMENT IN THE HUMID AND SUB-HUMID TROPICS (HST)

CHARACTERISTICS OF THE HST

The HST encompasses about 650 million hectares, or about a third of the agricultural land area of sub-Saharan Africa (Figure 1), and contains about 200 million people, roughly half the population of SSA (IITA, 1992). It consist of all the coastal countries of West and Central Africa, starting from Guinea Bissau and running through Zaire, with 3/4 of Nigeria, about half of Mozambique and Madagascar and a third of Tanzania in East Africa[2]. It can be sub-divided into two zones.

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[2] All individual country data presented in this paper for countries with only a portion of their landmass in the humid Forest and Moist Savanna zones (Madagascar, Mozambique, Nigeria and Tanzania) are national averages, except for total population and land areas. Regional averages are weighted averages using the proportion of the countries population or land area in the two zones.

The Humid Forest Agro-ecological Zone has a length of growing period (LGP) for crops[3] of 271-365 days, and a mean daily temperature (DMT) during the growing season above 20°C. The area includes both evergreen and deciduous rain forest formations and the dominant soils are Ultisols and Oxisols. The zone contains a mosaic of land use systems; patches of secondary forests and fallow vegetation, and small remnants of primary forests. The traditional farming systems are those of shifting cultivation and fallow rotation (IITA. 1992). There are a great many variations of practice within these systems, but fundamentally they are typified by the alternation of short periods of cropping (1-4 years) followed by fallow periods characterized by successional components of the natural vegetation. Tree crops such as oil palm, plantain, bananas, cocoa and coffee, and roots and tubers such as cassava, yams, cocoyams predominate, although cereals, particularly rice and maize are also important. Demographic and socio-economic structures vary significantly within the zone, with southern Nigeria, for example, recording the highest population density in SSA, and the Zaire basin among the lowest. There are areas of large urban populations and well developed infrastructure, and others with poorly developed infrastructure. In parts of the region, the rural economy is largely dependent on industrial plantation crops, while in others small scale food crop production have provided opportunities for substantial expansion of cash cropping.

[3] The growing period starts in the month in which rainfall is equal to or greater than half the potential evapo-transpiration (PET) and rainfall in the subsequent month > PET; and ends in the month in which rainfall + stored soil moisture < 1/2 PET. This is based on the assumption that soil water holding capacity = 100mm.

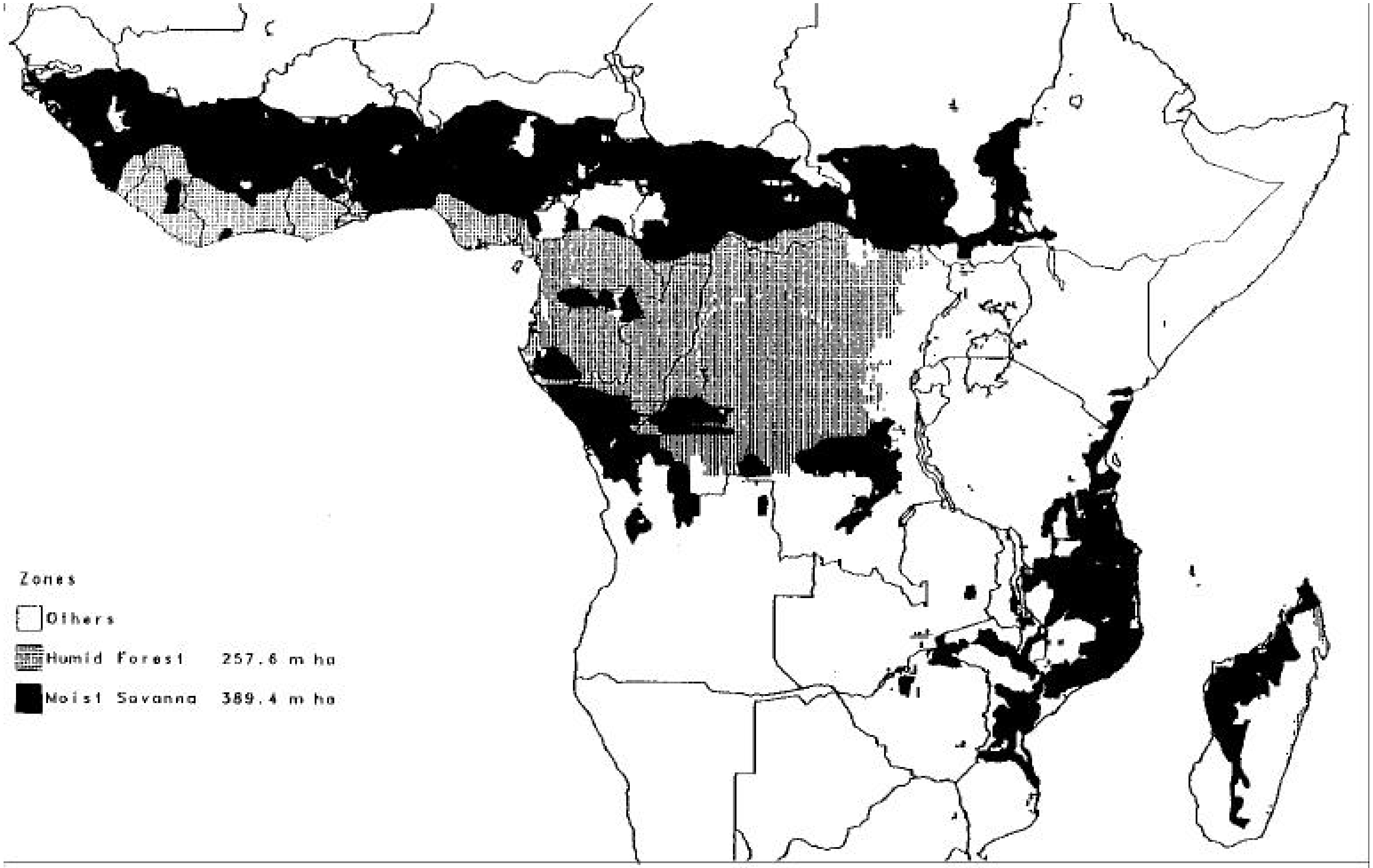

Figure 1: Humid and sub-Humid Tropics of Africa

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The Moist Savanna Zone has a LGP of 151-270 days and an MDT above 20°C. It comprises a total of about 380 million hectares, and stretches in a band across West and Central Africa, and includes coastal lowland in eastern and southern Africa. Soils are mainly Alfisols and Inceptisols, with inherent low soil fertility, and susceptibility to compaction and erosion. The natural vegetation changes from forest, through savanna woodlands to open savanna. Most areas have been modified through agricultural use, especially the forest-savanna transition areas which have lost their forest vegetation in many areas and are dominated by annual and perennial grasses and shrubs. Short-medium cycle crops such as maize, cowpea, sorghum, millet and cotton, predominate in the drier parts of the zone, while long-cycle annuals (yam, maize) or semi-perennial (cassava) become more important in the wetter parts. Population density is also quite varied in the zone. Fallow periods are declining and are non-existent in some areas, although bush fallow is still the usual method of restoring soil fertility. The zone is generally regarded as one with a high potential for cereal crop production.

RECORD OF ECONOMIC DEVELOPMENT

From the middle of the sixties to the middle of the eighties, agricultural growth in African countries averaged 2 percent, turning sharply downwards towards the end of the period, compared with growth rates of around 3 percent for developing Latin American and Asian countries. During the same time, per capita GDP in African countries grew by less than 1 percent, compared to 1.5 percent for Latin American countries and 2.5 and 5 percent respectively, for East and South Asian countries (World Bank 1989, 1993). The HST has not performed any better than SSA as a whole (Table 1) although it has not suffered from the droughts that have plagued the dryer Sahelian and Sudanian zones (Sanders, 1993). However, the aggregate figures in Table 1 hide a wide variation in performance between countries in the HST. For example, average annual growth in GDP during the last decade ranged from virtually zero for Cote d'Ivoire, Gabon and Mozambique, to over 3.2 percent for Ghana, Congo and Guinea Bissau. During the same period, agricultural growth ranged from less than 1 percent for Gabon and Cote d'Ivoire, to over 5 percent for Benin, Guinea Bissau and Togo. It was only in Benin, Ghana, Guinea Bissau and Nigeria that there was a positive growth in per capita food production during the decade of the 1980's, with only Benin and Nigeria averaging over 1 percent per year.

RECORD OF INFRASTRUCTURE DEVELOPMENT

Rural infrastructure, comprising rural roads, markets, irrigation systems, water supply, health and educational facilities, are basic to quality of life in rural areas, and are important facilitators of economic development (Ahmed and Donovan, 1992). Many types of infrastructure have critical roles to play in any agricultural development strategy for Africa (Cleaver, 1993). However, a detailed review of all aspects or rural infrastructure is outside the scope of this paper, so we concentrate on rural transport and irrigation systems. These are fundamental factors that influenced the success of the green revolution in Asia.[4]

[4] Although it is impossible to say that the green revolution would not have taken place in Asia and Latin America without the levels of irrigation and rural transport infrastructure that existed in those countries in the 1950's, it is true that the green revolution did not occur in countries with significantly lower levels of rural infrastructure.

Table 1 Economic and agricultural growth in Sub-Saharan Africa, 1965-1990

	1965-1973	1974-1980	1981-1985/87	1981-1991
GDP Growth:				
-SSA	5.9	2.5	0.5	2.1
-HST	5.5	2.2	0.6	1.3
Agricultural Growth:				
-SSA	2.2	1.0	0.6	1.8
-HST	1.9	0.4	1.7	2.0
Population Growth:				
-SSA	2.7	2.7	3.1	3.1
-HST	2.7	2.7	3.2	3.2
GNP Per-Capita Growth:				
-SSA	2.9	0.1	-2.8	-1.2
-HST	2.6	-0.1	-2.9	-1.4

Source: Calculated from data in Cleaver (1993), World Bank (1989, 1993).

Notes: SSA = Sub-Saharan Africa
HST = Humid and sub-Humid Tropics of Africa. See Figure 1 for countries covered.

The importance of rural transport infrastructure for agricultural development has been well established (Devres Inc., 1980; Ahmed and Donovan, 1992; Platteau, 1993). Research in Asia found that in villages with better access to roads, fertilizer costs were 14 percent lower, wages were 12 percent higher and crop output was 32 percent higher (IFPRI, 1990). In Africa, rural road construction has been found to be associated with increases in agricultural production, especially in non-food export crops, expanded use of agricultural credit, increases in land values, proliferation of small shops and expansion of rural markets (Anderson et al., 1982).

The rural transport system in the HST as in most of SSA, is grossly inadequate. Table 2 shows that there are about 300,000 Km of rural roads in the HST, with an average density of 63 Km/1000 Km^2. The lowest coverage is in the Congo, with the highest in Nigeria. These densities are much lower than those in other developing countries, and lower than required, given the existing population densities in the countries.[5] The "required" density for Nigeria in Table 2 is calculated using the level achieved by India in 1950, when she had a population density roughly equal to that of Nigeria today. The requirements for the other countries in the HST are calculated using a factor equal to the ratio of their present population density to that of Nigeria. The resulting figures in Table

[5] However, they are higher than densities generally found in the West African semi-Arid tropics. Excluding the Gambia, which has a density of about 88 Km/100Km2, densities in that region range from 1 Km/100Km2 for Mali to 19 Km/100Km2 for Senegal. Rural road densities in East and Southern Africa are generally higher than in the HST, except in Kenya where there is a substantial main road network, and Zambia, where there is a significant rail network. Zimbabwe for example, has a rural road density of 219 Km/100Km2, quite comparable to densities found in Asia.

2 illustrate that to achieve a road density equivalent to that in India at the start of the green revolution, HST countries should have an average density of 388 Km/1000 Km^2, roughly six times what exists today. Densities should range from 47 in Congo to 718 in Nigeria. Another major problem with the existing network is its poor state of repairs. It is estimated that half of the rural road network in SSA requires substantial rehabilitation (Riverson et. al., 1991).

Available statistics show that only about 6 percent of the arable and permanent crop land in SSA is irrigated. This is a slight increase from the average of 5 percent in the late 1970's, and compares with an average of 25 percent for India and 47 percent for China (WRI, 1993). For the HST only 2.5 percent of the crop land is irrigated (Table 3), with all countries except Madagascar having less than 4 percent of land under irrigation. In fact the published figures for irrigated crop land in SSA and HST are worse than the above statistics indicate as they include virtually all wetlands. While 52 percent of wetland rice in India and 95 percent in China can be regarded as properly irrigated i.e. with a reasonable degree of water control, only 34 percent of wetland rice in the HST falls into the same category. The last column of Table 3 shows that the area that can be regarded as properly irrigated amounts to only about 395,000 ha in HST, with Madagascar accounting for 45 percent, and Nigeria another 33 percent of the total. Despite heavy investments over the past three decades there has been very little increase in the area of crop land under irrigation in the HST.

Table 2 Rural road network in HST countries

Country[a]	Total (Km)	Density (Km/1000 Km^2) Existing	Required[b]
Benin	4,066	36	291
Cameroon	18,000	38	168
Car	14,400	23	33
Congo	200	1	47
Cote d'Ivoire	30,224	94	258
Equatorial Guinea	450	16	103
Gabon	2,400	9	30
Ghana	4,000	17	429
Guinea	11,500	47	161
Guinea-Bissau	1,404	39	186
Liberia	3,615	33	159
Madagascar (1/2)	19,750	67	137
Mozambique (1/2)	6,725	17	135
Nigeria (3/4)	67,425	97	718
Sierra Leone	5,767	80	391
Tanzania (1/3)	20,760	66	181
Togo	4,181	73	447
Zaire	84,100	36	110
HST	298,967	63	388

Notes: [a] Figures in brackets are proportion of land area that is estimated to be in the HST.

[b] To achieve a coverage equivalent to that of India in 1950. Where population densities are less than that of India in 1950, required road densities are adjusted downwards in proportion to the present population density of the country.

ADOPTION OF IMPROVED TECHNOLOGIES

The literature is replete with references to the innovativeness of small farmers in Africa, and the fact that they have adopted new crops and improved practices over a long period of time. Recent studies have revealed high rates of return to research which has produced new technologies (Oehmke and Crawford, 1993; Sanders, 1993) and the extension systems that helped introduce the technologies to farmers (Bindlish and Evenson, 1993; Bindlish, Evenson and Gbetibouo, 1993). However, adoption of improved technologies in the HST has been piecemeal, and not on a sufficient scale to lead to increases in per capita food production during the last three decades.

Improved Varieties

Modern, high yielding varieties (MVs') of wheat and rice spearheaded the green revolution in Asia. Much effort has therefore been put into developing such varieties for African ecosystems. For example, about 30 percent of the resources of the Consultative Group on International Agricultural Research has been devoted to germplasm conservation and varietal improvement research (CGIAR, 1993). It is estimated that 60-70 percent of the area of rice, wheat and maize in developing countries as a whole is now planted to MVs (Byerlee, 1993). The most important food crops in the HST are cassava, yam, plantain, banana, maize, rice, sorghum and cowpeas. Important non-food crops are cocoa, coffee, oil palm and cotton. There is very limited documented evidence of the level of adoption of MVs for these crops in the HST. Table 4 summarizes the data available, and show that adoption rates are low in the HST. Exceptions include Nigeria where 60 percent of the

Table 3 Irrigated land in HST countries

Country[a]	Cropland Irrigated (percent)[b] 77-79	87-89	Wetlands[c] (1000 ha) 1990	Percent Lowland Irrigated[d] 1980's	Irrigation (1000 ha) 1990
Benin	0	0	6	1.4	0
Cameroon	0	0	30	14.4	4
Car			50	14.4	7
Congo	2	2	4	14.4	1
Cote d'Ivoire	1	2	64	45.0	29
Equatorial Guinea			6	14.4	1
Gabon			11	14.4	2
Ghana	0	0	8	50.0	4
Guinea	1	3	25	9.4	2
Guinea-Bissau			0	2.6	0
Liberia	1	1	2	0.0	0
Madagascar (1/2)	19	29	460	38.3	176
Mozambique (1/2)	2	4	58	14.4	8
Nigeria (3/4)	3	3	652	20.0	130
Sierra Leone	1	2	34	0.0	0
Tanzania (1/3)	2	3	50	50.0	25
Togo	0	0	7	13.1	1
Zaire	0	0	10	50.0	5
HST	2	2.5	1477	20.8	395
India	22	25	43050	52	22300
China	47	47	47837	95	45397

Notes: [a] Figures in brackets are proportion of land area in the country that is estimated to be in the HST.

[b] From World Resources Institute (1993)

[c] Reported as Area irrigated in FAO (1992). For countries with no data (CAR, Equatorial Guinea, and Gabon) the HST average percent area irrigated was used in computing the area.

[d] From IRRI (1993) and Nyanteng (1986). The HST average was used for countries for which no data were reported in the above sources (CAR, Cameroon, Equatorial Guinea, Gabon and Mozambique).

cassava area in the sub-humid zone, 35 percent of the cassava area in the humid zone, about 90 percent of the soybean area, and 75 percent of the maize area in the sub-humid zone are planted to MVs (IITA 1992, Byerlee and Heisey 1992); Sierra Leone, where 70 percent of the sweet potato area is planted to MVs (Spencer, Polson and Kaindaneh, forthcoming).[6] Where successes are being recorded with MVs in the HST, as in most of SSA except for maize in the mid-altitude and highland areas of Eastern and Southern Africa, the MVs exhibit many of the characteristics identified by Spencer (1985), Binswanger and Pingali (1988) and Matlon (1990), as necessary for successful MVs in SSA. Such varieties are easily integrated into farmers inter-cropping systems, are nutrient efficient, pest resistant, stress tolerant, and meet farmers post-harvest needs (i.e., their processing and taste characteristics are acceptable to farmers and consumers).[7]

In most of the cases with substantial adoption of MVs the varieties have been adopted without complementary inputs such as fertilizer. Without such complementary inputs, small farmers get 32-75 percent increase in yield of cassava in the humid zone of

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[6] The situation is better in the mid-altitude and highland areas of Eastern and Southern Africa, with over 50% of the area planted to the staple food crop maize, as well as a substantial proportion of the soybean area, planted to MVs (Byerlee and Heisey, 1992, Howard, Chitalu and Kalonge, 1993). However, in the Arid and semi-Arid tropics, the most extensive agro-ecological zone in Africa, the situation with regards to use of MV's is worse than in the HST (Matlon, 1990).

[7] The lack of adoption of IITA improved cassava varieties outside Nigeria in contrasts to their success in Nigeria, is a clear example of the importance of post-harvest factors in adoption of MVs, although failure of the varieties to yield substantially more than traditional varieties, is also a factor in some locations (Spencer, Polson and Kaindaneh, forthcoming).

Table 4 -Percent crop area planted to modern varieties in HST countries

	Cassava	Sweet Potato	Yam[3]	Coco Yam[3]	Plan-tain[3]	HYB Maize[2]	OPV Maize[2]	Mang-rove	Irrig Rice	IVS Rice	Upland Rice	Cow-Pea[3]	Soybean[3]
Benin			..	..	..	1.0	18.0						
Cameroon			..	..	..	1.0	43.0						
Car			..	..	..								
Congo			..	..	..								
Cote d'Ivoire	..		..	..	..	4.0	28.0						
Eq. Guinea			..	..	..								
Gabon			..	..	..								
Ghana	..		..	..	..	0.0	32.0						
Guinea			..	..	..			9.0[1]					
Guinea-Bissau			..	..	..								
Liberia			..	..	..								
Madagascar(1/2)			..	..	..								
Mozambique(1/2)			..	..	..	1.0	17.0						
Nigeria(3/4)-H	60[4]		..	..	..	..	..					..	
Nigeria-sh	35[4]		..	..	..	3	75					..	89
Nigeria-Tot			..	..	..	2	55						
Sierra Leone	18[5]	70[5]	..	..	..			21.0[1]					
Tanzania(1/3)	..		..	..	..	6.0	12.0						
Togo			..	..	..	3.0	12.0						
Zaire	..		..	..	..	14.0	8.0						

Notes: .. = zero or negligible; blank = no data
Source: [1] Adesina and Zinnah (1992); [2] Byerlee (1993); [3] IITA (1992); [4] Nweke and Spencer (forthcoming); [5] Spencer, Polson and Kaindaneh (forthcoming).

Nigeria (Nweke et al., 1988), and over a doubling of sweet potato yields in Sierra Leone (Spencer, Polson and Kaindaneh, forthcoming). Even in the case of Maize, a crop noted for its high input demands, fertilizer use by farmers who have adopted MVs is low (Byerlee and Heisey, 1992).

Agronomy and Soil Management Technologies

The biggest constraints on increased agricultural productivity in the HST are poor soil fertility and weed competition (IITA, 1988, Carr 1989). The soils are very susceptible to degradation, and there is a tendency for soil productivity to decline rapidly with repeated cultivation (Nye and Greenland, 1960, Lal, 1987, Kang, 1993). There has been virtually no small farmer adoption of improved soil and crop management technologies recommended by research and extension systems in the HST. As clearly hypothesized by Anderson (1992), most of the recommended technologies, including chemical fertilizer use, are not more profitable than existing practices, given the constrained resources of affected farmers. With the removal of fertilizer subsidies its use is becoming even less profitable, threatening to cause a reversal in gains already made.[8]

Plant Health Management Technologies

Improved weed management systems recommended by research and extension systems have been based either on chemical control or more timely hand weeding. Both

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[8] See as an example case of improved maize varieties in the Northern Guinea Savanna of Nigeria (Smith et. al. 1994)

of these practices have proved to be unprofitable under most small farm conditions.[9] Similarly, chemical methods of disease and insect control have proved to be uneconomical. However, biological control methods in which natural enemies of pests are used to control them have shown some success. For example, the cassava mealybug has been successfully controlled in the HST (Neuenschwander et. al., 1989), and a benefit-cost ratio of 149:1 was estimated for the biological control program which resulted from research by IITA and CIAT (Norgaard, 1989).

3. ANTICIPATED CONTEXT FOR ECONOMIC DEVELOPMENT IN THE NEXT 2-3 DECADES

It has been shown that the infrastructure and other conditions in HST today are very different from those in Asia, and that adoption of intensive green revolution technologies has been very low. Since research yields its major benefits in the medium to long term, research managers need to plan for the situation that is expected to exist in the future. The question that arises is whether, and to what extent we can expect the conditions that existed at the start of the green revolution in Asia and Latin America to exist in the HST within the

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[9] A recent example of the unprofitability of the recommendation of more timely weeding emerged from an experiment in farmers fields in Nigeria (Spencer, Akobundu and Oriade, forthcoming). Four 100 m^2 plots were maintained in farmers fields. One plot was kept weed free by repeatedly hand-pulling all weeds and a second was kept free of Speargrass, a noxious weed (*Imperatta cylindrica)*. In a third Speargrass was the only weed allowed to grow, and in the fourth farmers weeded in their usual way. Although the farmers weeding practice resulted in 22-42% reduction in crop yield, economic returns were the same or higher than that of the recommended practice, indicating that there was no economic benefit in adopting more intensive hand weeding practices.

next two to three decades. If we expect "Asian" conditions to exist by then, research institutions will be justified in continuing to develop green revolution type technologies. If not, new strategies should be put in place now that would lead to production of more appropriate technologies.

In this section we discuss some aspects of the physical and socio-economic landscape of the near future that is likely to significantly affect the types of technology demanded by small farmers in the HST in the next two to three decades.

LAND AVAILABILITY

The present population growth rate in the HST is about 3.2 percent per annum. Based on World Bank projections, the average growth rate for the HST between 1991 and 2000 can be estimated at 3.0 percent. The total population of the HST is thus expected to increase from 204 million to 480 million by 2025. This means that population density will increase from 58 to 131 persons per Km^2, more than the present population density in China (Table 5). Most countries will have per capita arable land that is less than that of India in the mid 1960s'. There is no doubt that available crop land per person in most of the HST will be such as to make the need for intensification of agricultural production even more urgent than it is today.

LAND TENURE

Communal land tenure systems are predominant in SSA. The relevant question that arises within the context of this paper is whether the systems will still predominate in the

HST within the next 20-30 years, and whether they will be constraining to agricultural development.

There has been no significant attempt to change land tenure systems in the HST, and there are no land registration and titling programs on the horizon. We can therefore expect the existing communal systems to continue to evolve as they have been doing in the past. There is a continuing debate as to whether the communal systems are constraining on agricultural development. Place and Hazell (1993) have provided recent empirical evidence that with few exceptions, land rights are not a significant factor in determining investments in land improvements, use of inputs, access to credit, or the productivity of land. We can therefore agree with Cohen (1980), Boserup (1981), and others, who argue that traditional land tenure systems in SSA are dynamic, and are evolving in response to factor price changes. They should therefore not be a constraint to agricultural intensification over the next two to three decades.

CAPITAL SUPPLY

For output to grow at 4-6 percent a year, it has been estimated that SSA will need to raise investment from about 15 percent of GDP, where it was in the late 1980s, to about 25 percent (World Bank, 1989). Total expenditure on human resource development should expand to 8-10 percent of GDP annually, double present levels. Infrastructure spending should rise to about 6 percent of GDP. The bulk of expenditure in productive sectors (estimated at 4 percent of GDP for agriculture and 3 percent for industry) should come from private sources. Net transfers from foreign sources amounting to 9 percent of GDP

Table 5 Population projections for HST countries

Country[a]	Population (Millions)			Population Density (Persons/Km^2)		
	1991	2000	2025	1991	2000	2025
Benin	4.9	6.0	11.0	43	53	97
Cameroon	11.9	16.0	29.0	25	34	61
Car	3.1	4.0	7.0	5	6	11
Congo	2.4	3.0	6.0	7	9	18
Cote d'Ivoire	12.4	17.0	32.0	39	53	99
Equatorial Guinea	0.4	1.0	1.0	15	36	36
Gabon	1.2	2.0	3.0	4	7	11
Ghana	15.3	20.0	36.0	64	84	151
Guinea	5.9	8.0	14.0	24	33	57
Guinea-Bissau	1.0	1.0	2.0	28	28	56
Liberia	2.6	3.0	6.0	24	27	54
Madagascar (1/2)	6.0	7.5	13.0	20	26	44
Mozambique (1/2)	8.1	10.5	21.5	20	26	54
Nigeria (3/4)	74.3	96.0	162.8	107	139	235
Sierra Leone	4.2	5.0	10.0	58	69	139
Tanzania (1/3)	8.5	11.0	19.7	27	35	63
Togo	3.8	5.0	9.0	67	88	158
Zaire	38.6	49.0	97.0	16	21	41
HST	204.6	265.0	480.0	58	75	131
India	866.5	1017.0	1365.0	264	309	415
China	1149.5	1290.0	1569.0	120	135	164

Source: Calculated from World Bank (1993).

Notes: [a] Figures in brackets are proportion of land area in the country that is estimated to be in the HST.

will be required between now and 2020. For the external resource requirements of SSA to be met, the World Bank says that donors would need to increase ODA during the 1990s at about 4 percent a year in real terms, put in place debt relief mechanisms so that annual debt service payments are at most no greater $9 billion for all of SSA, leading to a gross ODA requirement of $22 billion a year in 1990 prices.

It is beyond the scope of this paper to analyze in detail, the feasibility of achieving these targets.[10] They are provided simply as a basis for comparing the magnitude of the investment needed to create the infrastructure and other conditions for adoption of green revolution technology in the HST with the likely supply of capital.

IMPROVEMENT IN INFRASTRUCTURE

The green revolution in Asia was fueled by the adoption of high yielding, fertilizer responsive varieties of rice and wheat on irrigated lands. Many analysts have therefore postulated that adequate irrigation, and rural infrastructure, especially rural roads, are necessary for economic development in SSA. The question that arises is the level of investment in infrastructure that will be necessary in HST countries to create conditions that will make it possible to use green revolution technologies, and the chances of the countries making the required investment within the next 20-30 years.

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[10] However, it should be pointed out that since the World Bank published its strategy in 1989, SSA countries and donors have not come close to meeting the targets.

Cost of Expanding Irrigation

The failure of large as well as small scale irrigation schemes in Africa are legendary, both in colonial days (Eicher, 1993; de-Wilde, 1967), and more recently (Adams and Grove, 1984; Spencer, 1991; Cleaver, 1993). However, because of projected reduction in per capita land availability, and the expected high yields from irrigated lands, most agricultural development strategies for SSA place much emphasis on irrigation.[11]

Table 6 shows what it would cost each of the countries in HST to reach the present level of irrigation coverage in India by 2020. HST counties would need to spend about $3 billion annually between now and 2020, i.e., about 4 percent of 1991 GDP each year on development of new irrigation systems to reach India's present level by 2020. To reach China's present level they would need to spend $10.8 billion, or 18 percent of GDP annually. Almost double the total amount of ODA currently received in the HST for all sectors each year, would need to be allocated only to irrigation to reach the India level, and almost 7 times as much as current amounts received to reach the level in China. Annual investment needed to reach the level of coverage in India range for -7 percent of GDP for Madagascar which already has a level of coverage greater than that in India, to 13 percent of GDP for Sierra Leone.[12]

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[11] For example, Binswanger and Pingali (1988) state "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".

[12] It should be stressed that the calculations in Table 6 assume that the average cost of irrigation in SSA will drop to that of India ($3,500 per ha). If we use the present cost of about $12,000 per ha. annual capital cost rise to about $10 billion, or 15% of 1991 GDP for the India level, and $37 billion or 60% of 1991 GDP for the China level! Also, the figures do not include cost of operating and maintaining the systems, once they are in place.

Table 6 Capital investment in irrigation needed to achieve a level of coverage by 2020, that would be equivalent to the level in India in 1991.

Country[a]	Target (1000 Ha)	Investment[b] ($ m)	Annuity[c] ($m)	Annuity As Percent of[d]: Gdp	Export	Govt. Exp	ODA
Benin	242	847	107	6	104	28	42
Cameroon	907	3175	400	3	20	15	80
Car	254	889	112	9	84	34	64
Congo	20	70	9	0	1	1	7
Cote d'ivoire	409	1432	180	2	6	8	28
Equatorial Guinea	29	102	13	9	64	41	30
Gabon	57	200	25	1	1	1	18
Ghana	350	1225	154	2	16	17	21
Guinea	81	284	36	1	10	5	10
Guinea-Bissau	44	154	19	9	69	15	19
Liberia	47	165	21	2	5	8	31
Madagascar (1/2)	-208	-728	-92	-7	-53	-46	-42
Mozambique (1/2)	161	564	71	12	158	78	15
Nigeria (3/4)	2558	8953	1127	4	9	16	430
Sierra Leone	215	753	95	13	65	130	90
Tanzania (1/3)	175	613	77	10	59	50	21
Togo	187	655	82	5	28	12	40
Zaire	1016	3556	448	5	28	28	73
HST	6544	22909	2884	4	25	22	184

Notes: [a] Figures in brackets are proportion of land area that is estimated to be in the HST.
[b] Capital cost of developing new irrigated area, at the Asia average cost of $3,500 per ha.
[c] Annual capital expenditure using a discount rate of 12.0 percent.
[d] Annual capital expenditure as percent 1991 GDP, etc.

Cost of Increasing the Coverage of Rural Roads

Green revolution technology evaluated earlier needs an effective rural transport system for input and output markets to function efficiently. For example, fertilizer, insecticides and herbicides need to be brought in and crops and livestock products sent to domestic and export markets. As indicated earlier, rural road densities in HST countries are well below those in Asia at the start of the green revolution. Table 7 shows that the investment needed in each HST country between now and 2020 to bring rural road densities to the level that existed in India in the 1950s,[13] using an average construction cost equal to the estimated replacement value of $50,000 per Km (Heggie, 1992). About 210,000 Km of new rural roads need to be constructed at an estimated cost of $ 53.5 billion. This means that HST countries would need to invest $ 6.7 billion annually, using a discount rate of 12 percent, equivalent to 12 percent of 1991 GDP, 73 percent of annual export earnings, 62 percent of annual government expenditures, or four times the amount of ODA received annually.[14]

How feasible are the investments above? First we note that even if the necessary finance could be obtained, it would not be possible to bring as much land as required under irrigation because the amount of irrigable land is not physically available. For

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[13] Recall that these desired densities are computed by adjusting the level of coverage in India in 1950 (730 Km/1000 Km_2, with a population density of 109 persons/Km^2), for the 1991 population density of the country.

[14] As in the case of needed investment in irrigation the calculations do not include the capital cost needed to rehabilitate the existing network, or to maintain the whole system.

Table 7 Capital investment in rural roads needed to achieve a level of coverage by 2020, that would be equivalent to the level in India in 1950.[b]

Country[a]	New Roads	Investment ($m)		Annual Cost as Percent:			
	(Km)	Total	Annual	GDP	Export	Govt.	
ODA							
Benin	28764	1438	181	10	176	47	71
Cameroon	61730	3087	389	3	19	15	78
Car	6370	319	40	3	30	12	23
Congo	15880	794	100	3	7	6	75
Cote d'Ivoire	52856	2643	333	5	11	15	53
Equatorial Guinea	2431	122	15	10	77	49	36
Gabon	5640	282	36	1	1	2	25
Ghana	98510	4926	620	10	63	69	86
Guinea	28030	1402	176	6	47	24	48
Guinea-Bissau	5296	265	33	16	119	25	33
Liberia	14073	704	89	8	23	34	132
Madagascar (1/2)	20450	1023	129	10	75	65	59
Mozambique (1/2)	47210	2361	297	49	660	327	65
Nigeria (3/4)	430050	21503	2707	11	22	38	1033
Sierra Leone	22373	1119	141	19	97	193	134
Tanzania (1/3)	36190	1810	228	31	174	147	63
Togo	21279	1064	134	8	46	20	66
Zaire	174721	8736	1100	12	69	70	179
HST	210056	53593	6748	12	73	62	440

Notes: [a] Figures in brackets are proportion of land area that is estimated to be in the HST.
[b] Investment cost estimated at $50,000 per Km - the replacement value of rural roads reported by Heggie (1992).

example, the total irrigable land in Nigeria has been estimated at between 1.6 and 1.9 million hectares (Cleaver, 1993), while area to be irrigated is 2.6 million hectares. Second, the total investment required, even just for rural roads, amounting to an average of about 12 percent of GDP, and ranging between 1 and 49 percent of GDP annually over the next three decades is double the 6 percent of GDP which the World Bank has set as the target rate of investment for all infrastructure in SSA. It is obvious that HST countries will not be able to provide the investment that would create a rural road network by 2020, that would be equivalent to the coverage that India had in the late 1950s', let alone meet the investment requirements to put a similar level of irrigation systems in place.

4. TECHNOLOGIES NEEDED IN THE NEXT 2-3 DECADES

It has been shown above that the infrastructure conditions that ensured the success of the green revolution in Asia do not exist, and are not likely to exist in the HST within the next two decades. Attempts to introduce input intensive, infrastructure dependent, irrigation based green revolution technologies into Africa have generally met with failures.

On the other hand population growth in the HST is expected to result in per capita land availability similar to those in Asia in the first quarter of the next century, and agricultural production must rise at an aggregate rate of at least 5 percent per annum if minimal economic growth and poverty alleviation targets are to be met. With this scenario, we can lay out some of the essential characteristics that agricultural production technologies must have if they are to serve the needs of the HST during over the next two decades.

a) Intensive production systems are needed. However, such systems must also result in significant increases in seasonal labor productivity, because there is evidence that this is the principal scarce factor of production in the HST, although it will become less so as population densities increase. The systems must be profitable given constrained resources of the small farmers, including the riskiness of the technologies.

b) New technologies must rely minimally on purchased inputs that are heavily dependent on rural transport infrastructure. Cropping systems need to rely heavily on internal sources of inputs for soil fertility maintenance and enhancement, such as nitrogen-fixing and mycorrhiza associations and crop residue use. Low doses of chemical fertilizers will be much more profitable under such conditions. Of course, where adequate rural transport infrastructure is in place high-purchased-input technology can be used. However, there is considerable doubt that such technology will pass the profitability considerations mentioned above, except in the case of high value export crops. Furthermore, exploitation of such pockets of adequate infrastructure, the so called high potential zones, is not likely to yield the aggregate agricultural growth rates required, let alone satisfy the income distribution, social welfare and poverty alleviation needs of HST countries.

c) Because of declining land-labor ratios and the resulting pressures on the natural resource base and because of the tendency of HST soils to degrade very fast under intensive cultivation, new production systems must not only be productive, they must be sustainable, i.e., they must not degrade the natural resource on which they depend. The following factors have been enumerated as necessary for sustainable food crop production in the HST (IITA, 1988):

- The soil must be kept covered at all times by crops or vegetative mulch
- Organic matter must be maintained in the topsoil
- Soil compaction must be prevented or corrected preferably by biological rather than mechanical means
- Deep and shallow rooted crop species should be intercropped
- Fertilizer should be used judiciously so as not to worsen the already tenuous soil nutrient balance
- Integrated pest management systems should be used, in particular biological control systems for, and vegetation management systems for weeds.

d) Concentration should be on rainfed systems, since sufficient irrigated land is not likely to be available to allow widespread reliance on them. In this context rainfed systems are defined to include improved inland valley systems with little or no water control, in which dryland crops are grown either as intercrops or sequentially with wetland crops such as rice.

e) Input efficient modern crop varieties are needed that are disease and pest resistant as well as stress tolerant. They must fit easily into the farmers intercropping systems which should be maintained to assure sustainability of the systems. MVs must meet local post harvest requirements in terms of taste and cooking qualities, so that they can satisfy farmers household as well as any domestic urban market or export needs. Furthermore such varieties, must be infrastructure efficient, i.e., they should not require services such as modern and specialized storage or seed multiplication systems, which will be out of the reach of most countries in the next two decades.

5. DEVELOPING APPROPRIATE TECHNOLOGIES

Are research institutions serving the HST producing an adequate stream of technologies that meet the characteristics above?. In reviewing the situation relating to the availability of MVs for food crops in the HST, Carr (1989) concludes that there are new releases of cassava varieties available that may offer farmers improved yields in situations in which disease is a constraint and short-duration cassava varieties are needed. MVs exist for the limited area of irrigated rice. No MVs exist for yam or upland rice, and hardly any exist for lowland rainfed rice or for maize grown as a secondary crop in other mixtures as a source of green cobs. For maize grown as the sole or principal crop in a mixture as a source of dry grain, MVs (hybrids and open pollinated varieties) exist, but must be accompanied by moderate to high doses of fertilizer. A number of sorghum MVs exist which might offer some advantage for farmers who want to produce grain for flour and who have above average soil conditions. For groundnuts, rosette resistant MVs exist, but nothing is available for the more important leaf rust disease. Carr also clearly highlights the general failure of World Bank projects to introduce MVs to small farmers, with the exception of maize in the sub-humid zone. Carr identified very few soil and crop management technologies that could be considered as appropriate and adoptable by small farmers in the HST.

More recently a group consisting mainly of African scientists examined whether there currently exists an important stock of appropriate technologies which are under-utilized due to policy and technology transfer constraints (Goldman and Block, 1993). For the HST, the group identified the following commodities for which there exists under-utilized MVs: cassava (capable of increasing production by 50 percent on 50 percent of currently planted area), sweet potato, oil palm, cocoa, coffee, and rice (for irrigated and mangrove environments). They expect that MVs should be available within five years for plantain and rice (upland and inland valley ecosystems). No improved MVs were identified for yam or maize and none were expected within five years. Appropriate improved breeds of livestock are not available either. The group stated that although MVs are available for maize and sorghum in the sub-humid zone, their superior performance is dependent on high input levels which are not sustainable. They identified no resource and commodity management technology for the humid zone. Alley cropping systems based on maize cropping were he only potential new technology regarded as available and adapted for the sub-humid zone, particularly on sloping land with degraded soils. The group recommended that much greater emphasis needs to be placed on resource management research relative to commodity improvement research.

In order to meet the demands for agricultural development over the next two to three decades, increased attention needs to be given to producing technologies that meet the characteristics enumerated in this paper. Are adequate research institutions in place, are physical and human resources adequate, are research agendas correctly focused, and are research methodologies adequate to produce these technologies? These are all questions that need to be addressed now, if the stream of appropriate technologies is to be increased.

Available statistics show that agricultural research personnel in SSA increased by an average of 6.8 percent annually between the early 1960's and late 1980's, while agricultural research expenditures increased annually by 4.7 percent during the same period (Anderson, Pardey and Roseboom, 1994). However, the growth rates have slowed down significantly in recent years. More importantly there has been a decrease in expenditure per researcher. Although the decline is partly due to a substitution of less expensive national researchers for expatriates, it also reflects a decline in the operational budget available to researchers in NARS, thus decreasing their ability to carry out the necessary research. Also, only about 0.5 percent of agricultural GDP is invested in agricultural research in the region, compared to a global average of 0.7 percent and 2 percent in more-developed countries. This proportion needs to be increased if research systems are to have the necessaryoperational funds to meet the challenges they face.[15] Adequate funding for NARS in SSA in the future will not on its own guarantee that they will develop the technologies needed for sustained agricultural growth in the near future. NARS must carefully choose

[15] Since operational funds, rather than staff strength is the greater problem faced by most NARS in SSA, it might be appropriate to put a moratorium on hiring of new staff until funding rises to the level that existing research staff are able to carry out their tasks efficiently.

the set of issues on which they will concentrate their scarce resources. Smaller systems particularly need to enhance their capacity to borrow and adapt technologies from neighboring countries and the international research community.

6. CONCLUSION

Over the last three decades the rate of agricultural growth in SSA has not kept pace with population growth. In order to achieve a respectable rate of economic growth, provide food security and reduce poverty, the agricultural growth rate must be significantly increased in the future. Because of finite land resources and expected high population growth rates, land-labor ratios are expected to decline by 2020 to levels currently found in Asia. Consequently, intensified systems of production will be increasingly required. The question that arises for technology generation and transfer institutions, is whether the conditions that existed in Asia in the mid 1950s and early 1960s, at the start of the green revolution will exist soon in SSA, thus allowing the high input, irrigation based, infrastructure dependent technology that fueled the green revolution to be widely used in the future, even though not successfully used in the past. The question is relevant since many research institutions catering to the needs of SSA are geared up to produce such technology.

In this paper it has been shown that the investment costs of putting in place by 2020 the irrigation and rural road systems that existed in India at the start of the green revolution, are almost certainly beyond the capacity of the HST countries. They will, therefore, be forced to rely on a different type of intensified agricultural technology to fuel agricultural development. The basic characteristics of such technology include input and infrastructure efficiency, high returns to seasonal labor and sustainability. While some of these characteristics have been identified by other authors, the feeling that somehow things will change and available green revolution technologies can be used in the near future has persisted. It is now indispensable the we put this dream to sleep.

A review of presently available technology shows that the stock of technologies that meet the characteristics enumerated in this paper, is inadequate to meet the demands for agricultural development in the next 10-20 years. Increased attention therefore needs to be given to producing the desired technologies.

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