AFRICAN DEVELOPMENT BANK

ECONOMIC RESEARCH PAPERS

N° 72

Technology Transfer for Agriculture Growth in Africa

by

Sami Zaki Moussa
Operations Complex
Agriculture and Rural Development Department
Central and West Region

ECONOMIC RESEARCH PAPERS

N^{O} 72
(March 2002)

Technology Transfer for Agricultural Growth in Africa

by

Sami Zaki Moussa
Operations Complex
Agriculture and Rural Development Department
Central and West Region

Abstract

This paper searches for the most effective technology for agricultural growth in Africa on the basis of FAO data available during the last forty years. The paper discusses the challenges for agricultural growth and evaluates the development assistance that was made by donors to the agricultural sector in Africa in comparison to the sector's performance and its growth during the last two decades. An analysis of the total versus per capita food production is conducted in relation to food exports and imports to identify the magnitude of the food problem in Africa and raise awareness of its future trend in the search for practical solutions.

The paper analyses five major variables of food production to explain the poor performance of the agricultural sector and concludes on the most effective factor to accelerate food supply as a mean to poverty reduction in Africa. In addition to the graphical analysis, a simple ordinary least squares (OLS) model is used to estimate an African food production and explain some of the divergences. Further, an alternate specification uses only three variables in a logarithmic model to confirm results obtained from the graphical analysis and the OLS model. The variables included in the analysis are land expansion, irrigation, mechanization, high yielding varieties, and fertilizers.

The findings of the study suggest that the most effective production factors for increasing food supply and reducing poverty are the use of high yielding varieties and improved seeds along with the application of appropriate fertilizers. Since high yielding varieties are produced by the agricultural research services, the paper looks more deeply into biological gradients and the yield potential impact through the African experience. The findings show that HYV seeds and fertilizers would increase cereal production by 75 percent with appropriate extension. The study examines other evidence from agricultural research in Africa and concludes that the field ex-post rate of return for the application of agricultural technologies in most of the cereals reaches 97 and 87 percent.

Having shown that biotechnology is the only effective technique for future food supply growth, attention is given to the African capacity of agricultural research and technology. The paper examines the ingredients of research and its efficiency and sustainability. Further, the paper developed and proposed an analytical technique using a capacity compound factor (research return and researchers intensity) to categorize African countries into four groups based on their AgGDP, research expenditure, number of researchers and population in each country. This identifies the need to strengthen the existing research institutions and establish a systematic improved seed production and distribution system in the African countries strengthened by rural infrastructure and marketing development.

For poverty to be reduced in Africa, the paper provides several scientific evidences that biotechnology is the only way for boost food supply surplus. Poverty in Africa can be significantly and sustainably reduced in a short period of time through intensive support to the usage of improved seeds, tissue culturing and micro-propagation along with self-reliance in the production of fertilizers. In this respect, the paper proposed a four-component strategy for rural development and poverty reduction in Africa. The four components are i) capacity building for technology transfer; ii) rural infrastructure for improved linkage to markets; iii) promotion of private sector for pre and post-harvest commercial activities; and iv) rural micro-finance for accessibility to farm inputs.

Résumé

Le présent document examine la technologie la plus efficace pour assurer la croissance agricole en Afrique, sur la base des données recueillies ces quarante dernières années par la FAO. Ce document analyse les défis qui se posent à la croissance agricole et évalue l'assistance au développement apportée par les donateurs au secteur agricole africain, par rapport à la performance du secteur et à sa croissance au cours des deux dernières décennies. L'analyse de la production vivrière totale comparée à la production par habitant est faite par rapport aux exportations et aux importations de denrées alimentaires, pour cerner l'ampleur du problème alimentaire en Afrique et susciter une prise de conscience de son évolution future alors que des solutions pratiques sont recherchées.

Ce document analyse cinq grandes variables de la production vivrière pour expliquer la performance médiocre du secteur agricole et conclut en présentant le facteur le plus déterminant pour accélérer la production vivrière comme instrument de lutte contre la pauvreté en Afrique. Outre l'analyse graphique, une méthode classique des moindres carrés est utilisée pour estimer la production vivrière africaine et expliquer certaines divergences. Ensuite, une autre spécification utilise uniquement trois variables dans un modèle logarithmique, pour confirmer les conclusions de l'analyse graphique et de la méthode classique des moindres carrés. Les variables introduites dans l'analyse sont l'expansion des terres, l'irrigation, la mécanisation, les variétés à haut rendement et les engrais.

Les conclusions de l'étude portent à croire que les facteurs de production les plus efficaces pour accroître les disponibilités alimentaires et réduire la pauvreté sont l'utilisation de variétés à haut rendement et de semences améliorées, ainsi que l'épandage d'engrais appropriés. Compte tenu du fait que les variétés à haut rendement sont produites par les services de recherche agricole, ce document procède à un examen plus approfondi des gradients biologiques et de l'incidence du potentiel de rendement, en se basant sur l'expérience du continent africain. Il ressort des conclusions que les semences de variétés à haut rendement et les engrais devraient faire augmenter la production céréalière de 75 pour cent si leur utilisation est bien vulgarisée. L'étude examine d'autres éléments probants de la recherche agricole en Afrique et conclut que le taux de rentabilité ex-post sur le terrain de l'application des technologies agricoles atteint 97 et 87 pour cent pour la plupart des céréales.

Ayant démontré que la biotechnologie est la seule technique efficace pour augmenter la production vivrière à l'avenir, ce document examine les capacités africaines de recherche et de technologie agricoles. Il analyse les éléments de la recherche, son efficacité et sa durabilité. Puis, il élabore et propose une technique analytique utilisant un facteur composé de capacité (rendement de la recherche et intensité des chercheurs) pour classer les pays africains dans quatre groupes, sur la base du PIB agricole, des dépenses de recherche, du nombre de chercheurs et de la population de chaque pays. Il en ressort la nécessité de renforcer les institutions de recherche existantes et de créer un réseau de production et de distribution systématique de semences améliorées dans les pays africains, appuyé par le développement de l'infrastructure rurale et de la commercialisation.

Pour réduire la pauvreté en Afrique, ce document présente plusieurs preuves scientifiques du fait que la biotechnologie est le seul moyen de stimuler la production alimentaire et de générer des surplus. En Afrique, il est possible de réduire la pauvreté de manière très sensible et durable en un court laps de temps. Pour cela, l'utilisation de semences améliorées, la culture tissulaire, le micro-bouturage et l'autosuffisance dans la production d'engrais, doivent bénéficier d'un soutien intensif. À cet égard, ce document a proposé une stratégie africaine de développement rural et de lutte contre la pauvreté à quatre volets. Il s'agit des quatre composantes suivantes : i) le renforcement des capacités de transfert technologique ; ii) une infrastructure rurale pour faciliter la liaison avec les marchés ; iii) la promotion du secteur privé dans le domaine des activités commerciales avant et après la récolte ; et iv) l'accès au micro-financement rural pour l'acquisition d'intrants agricoles.

Technology Transfer for Agricultural Growth in Africa

by

Sami Zaki Moussa*

Introduction

As the 20th century rolled into the 21st century, the moment has come to step back from regular daily problems and think how agriculture sector growth in the African countries could be accelerated. How could poverty be significantly reduced in shorter time frame at least cost? If the world economy is growing and technological means are available, why are the African countries still experiencing poor economic performance and widespread poverty?

Billions of dollars have been invested in Africa to develop and stimulate the growth of the agriculture sector during the past three decades. Yet it is widely recognized that little was achieved in motivating agricultural sector growth in spite of the large volume of investment in Africa. Weak institutions and internal economic policies are usually blamed for the poor performance. However, there is an increasing observation that the form in which international assistance provided is considered partially responsible for the poor economic performance.

Over the past several decades, the rate of growth in world food production has exceeded the population growth rate except in Sub-Saharan Africa. Further, during the last three decades, the average per capita food consumption increased for all developing regions except Sub-Saharan Africa. With its second highest rate of increase in cereal imports, Sub-Saharan Africa will face the greatest challenge in meeting food demand in the next decade. Net food import to Sub-Saharan Africa could increase by as much as 4 times by 2010. Statistics also indicate that expected change in food supply, demand and prices are very sensitive to small changes in population and / or yield growth rates. World food prices may increase by 40-70 percent as a result of a 20 percent decline in the growth rate of the yield per hectare.

Scarcity of financial resources with increasing net food imports and world food prices raises concerns of poverty outlook in African countries. Financing the expected increase in the cereal imports by the developing countries will depend mainly on their export earnings and on food aid. On one hand, the export earnings depend on international market prices and the rate of economic growth of the developed countries and, on the other hand, food aid depends on the surplus of food production and the competing demands for the development assistance among developing countries in the world. However, food aid as well as financing food imports neither lead to development nor reduce poverty. This signifies the vitality of agriculture development as the only option for Africa in order to achieve food security, reduce poverty and improve the quality of life of its population.

---

*The author is a Division Manager, Agriculture and Rural Development Department, Central and West Region. The author wishes to acknowledge the valuable comments received from Mr. P.M. Kaindaneh, Economist, Mr. Sam Onwona, Chief Agricultural Economist, and Mr. John Kanyarubona, Principal Economist.

The three factors likely to contribute to future increase in food supply in African countries are expansion of land under cultivation, irrigation intensive projects, and biotechnological increase in yield. The size of land currently under cultivation in Africa for all agricultural crops is about 76.1 million hectares. Potential land for crop production under rain-fed but not in agricultural use, is more than twice the current harvested land. However, future food supply increase will come from neither land expansion nor from irrigation intensive development. To bring new lands under cultivation would entail high economic and environmental costs, as it would require heavy infrastructure development. Furthermore, new lands are facing increased competition due to human settlements, urbanization and industrialization which make it more infeasible for economic growth and accessible food supply increase.

New irrigation projects are likely to increase scarcity of water in the continent. Water will become more scarce than land. Further, increasing competition for water in non-agricultural use, would raise the costs of new irrigation projects in addition to the cost of environmental mitigation measures that are usually associated with new irrigation development projects. These factors combined will limit the possibility of increasing food supply in the developing countries and especially in Africa.

Because of the limitations and constraints of land expansion and water resources, the only promising and sound economic factor, which would lead to sustainable food production increase and thus poverty reduction, is the biotechnological increase in yield[1] . Without widespread, intensified application and accessibility of the high yielding varieties of the major crops including cereals, increased food supply and poverty reduction may not be possible in Africa.

Biotechnological food supply increase would not be sustainable in African countries without building systematic multidisciplinary strong institutions. The adoption and adaptation of the existing technology require (1) a significant upgrading and capacity building of the existing National Agricultural Research Services (NARCs) institutions in African countries as the backbone for intensified sustainable food security; (2) rural infrastructure for improved linkage to markets including storage facilities to ensure a widespread distribution system; (3) private sector promotion for rural commercial activities and (4) rural micro-finance to support accessibility to farm inputs by small-holder farmers. However, in the absence of good policy initiatives, such technology transfer initiatives would tend to dissipate.

Part One: Development Assistance and Agricultural Growth

I. The Challenges for Agricultural Growth

In Africa, agriculture is central to economic growth and the reduction of poverty. The agriculture sector accounts for 35 percent of the continents GDP and corresponds to 40 percent of its exports. About 72 percent of the people live in the rural areas and the sector supplies 70 percent of the employment opportunities. Furthermore, 70 percent of the poor people live on the rural area in the African countries. Further, about 59 percent of the rural population are living below the poverty line[2] . Thus simulating the growth of the agriculture sector would be a key to poverty reduction, food security, and self-sufficiency.

Development in Africa is characterized by some internal and external challenges. For the purpose of this paper, focus is made on the major challenges of the agricultural growth. The first challenge is to increase growth rate of food supply in African countries to exceed the population growth rate so that food security and self-sufficiency can be attained. While the population growth rate was 2.9 the cereals growth rate was –0.2 during the period 1975-84. Recently, the population growth rate decreased to 2.6 and the cereal production growth rate increased to be 1.4 during 1990s.[3] As cereal represents the major product of agricultural output, results indicate the size of a substantial gab between cereals and population continues.

The second challenge to accelerate the growth of the agriculture sector in the African countries is to foster sector adjustment and reform the agriculture policy. Without enabling macroeconomic environment, agricultural growth will not be possible. Reform of policies must include macroeconomic as well as the rural development issues. Policy reform should treat the shortcomings relating to agricultural inputs and outputs, market liberalization, privatization, role of non-government organization, micro-finance policy, exchange rates, export taxation, urban biased investment policy, etc. For example, China's remarkable annual growth rate of 9.5 percent during the 1980s and 1990s was preceded by rural and agricultural policy reforms in the late and early 1980s.

The third challenge is to make the broad sector approach work as a main operation investment-lending instrument. This approach has been known as Sector Investment Program (SIP) since it was initiated by the World Bank in 1995. The SIP is designed by the borrowing country with technical assistance from the World Bank staff and has been implemented in some African countries such as Zambia, Mozambique, and Ethiopia. The SIP program is initiated to mitigate frequent problems that are usually associated with the implementation of development projects. The program addressed among other problems, the insufficient local ownership and commitment, the lack of maintenance after initial implementation, and weakness of government capacity.

The fourth challenge for agricultural growth is to promote the private sector to work, manage and invest on a larger scale in the agricultural sector. It is well known that no more financing would be made through the public sector to rural finance, marketing, supply of farm inputs, or food processing operations. But the agriculture sector can not be developed without strong market institutions and infrastructure or without smallholder farmers' access to farm inputs as means for technology transfer and growth. Thus, the only way to offset such weaknesses is to promote private sector investment in the sector.

II. Agricultural Aid and Growth

1) Aid for Agriculture Development in Africa

During the last three decades, billions of dollars have been invested to develop the agricultural sector in Africa. Massive support for agricultural sector and policy reforms has been made to simulate agricultural growth and improve its performance during the last decade. Donors are finding that these efforts have had only limited impact. Several countries in Africa have not made much progress in policy reform, technology transfer, and human capital development. However, it is useful, at this point of time, to review the relationship between the flow of aid and the annual growth rate with adequate time lag along with the target of assistance and previous experience to explore alternatives for rural development.

Official Development Assistance (ODA), consists of concessional financial flows and technical assistance aimed to promote economic development and welfare. ODA disbursement has significant importance to the African countries. For many of the African economies, development assistance through ODA flows is equivalent to a sizeable share of GDP and to the bulk of their domestic investment. According to 1996 data, 32 countries, among the 48 African countries, the debt ratio to its GDP exceeded 50 percent and 16 countries has debt ratios less that 50 percent of GDP. Ten countries out of the 32 has debt ratios of 100 percent of GDP and 6 out of the has debt ratios exceeding 150 or more[4] .

Table 1.1: Gross Disbursements: Official Concessional, Non-Concessional and Private long-term Loans Millions of US dollars (current prices)

Years	Concessional[5]	Non-Concessional	Private	Total	Agricultural Sector[6]
1974-1984[7]	4,392	3,030	9,216	17,832	4,993
1985-1989[8]	4,494	4,457	9,873	20,992	5,878
1986	4,494	4,457	9,873	20,992	5,878
1987	5,966	4,178	9,142	20,378	5,706
1988	5,967	4,031	11,046	22,245	6,229
1989	5,798	5,244	9,313	22,000	6,160
1990	6,436	5,680	9,210	22,054	6,175
1991	6,110	5,601	8,363	21,255	5,951
1992	6,312	5,055	9,713	21,829	6,112
1993	6,397	4,420	8,425	20,389	5,709
1994	6,227	4,130	9,108	21,273	5,956
1995	6,278	3,686	8,690	22,123	6,194
1996	5,402	3,466	6,734	16,998	4,759

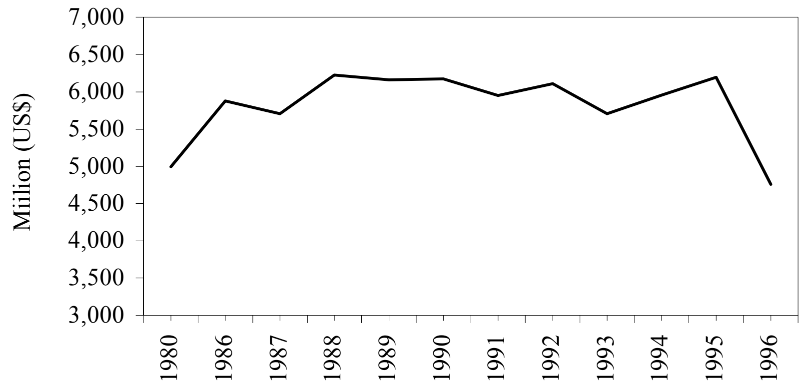
Source: Adopted from the World Bank. 1998. "African Development Indicators".

Sources of the official loans are multilateral organizations and foreign governments. These loans are either made directly to the government of the borrowing country or guaranteed by it, or its agencies, when made to a third party. Public and publicly guaranteed loans refer to loans from both official and private foreign sources that are made, or guaranteed by, the debtor government or its agencies. However, almost all loans from official sources are public or publicly guaranteed. Table 1.1 summarizes the gross disbursements official concessional, non-concessional, and private long-term loans. The average annual disbursement figure of the period 1997-84 was used as a single value for 1980 and the average annual disbursement during the period 1985-1989 was also used as a single figure for 1986 to generate a time series of 12 years.

Available ODA data does not provide a breakdown of the ODA flows as regards to the economic sectors i.e. the ODA disbursement flows for agriculture sector is not available. Thus it is estimated that about 28 percent of the gross disbursements are allocated to agriculture and agricultural related investments in Africa. Accordingly, development assistance flows into the agricultural sector are calculated in the last column of table 1.1 above.

Data of table 1.1 shows that between 1975 and 1984, the average annual ODA flows to agriculture in Africa was about 5 billion US dollars, increased to reach 5.9 billion US dollars during the period 1985 and 1989. However, during 1990 and 1995, the average annual ODA development assistance flows slightly increased to about 6.0 billion US dollars. Recently, in 1996, the ODA development assistance flows dropped to about 4.8 billion US dollars.

Figure 1.1: All Donors Development Assistance for Agricultural Sector in Africa (1980-96)



More than ever, with the economies of the African countries, apart from just a very few, showing negative growth rates or at best stagnant growth rates, ODA flows are life lines for Africa. If the decline in such assistance were to continue, there can be no hope of realizing the noble aims of Heavily Indebted Poor Countries (HIPCs) and other donor funded initiatives aimed at alleviating poverty, empowering the powerless of the working class, and generally ensuring economic development for the continent of Africa.

2) Agricultural Performance in Africa

Since the early recognition of the role that the agriculture sector can play in simulating overall economic development, focus has been on accelerating its rate of growth[5] . Steady agricultural development generates economic growth in nonagricultural sectors, which reduces poverty as well as urban unemployment rates. Most of the developed economies were supported by continuous agricultural growth. For the developing countries, the agricultural sector is still and will continue to be the engine of development and the overall economic growth. Continuos growth of the agriculture sector leads to favorable indirect impacts which can be observed in terms of generating i) development of agro-industry, which creates employment opportunities; ii) improvement of earnings of foreign currencies, and iii) reduction of food prices, which leads to better nutrition and less poverty.

However, a historical comparison of the regional economic growth in the world indicates that Africa has the poorest performance among other developing regions and during the period 1980-97. Maddison[9] (1996) presented striking evidence of Africa's poor performance. Between 1820 and 1992, Africa grew at 0.6 percent per annum, which was half the rate of world growth. A review of the agricultural growth trend shows that strongest growth in Africa was achieved between 1950 and 1970, a period of late colonial rule and early independence[10] . However, over the last

40 years agricultural growth has varied significantly. During 1960s, agriculture grew at 3 percent per annum, which was higher than the population growth rate. This was followed by a widespread slowdown growth during 1970s, where the growth declined to one percent per annum.

Table 1.2: Average Annual % Growth Rate in Real Agricultural GDP

Region	1980-90 Rate %	1990-97 Rate %
EPA[11]	4.75	3.80
MENA	4.75	3.25
S.Asia	3.20	3.00
LAC	2.15	3.00
SSA	2.20	2.60
Population % Growth	2.80	2.70

Source: World Development Indicators, 1998.

Table 1.3: Agricultural Growth in Sub-Saharan Africa (SSA)

Years	Annual Growth Rate %
1961-65	2.7
1965-70	3.5
1970-75	1.4
1975-80	0.6
1980-85	1.4
1985-90	2.3
1990-95	2.5

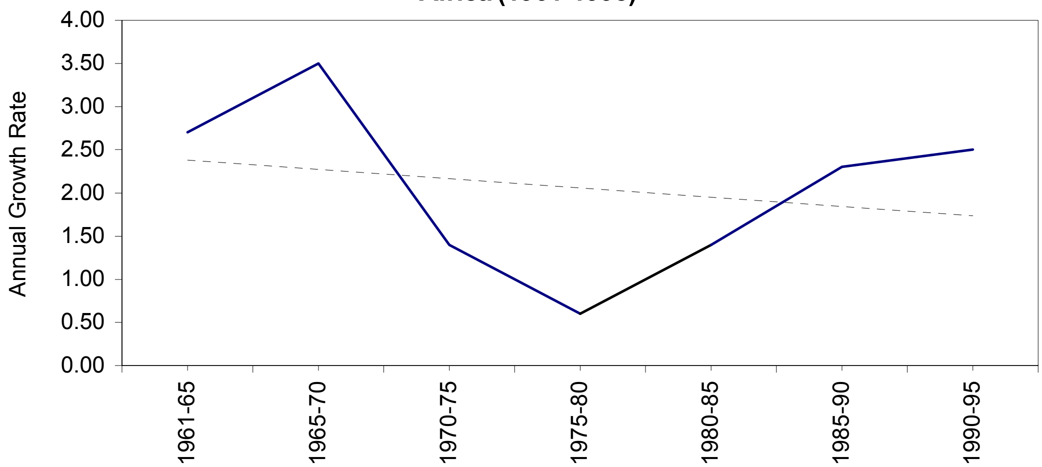
Source: FAO database.

Table 1.2 shows that while aggregate agricultural growth rate in real agricultural GDP improved in SSA during 1990s, it is still the lowest among all other developing regions. The important observation from table 1.2 is that even with the increased real agricultural GDP in SSA to reach 2.6 percent during 1990s, it is still below the present 2.7 percent annual population growth rate. This suggests that sustainable food security and poverty reduction would need intensive and collateral effort to be achieved.

Further, table 1.3 provides time series of the agricultural growth in SSA during the period 1961-65 and 1990-95. The data shows the decline of the annual growth rate to its minimal of 0.6 during 1970s and the revised increase to reach 2.5 annual growth rate during 1990-95.

In review of the Africa's real Gross Domestic Product (GDP) data[12] , it shows that during 1975-84, the Africa's real GDP was 3.3 and declined significantly to reach 2.1 and 2.0 during 1985-89 and 1990s respectively. Between 1985 and 1989, 5 countries had real negative GDP growth rates, 36 countries had GDP growth rates above 2 percent including 19 countries with GDP growth rates above 4 percent. In comparison, during 1990s, three more countries joined the negative growth rate to become 8 countries. Further, the number of countries with GDP growth rates above 2 percent decreased to 32 countries instead of 36 countries during late 1980s. Out of these 32 countries, only 11 countries had GDP growth rates above 4 percent instead of 19 countries during late 1980s[13] .

Figure 1.2: Average Agricultural Growth Rate (%) in Sub-Saharan Africa (1961-1995)



However, some encouraging indicators started to be observed during the 1990s. Between 1990 and 1997, 25 countries had real agricultural GDP growth rates over 2 percent, with 12 of theses countries having growth rates of over 4 percent. Over the last five years, 6 more countries joined this group. It is expected that this improvement in the recent years in the agricultural growth rates, would be reflected in the overall economic GDP growth rate of theses countries in the near future.

III. Evidence of the Last Forty Years

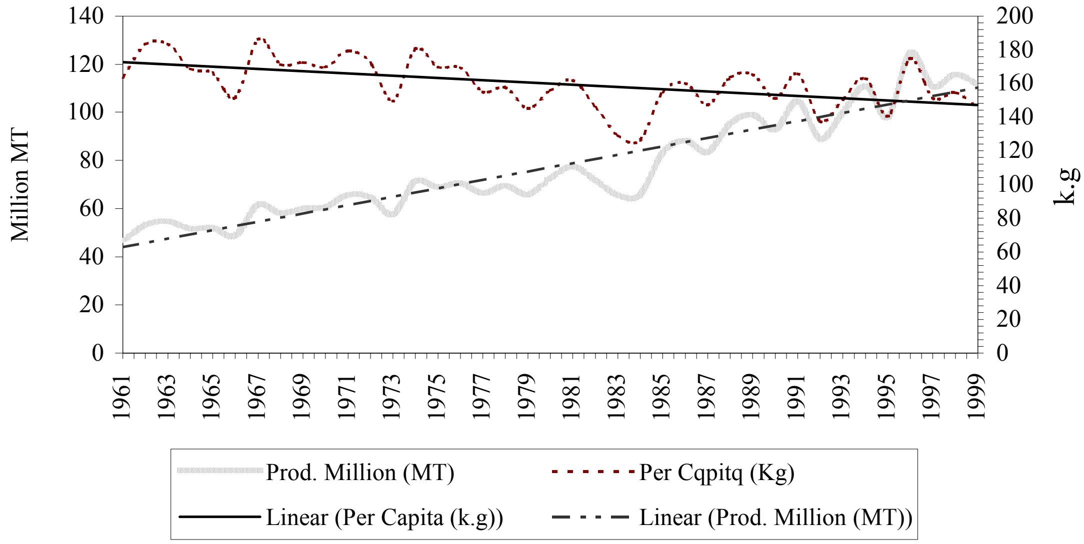
1) Cereal Production: Total versus Per Capita

While desegregation of agricultural products limits sector-wide comparison studies especially for groups of countries, the use of money term is constrained by uncertainty regarding its real value, especially for time series data analysis. Cereals are major product of agricultural outputs, it is used as a proxy for agricultural production in Africa during the last forty years to investigate the size of the gap between cereals production and population growth rate reflected in the per capita cereal production.

Per capita production of cereals has been declining over the last forty years in Africa, as illustrated in Figure 1.3. The only logical explanation for this scenario is that although cereal production has been on the increase during the entire period, it has not kept pace with the population growth rate.

This analysis provides another justification for re-energized efforts to increase food production in Africa, while at the same time continuing the efforts to develop rural infrastructure in the continent. Certainly, if the situation is not reversed then efforts such as the Heavily Indebted Poor Countries (HIPCs) initiative and others made by international organizations, in a bid to curb poverty in Africa, would not come to fruition.

Figure 1.3: Total and Per Capita Cereal Production in Africa (1961-1999)



2) *Exports and Imports of African Cereals*

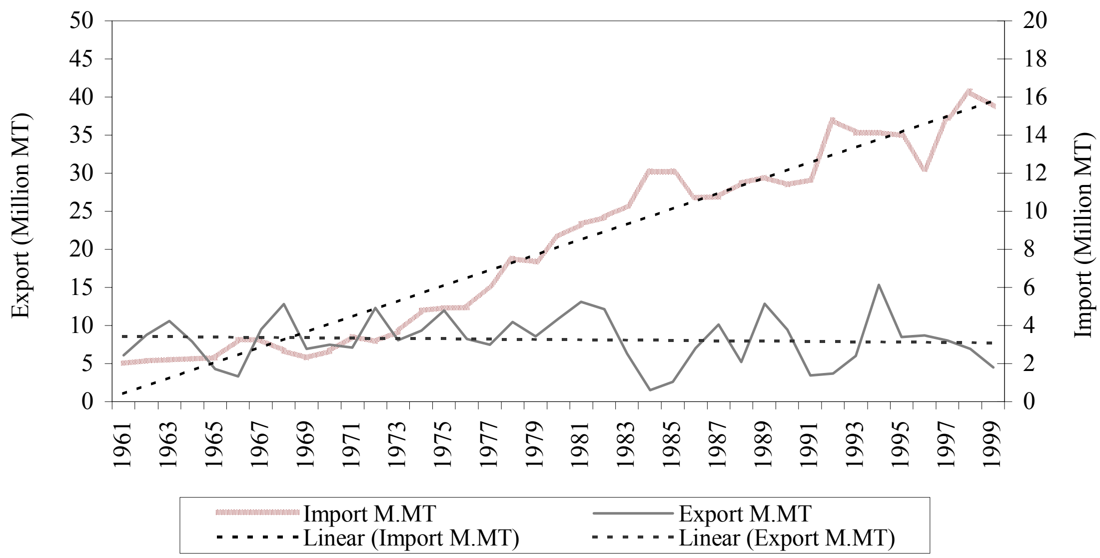
Empirical data indicate that in the early 1960s, about the time most African countries were gaining independence, the continent was not only food-self sufficient, but that cereals, which as a food group could easily be a proxy for the African staple, was being exported (Figure 1.4). Cereal importation, on the whole, remained low until the early 1970s, when it increased from an average of 6.26 million MT between 1961 and 1970 by nearly 37 percent to reach an average of 9.19 million MT in 1971. The trend continued right through the following decade, bringing the average annual import to 13.63 million MT, an increase of 120 percent over the previous decade. Cereal imports continue to increase to reach an average of 24 million MT during 1980s and 34.8 million MT during 1990-99, an average of 45 percent over the previous decade and 456 percent over the 1960s decade. During the same period, cereal exports increased, though at a rate of increase far less than that of imports. However, by 1978, cereal exports started to decline a trend that has continued to the end of the 20th century.

Figure 1.3 also shows that the per capita cereal production has been declining all through the four decades under consideration. Explanations for this phenomenon could be traced to increase in population growth rates within the continent, coupled with a decreasing return to cereal production.

Over the past four decades, the rate of growth in world food production exceeded the 00 population growth rate except in SSA. Further, during the last three decades, the average per capita food consumption increased for all developing regions except SSA. As a result, SSA became the second highest cereal importer in the world. Thus, it is expected that SSA will face the greatest challenge to meet the demand for food in the next decade. Net food imports to SSA could increase by as much as 4 times in 2010. Statistics also indicate that expected changes in food supply, demand

and prices are very sensitive to small changes in population and or yield growth rates. World food prices may increase by 40-70 percent as a result of a 20 percent decline in the growth rate of the yield per hectare.

Figure 1.4: Total African Export and Import of Cereal (1961-1999)



Scarcity of financial resources with increasing net food imports and world food prices raises concerns of poverty outlook in African countries. Financing the expected increase in the cereal imports by the developing countries will depend mainly on their export earnings and on food aid. On one hand, the export earnings depend on the international market prices and the economic growth of the developed countries and on the other hand, food aid depend on the surplus of food production and the competing demands for development assistance among developing countries in the world. However, food aid as well as financing food imports neither lead to development nor reduce poverty. This signifies the vitality of agricultural development as the only option for Africa not only to achieve food security but also to reduce poverty and improve the quality of life of its population.

Part Two: The Search for the Most Effective Technology

I. Development Factors in Literature

In the agricultural economic literature, many econometric models have been formulated to determine sources of agricultural growth. Models of agricultural production have included internal and external factors among other explanatory factors, to verify the effectiveness of development and agricultural investments. Historical review of such models show that early efforts included only land and labor as major factors for agricultural growth. Modern models however have added fertilizer and machinery inputs. Soil fertility, climate, and life expectancy were also proposed for statistical analysis as explanatory variables. In comparison to Asia, some studies suggested that animal and human diseases along with soil fertility are the main factors behind the poor performance of the agriculture sector of Africa.

More recently, researchers added to the list of explanatory variables several alternative factors such as agricultural research, marketing infrastructure (roads, transports, and communication), education and specifically agricultural technical education in addition to irrigation versus rainfall factors. Findings of agricultural growth studies suggest that civil strife, political unrest and poor economic policies played an essential role in causing the poor performance of agricultural growth in Africa. Some of the literature has focused on government intervention and price control as policy constraints that reduces the profit margins and thus prevent usage of technology. It is argued that technology transfer can not be of significant impact in Africa without strong institutional foundations.

More attention has been given to macroeconomic policies in the African countries as a consequence of the economic crises and increasing indebtedness of African countries. Several research studies examined the effect of the poor macroeconomic and price policies on the level of agricultural production of export crops and food crops. Since early 1980s, macroeconomic and agricultural policies have been highlighted as the key component to enhance agricultural growth. Macro policy reform and structural adjustment programs were used as lending instruments for agricultural development to remove production constraints. However, effectiveness of these instruments would mainly depend on the structure of such programs.

In spite of these constraints on agricultural growth, some African countries were able to achieve 12.2 cereal production growth rate during 1990s, which is much higher than that of the population. Some other African countries were able to double their cereal production during 1980-1990s from the same existing soil fertility and labor. Thus, agricultural development, under certain conditions, could be accomplished in terms of cereals and food production in Africa.

A recent World Bank agricultural sector strategy paper, Rural Development: From Vision to Action, highlights many of these issues along with the targeting of a real agricultural growth rate of at least 4 percent annually through improving technology and increased productivity (World Bank, 1997). Specific objectives are identified by the World Bank to promote the development impact: a) increase food production and farm income, b) secure households food, water and energy, and c) maintain the natural resources base. In achieving these objectives, the World Bank's agricultural strategy in Africa has identified five key elements: 1) policy regime improvement; 2) technology development and adoption; 3) rural infrastructure development; 4) rural people empowerment; and 5) natural resource management. In its rural development strategy, the World Bank emphasizes the necessity of decentralization of the public sector, gender sensitivity, popular participation, and market-oriented approach (World Bank, 1997).

II. Time-Series Data Analysis and Results

1) Major Explanatory Variables

Inputs are a subset of the explanatory variables for agricultural output growth. The performance of the major inputs or production factors is an important indicator to determine the most efficient development intervention. These inputs include land, labor, water resources, mechanization, seeds, management and fertilizers. The productivity of the major crops grown, and the subsequent production levels, are obviously affected by the level and the combination of resources used. In order to effectively determine the effect of technology transfer on agricultural growth in Africa, it is imperative that a look is taken at the trends in the aggregate use of inputs in agricultural production in Africa.

Land, as defined in this section, refers to agricultural land under cultivation for the major staple food groups in Africa - cereals, roots and tubers and pulses. The emphasis will be on food crops because of the urgent need to redress food insufficiency in Africa and the consequent poverty situation.

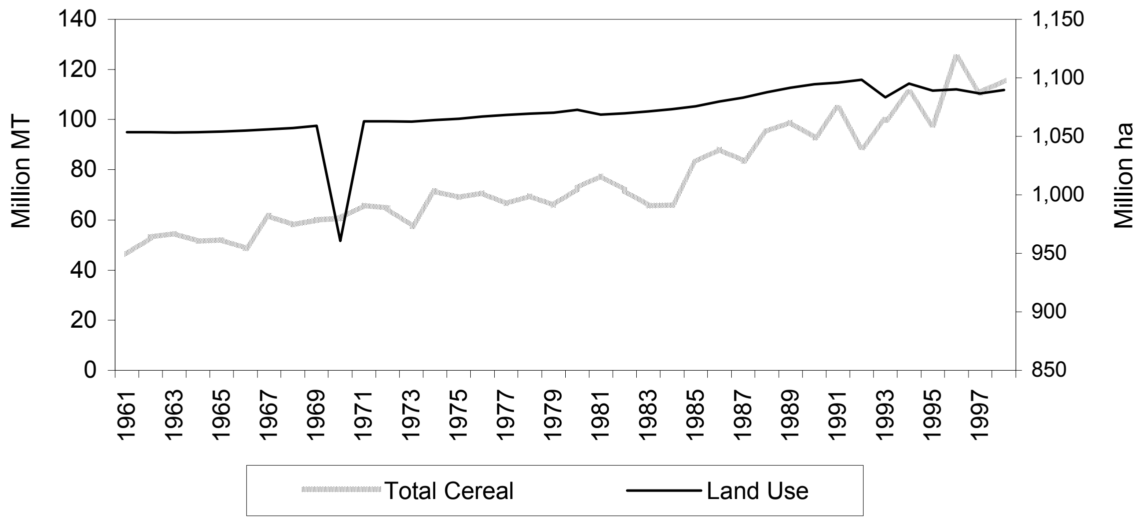
2) Land Expansion and Food Production

Agriculture production growth during 1950s and 1960s, in most of developing countries, basically relied on expanding cultivation of new land areas. Land and human labor were the principal sources of growth making the contribution of technological changes very insignificant. Over time, land for agricultural development has decreased, particularly in North Africa. Further, large areas of land are unsuitable for agriculture because of desert as in North Africa, rock outcrops, and in East Africa, steep slopes. Moreover, over relatively small areas, quality of soil widely varies and better soils are usually already under cultivation. Therefore, any expansion of cropped areas often involves a decline in productivity with lower returns to farmers.

It is important to note that cultivation cannot be maintained for more than two or three years under traditional methods of husbandry without a fallow period. This situation is due the interaction between the climate and soil in addition to the low inherent fertility of many African soils. The fallow period, which reaches 5:1 ratio, is being progressively shortened under population pressure, leading to degradation of soil fertility.

In this respect, the impact of land expansion onto the total cereal production could be seen in figure 2.1 above where the total land in use including the new land brought into cultivation has no impact onto the total cereal production in Africa. Total land in use is almost constant, or has a marginal increase, over the four decades under the study while the production of cereal is positively moving upward. This result indicates insignificant relationship, which explains the negative sign that is always attached to the land variable in several statistical models that have been tried in this study. Figure 2.1 utilized the total land in use for agriculture because it is not expected that the new expansion of land, which brought into cultivation, would be allocated into cereal production only. Furthermore, the use of the new land, which is cultivated with cereal, would not lead to a realistic conclusion. The above analysis therefore, used total land in agricultural use including cereal cultivated land and the new expanded land as an explanatory variable for the independent cereal production variable.

Figure 2.1: Land in Use and Total Cereal Production in Africa (1961-1998)



New land is being brought into cultivation at the expense of forest and range-lands. In the last two decades, in aggregate, the African forests declined by 31 million hectares which is more than four times the recorded increase in the area of arable land under permanent crops over the same period of time. It is obvious that these resources are lost for only short-term gains in arable area at the expense of the sustainability of other natural resources are likely to prove illusory. For these reasons, among other factors, only a slow expansion of the total cultivated area is foreseen in the current decade, perhaps around one per cent per year. Thus, the emphasis has shifted to raising productivity on existing land through investment in soil improvement, irrigation, infrastructure, and through technological change.[10]

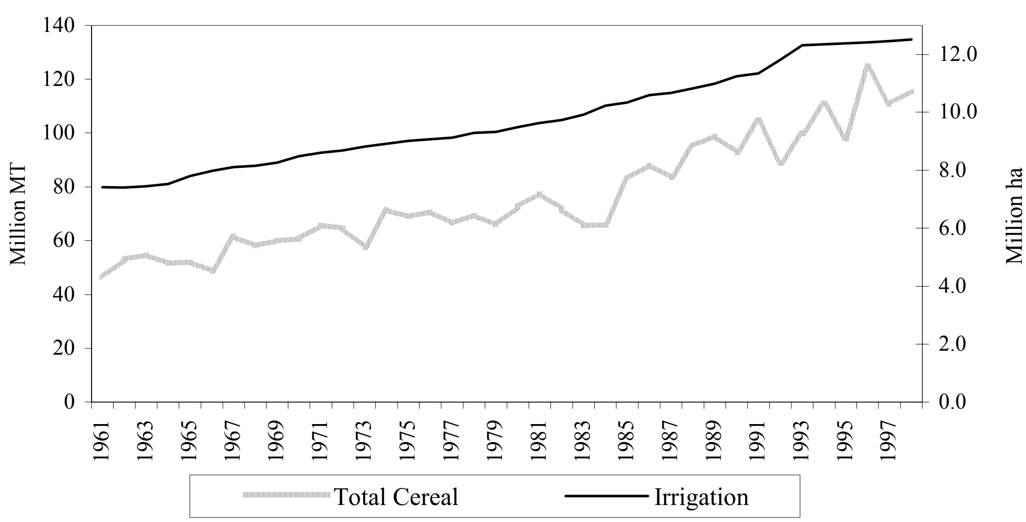
Expansion of land under cultivation has little effect on total agricultural production increase. There is general understanding that agricultural growth could be accelerated significantly without bringing more new land under cultivation. Further, expansion of new land to be economically productive is an expensive investment and in most cases the new land would never reach the economic marginal productivity. Recently, more attention is given to the environmental impact of development to ensure sustainability of development. It is recommended to best allocate and utilize the available natural recourses to increase food production but in a sustainable environmental framework. On the other hand, governments and researchers have realized that the land frontier for increased food production has been reached and other technological factors must be brought into play to sustainably increase food supply at a growth rate higher than the population growth rate.

3) Irrigation and Food Production

Cereal production in most parts of Africa, like other agricultural products, is carried out without the use of irrigation. This position is clearly illustrated in Figure 2.2, in which it is shown that even though total cereal production has increased over the last forty years, use of irrigation for agricultural products has remained virtually unchanged throughout this period, taking in consideration the graphical different scale that is used. Further, the slight increase in the trend of the irrigation variable is steady while that of cereal production is sharply fluctuated. The sizeable gap in the variances of the two factors shows that irrigation is a poor explanatory variable for cereal production. In other words, the time series graphic analysis in Figure 2.2 shows insignificant relationship between irrigation development in terms of irrigated area of land and the total cereal production during the last forty years in Africa.

On the other hand however, this analysis shows consistency with the known information that only 7 percent of African agricultural practices are using reliable water supply, out of which 5 percent is in the North West of Africa. It should be noted that the poor impact of irrigation could be attributed to its low volume at the aggregate production level. Although, this situation raises concerns of reliable food production in Africa, as irrigation reduces the production fluctuations as it is used as supplementary irrigation during the drought. Yet at a desegregated level, irrigation increases the number of harvests over one time per year, as it is common with rainfed production systems in Africa. However, due to the costly investment that is usually associated with the irrigation infrastructure in addition to other related costs for environment and health mitigation measures that African countries might not be able to contain the necessary maintenance, as irrigation development would require higher maintenance cost to insure its sustainability. Other development methods to simulate agricultural growth that could ensure the same goals, without a heavy reliance on irrigation.

Figure 2.2: Irrigated Area and Total Cereal Production in Africa (1961-1998)



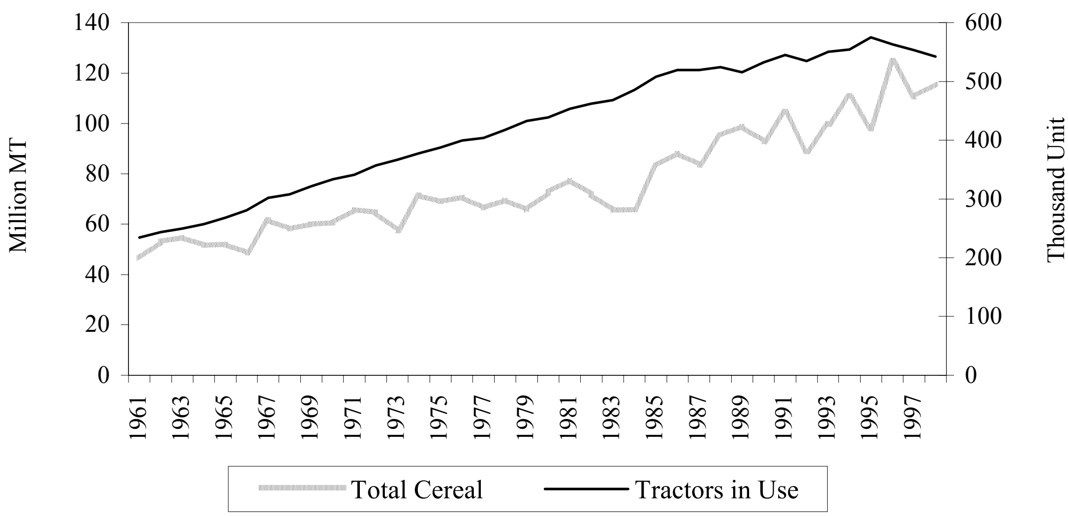
While the paper is not suggesting a cut down on irrigation development infrastructure for agricultural production, it would be sensible to search for the most effective technology for agricultural growth and rural development in Africa that would increase production, in collaboration with irrigation. In this same vein, African governments must ensure that facilities are put in place to address the downside of irrigation, so that the panacea to increased food production, does not become a cause of concern over health or the environment.

4) *Mechanization and Food Production*

Food production farming systems in Africa, especially in sub-Saharan countries, are mostly human-labor based. The use of animal draught for tilling land and transportation is gaining grounds in some of these countries. The picture of a steep increase in the number of tractors used in agricultural production in Africa could be misleading, as over 80 percent of tractor use is carried out in countries North of the Sahara with Egypt alone accounting for over 50 percent of the continent's use.

Further, taking in consideration the graphical different scales that are used in Figure 2.3, the positive upward increase in the trend of tractors in use is a unwavering while that of cereal production is sharply fluctuated. Since the variance in the tractor variable is almost minimal, this factor is insignificant explanatory variable for the cereal production. In other words, none of the shifts or the drops in the cereal production can be directly contributed to the number of tractors that was in use at the same period of the fluctuation during the last forty years.

Figure 2.3: Tractors in Use and Total Cereal Production in Africa (1961-1998)



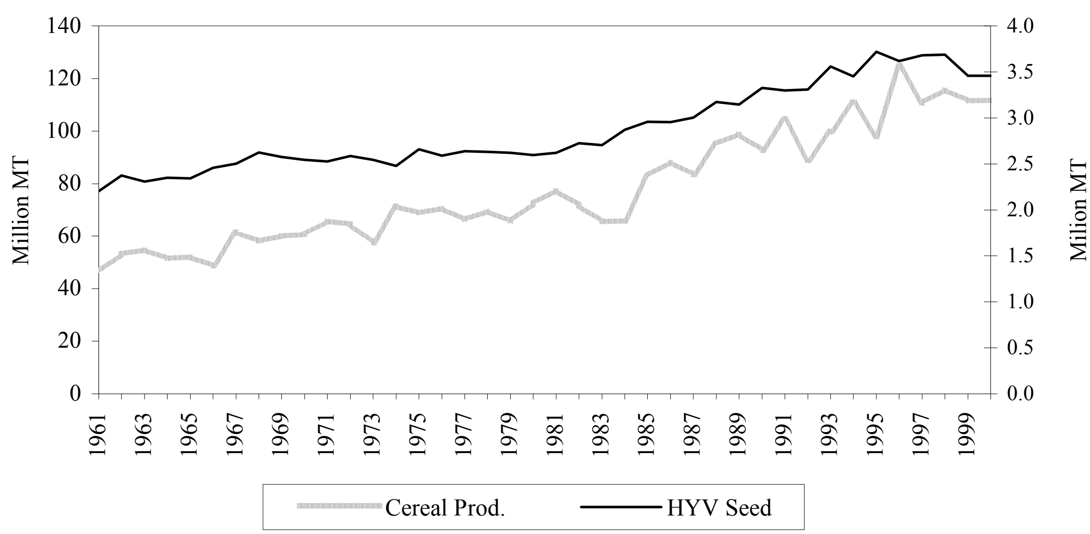
A deeper look into the time series data reflects the fact that between 1975 and 1990 the rate of growth of cereal production was very marginal, or even decreasing, while that of tractors in use was at a much higher rate. This fact could be simply explain that the use of tractors for cereal production in Africa, as a continent, was not a momentous factor for agricultural growth in Africa during the last 40 years. As the majority of the population in African countries lives in the rural areas and it would be the case for the coming 20 years, tractors and as well as other small mechanization tools would not be significant for food supply increase in the near future.

5) *High Yielding Varieties of Cereals*

During the last four decades Africa has experienced a decline in its overall development on a scale that is unprecedented. The irony is that while the rest of the world has taken quantum steps in technological advances in practically all aspects of development, there are hardly any indications that Africa has benefited from these advances. The natural reaction by Africa would have been to take advantage of this global outlet of technologies and pattern its development efforts around it. The continent, in more ways than one, has been spared the re-invention of the wheel, but with no apparent evidence of having taken advantage of the technological opportunities. There few sectors in which research and development have been made so simple that it is easy to adapt to the specific needs, as in agriculture.

Literature sources from the Consultative Group on International Agricultural Research (CGIAR) indicate that very few local varieties now exist for most major cereals grown in Africa. Indeed, efforts by these international centers and the African National Agricultural Research Services (NARS) to introduce high yielding varieties (HYVs) and their attendant cultural practices, have shown encouraging results. It is with this view that the paper assumes that seed as an input of agricultural production in the FAO database could only be referring to HYVs. The paper would attempt to identify the relationship between the use of HYVs and growth of cereal production in Africa.

Figure 2.4: High Yielding Varieties and Total Cereal Production in Africa (1961-2000)



The trends in Figure 2.4 illustrate that increases in total cereal production are directed related to the use of HYVs. It should be noted that each small variation or change in the use of HYVs of cereal seeds is followed directly by significant increase in the total cereal production and in the same direction. This is a noteworthy result that should be fully observed and taken into consideration when financial development institutions plan for food supply and agriculture growth in African countries as the main effective method for fast poverty reduction.

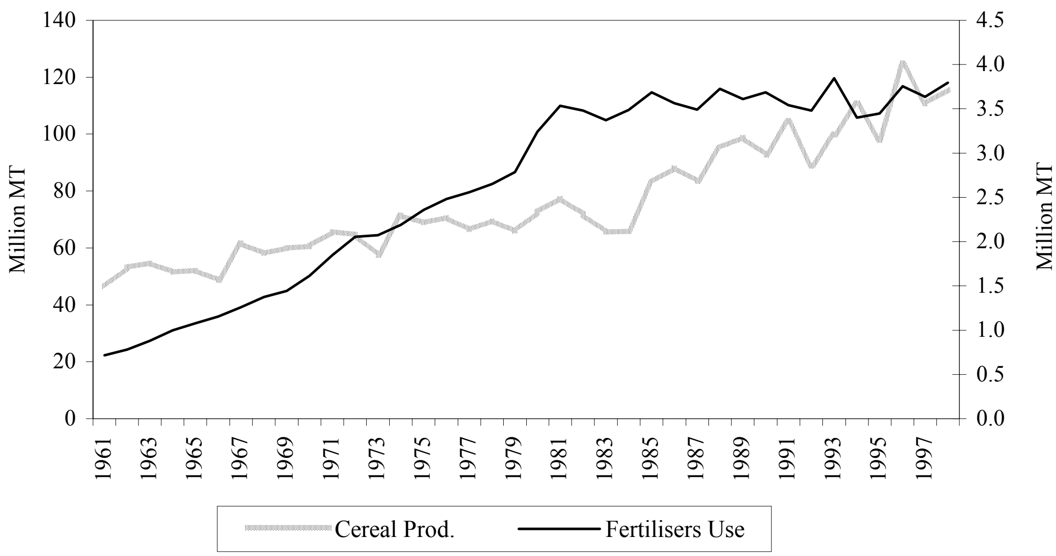
This result is consistent with the green revolution technology that requires the use of high yielding varieties with suitable fertilizers and reliable water supply. Furthermore, recent studies by the World Bank stated clearly that the future increase of food supply would be only achieved through biological increase in the crop yield.

Because of the limitations and constraints of land expansion and water resources, the only promising and sound economic factor, which would lead to sustainable food production increase and thus poverty reduction, is the biological increase in yield. Without widespread, intensified application and accessibility of the high yielding varieties of the major crops including cereals, increased food supply and poverty reduction would not be possible in Africa. Now the question that should be asked is how effective is the use of fertilizers in African agriculture production. For practical experience, data of the last forty years is used in answer this important question.

6) Fertilizers and Food Production

The relationship among cereal production and fertilizer use during the period 1961 and 1998 is illustrated in Figure 2.5. Between 1960 and 1980, fertilizer use increased from a little less than 1 million MT to about 3.2 million MT, which translates to an annual growth rate of about 11 percent over the period. On the other hand between 1980 and 1998, the use of fertilizers continued to increase at lower annual rate of increase of about only 0.96 percent.

Figure 2.5: Consumption of Fertilisers and Total Cereal Production in Africa (1961-1998)



Within the same period of 1961 to 1980, cereal production increased from 46.4 million MT to nearly 72.6 million MT, or a 2.8 percent annual rate of increase. It is interesting to note that during this same period, area harvested, which is a proxy for agricultural area under cultivation, remains almost unchanged, increasing by a mere 0.5 percent. It could be concluded that the increase in cereal production is a consequence of the intensive use of fertilizers by the farmers during that period (1961-1980). From 1980 to 1998, fertilizer varied from about 3.2 million MT to 3.8 million MT or a 0.96 annual percent increase in fertilizer use over the period under review. While fertilizer use in Africa remained almost unchanged in the last 20 years, cereal production increased at a higher rate, of 3.3 an annual rate of increase, in comparison to the pervious rate of 2.8 percent during the previous two decades.

However, it should be noted that the annual increase in the use of fertilizers during the last two decades is a commutative increase for almost the same fixed size of land that were allocated for cereal production. This could also be viewed as increase of an average annual rate of 10 percent in the use of fertilizers that was accompanied by an average annual rate of increase of 3.5 percent in cereal production during the last four decades. However, the variation in both fertilizers and cereal production in the above graph clearly explains the close and significant relationship that the fertilizer is leading the production of cereals in the same direction in each single movement especially during the period 1980 and 1998.

Scientist and researchers have stated, as this paper proves using econometric modeling and African experience that if poverty is to be reduced, the effective factor is through biotechnological support and fertilizer application. This identifies the need to strengthen the existing research institutions and establish a systematic improved seed production and distribution system in the African countries strengthened by rural infrastructure and marketing development.

III. Statistical Analysis of African Cereals

The Green Revolution Technology requires using high yielding varieties with fertilizer application agreeable with these varieties and with reliable water supply. Although, the above-obtained results are partially pertinent to the requirements of the green revolution technologies, it is important to estimate an Aggregate Production Function in order to test the significance of the contribution of the high yielding varieties (biological increase yield) and fertilizer application among other variables.

It is worth mentioning that several econometric models were used before reaching the final two models that are presented below. During these practices results that were obtained provided a negative coefficient sign i.e. impact of the land use and irrigated land areas as well as tractors in use on the production of cereals during the period under review. Although, fertilizer use was also negative in some of the trials, by removing the irrigation variable its sign was reversed to positive. Furthermore, fertilizer was always positive during the period 1961 and 1980 where its rate of increase was clearly high and effective.

The following two econometric models are used to reveal scientific credence to the previously obtained results from the above graphical analysis and to retest hypothesis that HYVs of seeds and fertilizer application are the two most pressing variables in increasing cereal production in Africa. In this respect, two simple ordinary least squares (OLS) regressions were ran, linear and logarithmic models, using an FAO time series data (1961-1998).

1) Liners Production Function:

$$y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + u$$

Where: y = Cereal production;
x_1 = Level of fertilizer use;
x_2 = Level of tractor use;
x_3 = Land; and
x_4 = Seed

Results Obtained:

$R^2 = 0.91$

The above statistical estimated results shows that the proposed four explanatory variables are highly correlated to the independent variable (total cereal production) at a level of 91 percent. Further, all explanatory variables' coefficients are positive but only seed and fertilizers are statistically significant. On the other hand, Durbin-Watson test did not indicate any sign of autocorrelation among the variables. However, with the high R^2 and no other significant variable apart from seed, this model does not support the hypothesis.

The function is included in the paper to demonstrate that seed and fertilizers are such important variables, in addressing increased cereal productivity in Africa, that even in an unacceptable econometric model, they are both significant. This indicates that the HYVs of seeds and fertilizer application are the two most critical variables in increasing food supply while irrigation, with its limitations; is not a momentous factor for significant food production increase in Africa.

2) Logarithm Production Function:

$$\ln y = \alpha + \beta_1 \ln x_1 + \beta_2 \ln x_2 + \beta_3 \ln x_3 + u$$

Where: $\ln y$ = log of cereal production;
$\ln x_1$ = log of level of fertilizer use;
$\ln x_2$ = log of level seed use; and
$\ln x_3$ = log of level land use

Results obtained:

$R^2 = 0.92$

(-1.24) (3.06) (8.43) (0.66)

The above logarithmic statistical estimated results shows that the proposed four explanatory variables are highly correlated to the independent variable and are capable to explain about 91 percent of the variations that occurred in the total cereal production during the past forty years. Further, all explanatory variables' coefficients are positive. On the other hand, Durbin-Watson test showed no indication of autocorrelation. Under assumptions of normality, this OLS production function is efficient, because not only do all the variables have positive signs, both fertilizer and seed are statistically significant. The function also supports the hypothesis that HYVs and fertilizer application are the most important factors in simulating agricultural growth and food supply in Africa.

Part Three: The Need for Biotechnological Transfer

I. Comparative Advantage of Agricultural Research

1) Introduction

The important question that emerges from these scenarios, and which this paper intends to answer is "should donors continue financing the same type of agricultural development investments in Africa?" The explanation for this poor performance of the agricultural sector and consequently, the inefficacy of poverty reduction efforts could be explained in part by the low attention made to agricultural research in Africa. Research efforts on food staples in Africa must focus mainly on high yielding varieties, through improved breeding practices. As this paper will shows, HYVs are important means to ending the persistent food insufficiency plague that has been a constant feature on the African development scene. Analyses of data from both the FAO and other sources would justify the emphasis on HYVs as a research development goal. However, though the ICRCs and the National Agricultural Research Systems (NARS) recognize that the availability of HYVs alone is not the panacea, and that improved soil fertility is an inevitable cog in the wheel of agricultural development and subsequently poverty reduction efforts, very few governments put into place policies to adequately address the problem.

Agricultural research in Africa received low attention during 1960s and early 1970s. Within 1961-65, scientific manpower for 43 sub-Saharan countries reached 1,323 researchers, representing 2.2 percent of the world total researchers. Within the same period, agricultural research expenditure increased to US$150 million, representing 4.5 percent of the world agricultural research expenditure. By 1985, significant changes had taken place. Excluding agricultural researchers at university faculties, number of researchers in African NARS shot up to 4,944 researchers. At the same time, financing of agricultural research had gone up by more than 50 percent, to US$373 million.

It is important to recognize that North Africa alone accounted for about 50 of the total number of researchers in Africa. However, its expenditure on agricultural research, of US$126 million, represents only 26 percent of the total national agricultural research expenditure in Africa. On average, Africa spends on agricultural research about US$ 50,000 per researcher. At the country level, Egypt has about 43 per cent of the total number of agricultural researchers in Africa, though it has the lowest expenditure per researcher. Soa Tome & Principe, and Seychelles have three and seven agricultural researchers respectively. Lesotho has the highest research expenditure, of US$ 333,000 per researcher. African agricultural research expenditure and personnel estimates, expenditure per researcher, and agricultural growth domestic product (AgGDP) at country level is shown in Table 1 of Annex 1.

In sub-Saharan Africa, scientific manpower of 4,944 researchers composed of 53% postgraduate researchers and 38% national researchers during 1980-86. By including north Africa, total expenditure on agricultural research represents 0.98% of the AgGDP and the agricultural research expenditure per researcher is averaged at about US$50,000. This situation has a bearing on the hiring of expatriate researchers in sub-Saharan Africa countries. It also reflects the inconsistency between the expenditure and personnel. Table 2 of Annex 3 presents a distribution of scientific manpower in agricultural research in sub-Saharan Africa.

In order for agriculture to contribute effectively to national development, the United Nations Food Conference of 1974 suggested that NARS in Africa must increase their research expenditure to 0.5 percent of AgGDP. By 1990, FAO and the World Bank respectively suggested the levels to 1 and 2 percent. That notwithstanding, the average today stands at only 0.54 percent, with only four countries spending over 2.0 percent of their AgGDP on research, while 22 countries spending less than 1.0 percent, out of which 11 countries are spending less than 0.35 percent of their AgGDP on research.

There is an urgent need to ensure an adequately funded system to attract and retain qualified staff, so that NARS could build on past growth levels. Many African institutions are still young and understaffed, and they lack experienced management to handle problems facing their countries. This poor funding situation is feeding upon itself, to the extent that most qualified researchers are looking for greener pastures, thus leaving the NARS in more vulnerable situations than before. One purpose of this paper is to show that through research, technology development and dissemination, poverty can be reduced significantly in Africa over a short period of time.

2) Technology as the Primary Source of Growth

Advances in conventional technology will remain the primary source of growth in crop and animal production over the next quarter century. Almost all increases in agricultural production in the future must come from further intensification of agricultural production on land that is presently devoted to crop and livestock production. Until well into the second decade of the 21st century, the necessary gains in crop and animal productivity will continue to be generated by improvements resulting from conventional plant and animal breeding and from more intensive and efficient use of technical inputs, including chemical fertilizers, pest-control chemicals, and higher-quality animal feeds.

The productivity gains from conventional sources are likely to come in smaller increments than in the past. Even such marginal increments must result from higher plant populations per unit area, improved tillage practices, improved pest and disease control, more precise application of plant nutrients, and advances in soil and water management practices. Gains from these sources will be crop, animal, and location-specific. It will also require closer articulation between the suppliers and users of new technology. If they are to be realized, research and technology transfer efforts in the areas of information and management technology must become increasingly an important source of growth in both crop and animal productivity.

Within the next two decades it is not envisaged that there could be other sources of growth in production that would be adequate to meet the demands arising from growth in production and income. The logical conclusion is that both national and international agricultural research systems will find it productive to increase the proportion of research resources devoted to improving agronomic practices relative to plant breeding.

3) Biological Gradients and Yield Impact

There are two types of gaps in the agricultural productivity. The first is the difference between potential yield obtained under controlled trials on experiment stations, and that obtained from on-farm trials. Second type of gap exists among different farms in the same country or between different countries for the same crop. Empirical studies have shown that a yield gap of 60% could exist between experimental yields and farm yields. While, for example, experimental maize yield could be about 15 ton/ha, farm yield is about 8.5 ton/ha.

The situation is worse in Africa, where average farm yield of maize in East Africa varies between 0.6 ton/ha to 2 ton/ha, indicating the need for considerable efforts to narrow that gap. One obvious mean would be through the adaptation of generic material to local situations along with improved agronomic practices. This suggests an essential need for agricultural research, and an effective extension delivery system.

Table 3.1 shows maize yield impact of applied innovations in sub-Saharan Africa. Narrowing the gap between the farm yield and the experimental potentials could not be achieved by any single piece of technology listed in the table. Rather, an efficient interaction of technologies should be considered. Transfer of technological components indicates that the use of improved and hybrid varieties of maize result in 20 percent increase in yield. Maize yield is increased by 51 percent with the use of fertilizers. Using HYVs in isolation increased yield by 17 percent

Table 3.1: The Impact of Innovations on Yield of Maize

Technology	Technology Description	Yield Kg/ha	% Increase
Basic Inputs	Traditional variety, low fertility, one weeding	600	15 %
Improved Seeds	Improved seeds with small increase in plant population	700	18 %
Fertilizers	Application of 40 KgN/ha and 15 KgP/ha	1,100	28 %
Extension	Plant density, time of planning and second weeding	1,500	38 %
Hybrid Seeds	Change to suitable high yielding varieties (HYV)	2,200	55%
Further Fertilizers	Additional fertilizers of 50 Kg N/ha and 20 Kg P/ha	2,800	70%
Pest Control	Application of pert control	2,950	74%
Further Fertilizers	Addition of 50 Kg N/ha and 30 Kg P/ha	4,000	100 %

Source: Calculated from Carr, S. J

while extension adds 10 percent and pest control 4 percent to the yield. In other words, the use of suitable HYV along with appropriate fertilizer application would increase the maize yield by a total of 71 percent.

4) Potential Contribution: Yield Impact

The agricultural productivity of given crops within the major African producer countries indicates a wide variation in their yields. Data analysis for yields of wheat, maize, and rice were conducted for a comparison study of variation among the major producing countries in Africa and other continents. Data used for this analysis covered the average productivity for the period of 1979-81 and 1991-93. Result of analysis estimated a yield gap of 80 percent among major African producer countries for wheat, a yield gap of 150 percent for both rice, and 300 percent in case of maize. Results show potentialities for agricultural production growth in Africa.

Average and highest gap is used in this analysis for measuring variation in productivity among various countries. The average gap is defined as the potential possible increase in the lowest yield among African major producer countries to reach average yield of Africa. The highest gap is defined as the potential possible increase in the lowest yield among African major producer countries to reach highest yield of African countries.

Such variations could be attributed to two factors (i) transferable and (ii) non-transferable factors. Transferable factors are the technological changes that can be transferred from country to another with or without modifications such as the application of improved agronomic practices, such as properly timed planting and weeding, improved genetic material for a range of ecological situations, pest control, use of improved variety and fertilizers, cumulating knowledge and policy design. Non-transferable factors are ecological factors that can not be transferred from country to another such as weather and soils.

Data of Table 1 of Annex 2 shows wide variation of yield for wheat between eight major African producer countries. An obvious technological change took place in Egypt during last 25 years, leading to an increase in wheat productivity from 3.2 ton/ha to 5.1 ton/ha. This represents a 61% increase in productivity as a result of research and new knowledge especially improved seeds and application of fertilizers. During the same period, other African countries experienced a decrease in wheat yield. For example, in Kenya wheat yield decreased from 2.0 ton/ha to 1.7 ton/ha during the same period.

According to the above-mentioned definitions of both average and highest gap of productivity, the analysis indicates that the estimation of wheat yield gap ranges from 80% to 400%. The average gap of wheat shows that Algeria, as a lowest yield country, may increase its yield of wheat by 80% to reach the average yield of Africa i.e. to increase wheat productivity from 0.96 ton/ha to 1.71 ton/ha. The highest gap explains the potentiality of an increase by 400% in Algeria's wheat yield to reach the Egyptian yield of 5.14 ton/ha as the highest during the period of 1991-1993. Table 1 of Annex 2, indicates that wheat yield in Africa (1.71 ton/ha) is the lowest in comparison to other continents. The yield in Asia is averaged at 2.49 ton/ha, 2.00 ton/ha in South America, 2.44 ton/ha in North America, and 5.60 ton/ha in Europe as an average of the last three years period (1991-1993). Tables 2, and 3 of Annex 2 exhibits similar variations in yields of crops. Such analysis would signals means for increase in crop productivity in the lower producer countries.

II. Evidence of African Agricultural Research Activities

1) Role of Scientist and Researchers

While the above description indicates the level of possible agricultural productivity improvement, it also reflects the essential role of the agricultural research results and technology as the primary source of growth. This wide range of crop yield variation between African countries is a function of the types of technological changes that can be transferred and their consequent impact on poverty reduction. Most of these factors are technological changes, including research results and knowledge dissemination, as well as the anticipated effect of agricultural and price policies within the African countries.

Scientists and agricultural researchers are expected to study the related constraints and variables that may affect the expected results when technology transfer takes place. Such constraints include socio-economic factors, acceptability of the new knowledge and technology, farmers training and extension, ability to finance the new technology at the smallholder level, ability to adopt the research results and minimizing risks taken by small farmers. Ecological conditions such as soil, water, weather, and humidity, could also affect results. On the other hand, acceptability of the final product by local consumer is also important to be investigated before any action plan or investments in the application of research results.

2) Rate of Return of Agricultural Technology

Most sub-Saharan African countries depend on agriculture for their livelihood. Improving the welfare of the next generation of Africans is thus a function of the sustainability of agricultural development. This would require the use of sustained improvements in the productivity with which the human and natural resources are employed in agriculture.

To assess the contribution of research to Africa's food crop production, agricultural recovery and economic growth, it is helpful to carry out impact assessments of all the NARS in Africa. However, because of the enormity of such an exercise, this paper will only focus on a few countries. It will use data compiled by Oehmeke and Masters (1997), Mudhara *et al* (1995) and Isiniki (1995), reproduced in Oehmeke, Anandajayasekeram and Masters (1997). While these data, shown in Table 2.2, did not be cover every country, they include a broad cross-section of the major types of research programs carried out in the NARs of Africa.

The fact that Oehmeke et al (1997) conclude that research returns to research in Africa are similar to those found elsewhere, showing high payoffs for a wide range of programs, only butress the position that research targeted at the smallholder is the solution to poverty reduction in Africa.. The contribution of research to agricultural performance and economic growth is not easily visible, since it occurs gradually and is spread widely across the population, but careful investigations generally find the net benefits to be significantly larger than funding provided.

In order to examine the overall contribution of agricultural research, which Oehmeke et al refer to as technology development and transfer (TDT), to a country's standard of living and economic growth, many different kinds of impact were added using a common yardstick. This was done by assessing the monetary value of each change caused by TDT, in terms of its social opportunity costs, or what it would cost to achieve that effect using other kinds of intervention.

A partial equilibrium approach is used in determining economic surplus, which becomes a measure of TDT. Research programs involve making short-term investments to create longer-term benefits. The economic rate of return, defined simply by Oehmeke et al as the rate of return (ROR), is used to summarize the year-to-year stream of costs and benefits, earned on the initial investment in returning the longer term benefits.

Table 3.2: Summary of Ex Post Rate of Return Studies for African Agricultural Technologies

Author and Date of Study	Location, Commodity, and Year Covered	% ROR
Makau (1984)	Kenya, 1922-1980, wheat	33
Evenson (1987)	Africa, maize and staple	30-40
Karanja (1990)	Kenya, maize, 1955–1988	40-60
Mazzucato (1992)	Maize, maize, 1978	58-60
Ewell (1992)	East Africa, potato, 1978-1991	91
Sterns and Bernsten (1992)	Cameroon, cowpea, 1979-1991; sorghum, 1979-91	3 <0
Howard, Chitalu and Kalonge (1992)	Zambia, maize, 1978-1991	84-87
Schwarrtz, Sterns, and Oehmke (1993)	Senegal, cowpea, millet and sorghum, 1980-1985	31-92
Mazzucato and Ly (1994)	Niger, cowpea, millet, and soybean, 1985-1991	<0
Laker-Ojok (1994)	Uganda, sunflower, cowpea, and soybean, 1985-1991	<0
Boughton and de Frahan (1994)	Mali, maize, 1969-1991	135
Sanders (1994)	Ghana, maize, 1968-1992	74
	Cameroon, sorghum, 1980-1992	2
Smale and Heisey (1994)	Malawi, maize, 1957-1992	4-64
Kupfuma (1994)	Zimbabwe, maize 1932-1940	43.5
Khatri,, Thirtle, and van Zyl (1995)	South Africa, aggregate agriculture	44
Ahmed, Masters, and Sandres (1995)	Sudan, sorghum, 1972-1992	53-97
Ouedraogo, Illy, and Lompo (1996)	Burkina Faso, maize, 1982-1993	78
Seidi (1996)	Guinea Bissau,, rice, 1980 –1994	26
Makanda and Oehmke (1996)	Kenya, wheat, 1921-1990	0-12
Akgungor et al.	Kenya. Wheat 1921-1990	14-30
Isinika (1995)	Tanzania, all crops, 1972-1992	33

Source: Adapted from Oehmeke and Masters (1997).

Although countries' individual experiences are highly complex and uneven, a clear pattern emerges from aggregate data. FAO data reveals that in the 1960s production, exports and imports performed relatively well. From 1971 to 1984, agricultural production per capita fell consistently, for a cumulative decline of 22 percent, from an index value of about 115 in 1971 to a value of 90 in 1974. The fall in per capita production translated into much larger proportional change in decline in exports and rise in imports, as volume of agricultural imports fell 40 percent, and the volume of agricultural imports more than tripled.

Africa's agricultural decline was dramatic but limited to the period between 1971 and 1984. The onset of the decline can perhaps be linked to the Sahelian drought of 1972 and 1973, and its end may be linked to good rainfall in Southern and Eastern Africa in 1985. But Africa as a whole did not experience a prolonged drought during this whole period.

Out of a total of 21 studies carried out in 15 countries, stretching from Sudan to South Africa and from Ghana to Kenya, the ROR varied from between 30 –100 in over 50 percent of the cases. In the two cases where the returns were less than zero, HYVs were either not used or data represented only the civil war period in Uganda.

If the return to research in food crops in Africa is identical to results attained in other parts of the world why are African countries unable to feed themselves? The only logical explanation is the lack of policies that would enable smallholders to have access to HYVs and fertilizer. However, the significant questions that arise from the above discussion are "What is the most appropriate lending instrument to agricultural research?, what is the appropriate form of aide for agricultural research? and "what is the type and the scope of research that donors should finance"? The coming section will discuss these concerns.

3) Biotechnology for The Poor

While genetically modified crops have occupied headlines, another biotechnology is quietly transforming agriculture in Asia. Tissue culturing or reproducing plants on a mass scale – reaps benefits for firms and rural communities. The peaceful scene belies the intense pace of development of a biotechnology known as tissue culturing. The relatively simple—and inexpensive- process has potentially unlimited applications, ranging from boosting harvests to reforesting logged areas. But in the shadow of controversy surrounding genetically modified crops, the increasing use of tissue culturing in Asia has gone largely unnoticed.

Tissue culturing- also known as micro-propagation- was developed more than three decades ago by researchers at Thailand's Kasetsart University and the University of Hawaii. Since then, the process has been profitably applied to dozens of other crops in the region. While tissue culturing will likely never replace the conventional sowing of seeds in Asia, it's having a profound impact on agricultural research and production.

The reproducing process has yielded amazing results. A single banana tree, for example, can produce up to 30,000 offspring in one year, compared with the five-to-10 offspring it would naturally produce. Thailand is the leader in tissue culture in Southeast Asia, producing 50 million plant lets a year. Most are orchids, which have helped the country become the biggest exporter of whole and cut orchids in the world. Based on its success in mass-producing orchids, commercial plantation company Thai Orchid—one of the biggest producers of tissue-cultured plants in Asia—is now using micro-propagation to speed the production of crops such as teak, eucalyptus and jackfruit.

While micro-propagation is a biotechnology, it doesn't face the same testing and regulatory hurdles as genetically engineered crops, which insert genes from unrelated species. "The selection we do relies on random genetic events and natural variations or mutants which are either induced or spontaneous. No genetic manipulation is involved," says Suhaimi Napis, a research fellow at the Department of Biotechnology at University Putra Malaysia. With no opposition from consumer or environmental groups, the turnaround from investment to profit can be much faster.

Other countries are jumping on the bandwagon. Indian plant-producing company AVT Biotechnology produces 8 million plantlets a year from tissue culture. It says the ability to quickly multiply superior varieties via tissue culturing has led to a threefold increase in the productivity of their plantation crops, including date palm, asparagus, calla lily and orchids. Researchers from Laos and Vietnam are learning tissue-culture techniques in Thailand to use in their own cut-flower industries and reforestation efforts.

Japan, Europe and the United States also make use of micro-propagation, but mostly as a step in the hi-tech development of genetically modified organisms. Since genetic modification takes place on a cellular level, tissue culturing provides the critical link that allows a cell to turn into a whole plant. But industrialized countries don't use the process widely for agricultural production. Their major commodities are mostly annual crops such as corn, soybeans and wheat, which are produced efficiently by traditional seed-and-soil cultivation methods. Many commodities of tropical Asian countries, however, come from trees, which produce few seeds and can be difficult to multiply.

Researchers have worked on this problem for 30 years, with almost no progress. What would take years to observe in the field, it can be done in a few days. So far, the researchers have identified several species that not only can be used to reforest saline areas, but that also can reduce the salinity of soil. That same speed is being harnessed by seed companies and industry groups, such as the Malaysian Palm Oil Board, to screen for resistance to diseases in papayas and oil palms. Work to produce disease-resistant coconut and rubber trees that contain synthetic proteins used in pharmaceutical drug production is still in early stages in India and Malaysia respectively.

Part Four: The Search for Effective Research Development Assistance

I. Ingredients of Agricultural Biological Research

1) Introduction

The global agricultural research systems can be classified into five types of research: Basic, strategic, applied, adaptive, and screening and testing. Further, agricultural research covers several research topics and subjects. Some of these topics are agro-forestry, root and tuber crops, cereal crops, banana and plantain, oil seed, sugar crops, cotton and fibers, horticulture, soil and water, pesticides, livestock and forage, agricultural mechanization, extension, and agricultural economics and marketing. Thus, a simple combination between agricultural research topics and types of research explains the huge task that the agricultural research sub-sector is responsible for.

Prioritized research topics, according to the agriculture strategies and policies of the African countries, together with maximizing the research efficiency through allocating scarce research resources will result in narrowing and sharpening the focus of research as a tool for agricultural development in Africa. Further, since impact of research cuts across boundaries, geography, therefore is an important dimension to be considered. Geography dimension suggests national, sub-regional, regional, and international levels for research cooperation, and new technology transfer.

2) Capacity of Biological Research

Capacity is a measure of the size of a research system, based on the level of available resources and the way they are brought together to establish a given level of research. The amount of financial, human, physical, and managerial resources that a developing country, with limited resources, can allocate to its entire agricultural research program may not be sufficient for efficient and effective research results. In this case, financing a research program will be associated with higher risk and uncertainty. In general, developing countries are faced with stiff competition for their limited resources from development programs, such as health, education, and social infrastructure that are equally as important as agricultural research. In this paper, part of our concern is the limited capacity of the National Agriculture Research Services (NARS) which will be our focus in order to reach policy position for financing agricultural research programs in Africa.

A major constraint on the capacity of research is finance. The criterion most widely used for sustainable level of resource allocation for agricultural research is expressed as a percentage of the agricultural gross domestic product (AgGDP). In 1981, the World Bank has recommended that annual expenditure for research should be on the order of two per cent of AgGDP. However, applying this formula for low-income countries that AgGDP is so low resulted in low expenditure for research and therefore research capacity limitation problem. This places an inherent limitation on research, which should be taken in account in determining a sustainable capacity for agricultural research.

3) Scope of Research

Scope is the range and intensity of research activities that can be sustained by the NARS with the resources it has available to meet specific objectives of the system. This is, scope normally measured as the number and type of commodities and research topics that are covered. Objectives, coverage, and focus of a research program are terms related to the research scope. The question of scope is somewhat more subjective than the question of capacity (scale), and it requires informed judgement by research managers on how to set the scope. In other words, research managers are required to determine type of research to conduct, as well as technologies and programs to focus on.

In the short run, research capacity is relatively fixed (parameter) and primarily concerns the availability of existing resources that can be allocated to a variety of objectives. On the other hand, scope of research is always variable unless it is defined by objectives and by the activities required to meet those objectives. However, determination of scope is usually done after capacity has been identified. First step in defining the scope of a research system is to examine the choice of research goal. A realistic scope should define an area where relatively unhampered activities take place to achieve planned objectives. The scope should also be consistent with the mandate and goals of the agricultural sector that is determined by the government.

4) Type of Research

There are five types of research that are used in this analysis, which are i) basic research; ii) strategic research; iii) applied research; iv) adaptive research; and v) screening and testing type of research. The basic research is non-location-specific and usually requires high sophisticated facilities. Further, basic research can be defined as scientific activities that include: a) develop discipline inputs; b) synthesize new basic materials; c) collect and evaluate new material; or d) develop understanding of basic organism functions.

The second type of research is the strategic research, which is non-location-specific and can be obtained from any source. Strategic research is defined as a set of scientific activities that includes: a) identify and assemble discipline units; or b) identify appropriate research methodologies.

Applied research can be done locally or non-locally and defined as scientific activities that include: a) generate technology prior to adaptive research; or b) develop the broad answer. The fourth type of research is the adaptive research. It is defined as a scientific activity that adopt to location-specific conditions. This type of research ideally should be done locally or could be done to order. The fifth type is the screening and testing research. Screening and testing research must be done locally on research stations or on-farm in target farming systems. This type of research can be defined as scientific activities that includes the following: a) full-spectrum testing; b) pre-release testing; and c) farmer's field evaluation.

5) Research Topics

Scope determination requires definition and grouping of regional and global sources of agro-technology and new knowledge, flows, availability, and distribution. Further, various research subjects must be taken in consideration. Classification of the research topics is based on similarities in the density and distribution of technology generation and transfer with respect to a set of agricultural commodities. The following is a list that groups and classifies agricultural research topics and commodities in order to identify technology gradients and information flows that influence scope of research.

Research topics are classified into seven main topics: i) global staples; ii) traditional exports; iii) minor food crops; iv) high-input non-traditional exports; v) natural resource management; vi) livestock; and vii) socio-economic and rural engineering.

Global staples are major food crops with a global distribution, both in terms of production and in the distribution of sources and transfer of new technology. Tropically, these crops are the focus of work by the International Agricultural Research Centers (IARCs). NARS and the private sector are also significant sources of technology information on these commodities. Information for research on these commodities is intensive and widely available to NARS.

The second category includes crops that are historically produced for the global market. Research on these crops is distributed worldwide, where the private sector has important contributions. Within certain channels, information on these commodities is widely and quickly available. The minor food crops are the crops that are locally important to the food-producing sector within a country and are not a major component of a country's agricultural exports. New technology on these crops is either less readily available or is not specifically targeted to developing countries. Often, developing countries have difficulty to obtain relevant information on these crops or find it completely unavailable.

The high-input nontraditional export category includes crops that are grown primarily for export. The major emphasis in production is on quality, uniformity, and timing, which required a high level of inputs, controlled conditions, and special handling. Post-harvest considerations are particularly important. The private sector plays a major role in the generation and transfer of technology for these crops. Therefore, private sector is a major source of new technology for this group of commodities.

The natural resource management category includes research topics that are not commodity based but are concerned with managing an existing resource, such as soil, water, plant, and fish stocks, with the aim of increasing, extending, or conserving the productivity of that resource. There is an inherent logic in conducting this type of research within the country, but it can be complex, even at what can be considered an adaptive level. Non-government organizations (NGOs) have played an important role in this type of research, with recent involvement of international agricultural research centers.

Livestock research includes all topics related to animal diseases, fodder, nutrition, and livestock management. Principal sources of technology are international agricultural research centers and the veterinary services in more-developed countries. Finally, the socio-economics and rural engineering category includes research topics dealing with the management and allocation of resources to farm enterprises. It covers socioeconomic studies of farmer's choices and preferences, production, constraints, farming systems research, marketing research, storage, and farm structure. This research is country-specific and employs widely applicable methodologies.

6) Efficiency of Research

There are two dimensions for setting the scope of research. First is the type of research whether it is basic, strategic, applied, adaptive, or testing. Second dimension is the range of possible programs and disciplines that can be covered by the given research capacity. Important factors that must be considered in choosing among the range of programs are the actual technologies to be developed and the existing flows of information, resources, and technology that are available for particular program or focus.

While capacity places fixed limits on research level, there is a wide range of choice as to where the research activities/operations should be focused and how they should be organized. These are decisions that research managers must make in consultation with policy-makers, stakeholders, and clients. It involves selecting among a range of possible research programs and objectives, organizing them, and then making the appropriate links to achieve their goals. Links are made to components in governments, to the agricultural industry, and to direct clients. As the full use of the existing capacity makes economies of scale for research, also economies of scope involves selecting areas of research in which the NARS is likely to achieve its goals, make the best use of linkages and technology flows, and have the greatest impact. Even though, the small capacity will limit the choice of scope, setting the scope will direct the system to provide new knowledge and technologies. Setting the scope, therefore will maximize the effectiveness and efficiency of the research system.

Small developing countries are not likely to have the capacity of resources necessary to conduct basic research globally. Most basic research is concentrated in larger and more industrialized countries, and even in those countries, basic research projects tend to be concentrated in a few institutions that can assemble the necessary resources and expertise. This leads to conclude that the limited capacity and available resources in smaller developing countries imposes a rather fixed constraint on the type of research they may conducted. Most of those countries could be efficiently involved in the adaptation and testing type of agricultural research. In some cases, applied research might be possible, particularly in areas of natural resource management.

Efficiency of research capacity implies resource utilization close to the full capacity. Since capacity is normally based on fixed or recurrent cost that must be paid whether they are being used or not, under-utilization is therefore costly and inefficient. Attempting to conduct research operations on a capacity that goes beyond the existing capacity of available facilities is also inefficient. When this is done, objectives of the research system are not likely to be met and the resources expended will be largely wasted.

7) Linkages and Level of Research

Access to external sources of knowledge and technology is crucial to the development of research system in developing countries. Sources of technology and information for research are varied and numerous. NARS should be able to identify these sources and evaluate their relevance and gain access to them. Regional flows of new technology and information could be best used, by research managers, to expand the capacity or alter the scope of research efforts. New knowledge and technology that are produced by an existing regional/international center (IARC) for similar environments, may be used to reduce the planned research level to a testing level in a certain country. This adjustment of the research level may be reached provided that good linkages are maintained with sources of technology.

Available technologies, to overcome some of the agricultural constraints that are facing growth of agricultural production may often be inapplicable or impractical for smallholder due to financial constraints. Therefore, it is important to distinguish among technology availability, its applicability, acceptability, and economic feasibility.

The value of a technology to community or a farm family is dynamic over time. Therefore, timing is critical to a successful adoption of innovations. Frequent contacts between research and extension staff and farmers are essential so that farmers' acceptability constraint may be better understood. For such problems, socio-economics studies are required to be achieved at a country-specific level. It is a necessity that the socio-economic studies are conducted prior to any technology or new knowledge transfer is made or financed. The main purpose of the socio-economic studies is to investigate technology applicability within producers, and to study acceptability of the final product within consumers and local markets.

II. Categorization of National Agricultural Research Services

Agricultural research in Africa received low attention during 1960s and early 1970s. Within 1961-65, scientific manpower for 43 sub-Saharan countries reached 1,323 researchers, representing a percentage of 2.2% of the world total researchers. Agricultural research expenditure recorded US$150 million, representing 4.5% of the world agricultural research expenditure. By 1985, significant changes had taken place. Excluding agricultural researchers at university faculties, number of researchers in National Agricultural Research Service (NARS) recorded 4,944 researchers, and research fund had gone up to US$373 million.

A distribution of 1981-85 average of Africa's regions national agricultural research personnel and expenditure shows that total number of researchers reaches 9,960, and total expenditure realized is US$499 million. Although North Africa's share of agricultural researchers represents 50% of the total number in Africa, its expenditure on agricultural research, of US$126 million, represents 26% of the total national agricultural research expenditure in Africa. African agricultural research expenditure and personnel estimates, expenditure per researcher, and agricultural growth domestic product (AgGDP) at country level is shown in table 1 of Annex 3.

Scientific manpower and expenditure may partially measure the institutional capacity of national agricultural research. In view of agricultural research expenditure statistics, Africa has less than 7.5% of the world number of agricultural researchers, and its expenditure is less than 6% of the world agricultural research expenditure. In sub-Saharan Africa, scientific manpower of 4,944 researchers composed of 53% postgraduate researchers and 38% national researchers during 1980-86. Out of the 4,944 researchers are postgraduate, 2,374 scientists have M.Sc. and PhD or equivalent degrees. On the other hand, total expenditure of agricultural research represents 0.88% of the Agricultural Growth Domestic Product (AgGDP). Further, agricultural research expenditure per researcher averaged about US$ 76,000 during the same period. By including north Africa, total expenditure on agricultural research represents 0.98% of the AgGDP and the agricultural research expenditure per researcher averaged about US$ 50,000. This may reflect the expense of hiring expatriate researchers in sub-Saharan Africa countries and also reflects inconsistency between the expenditure and personnel.

A target of 0.5% of the Agricultural GDP was suggested for developing countries by the 1974 United Nations Food Conference. FAO and World Bank increased this suggestion to one and two per cent respectively in 1990. Statistical data indicated that on average Africa spent 0.54% during the period 1980-85. Only four countries spending over 2.0% of their AgGDP on research, while 22 countries spending less than 1.0% of their AgGDP, out of which 11 countries are spending less than 0.35% of their AgGDP on research.

However, it is important to insure an adequately funded system to attract and retain qualified staff. Much remains to be done to reinforce NARS and build on past growth. Many African NARS are still young and understaffed, and they lack experienced management to handle problems facing their countries. There is a higher proportion of expatriate researchers there than in any region in the world. Numbers of workers with advanced degrees should be increased, and some NARS appear seriously under-funded.

Expenditure per researcher, is not a sufficient criterion for research capacity since low number of researchers, as a deficiency, illusory leads to higher expenditure per researcher. Further, expenditure as a percentage of the AgGDP, is not an adequate indicator for the capacity of national research. Other factors are therefore considered in developing Capacity Compound Factor (CCF) as a developed formula to measure research efficiency. This CCF includes Gross Domestic Product of agricultural sector (AgGDP), agricultural research expenditures (Exp), number of researchers in the NARS, and population.

Research Return Factor (RRF) is calculated by dividing AgGDP by agricultural research expenditure (Exp). CCF is calculated, therefore by weighting RRF factor by Researchers Intensity Ratio (RIR) per thousand. That is, CCF is calculated by multiplying RRF by the ratio of agricultural researchers per one thousands of population for each country. Therefore, research efficiency of the NARS is measured by Capacity Compound Factor (CCF) together with the percentage expenditure of the

AgGDP for each country. The following formula is used to calculate the CCF for NARS in the RMCs. Calculations of CCF for all African countries are presented in Annex 1.

$$CCF = \left(\frac{AgGDP}{\text{Exp}} \right) . \left(\frac{No.Researchers}{Pop./1000} \right)$$

RMCs therefore may be classified into four categories according to the results of applying the above formula of CCF along with percentage expenditure of AgGDP criteria. This classification is used to categorize the research capacity, and therefore assign appropriate type and topics of research as long as relevant conditions to ensure sufficient and efficient research results. Proposed policy framework is presented in table 4.1.

First Category:

Category one includes the RMCs that have CCF greater than or equal to 2.0 points, and spend greater than or equal to 1.0% of the annual AgGDP. In this category, and according to the available data of the period 1981-85, eight countries are ranked as sufficient and efficient for conducting certain types of research for specific research topics. Recommended types of agricultural research are applied, adaptive, and screening and testing. Further, proposed research topics are traditional exports, minor food crops, high-input non-traditional, natural resource management, livestock, and socio-economics and rural engineering. Those countries are Cameroon, Cape Verde, Guinea, Ivory Coast, Congo, Mauritius, Seychelles, and Uganda.

Second Category:

The second category includes the RMCs that have CCF greater than or equal to 2.0, but spend less than 1.0% of the AgGDP. According to the result of this analysis, nine countries fall into this category that are ranked as efficient to conduct specific types for certain topics of agricultural research. Accordingly, proposed research types are applied, adaptive, and screening and testing. Recommended research topics are minor food crops, high-input non-traditional, natural resource management, livestock, and socio-economics and rural engineering. Those countries are Algeria, Egypt, Ghana, Mauritania, Niger, Nigeria, Sierra Leone, Somalia, and Sudan.

Third Category:

Category three includes the RMCs that have CCF less than 2.0 points, and spend greater than or equal to 1.0% of the annual AgGDP In this category. Accordingly, there are 20 countries that satisfy these characteristics. These countries may consider as sufficient but not efficient countries for conducting all types and topics of agricultural research. Recommended types of agricultural research are adaptive and screening and testing for the following research topics: high-input non-

Table 4.1: Research Categorization for Development Finance in Africa

Category	Characteristics	Type of Research	Research Topics	Country
One	CCF >= 2.0 and AgGDP >= 1.0%	Applied Adaptive Screening and Testing	Traditional Exports Minor Food Crops High-input non-traditional Natural Resource Management Livestock Socio-economics and rural	Cameroon, Cape Verde, Guinea, Ivory Coast, Congo, Mauritius, Seychelles, and Uganda.
Two	CCF >= 2.0 and AgGDP < 1.0%	Applied Adaptive Screening and Testing	Minor Food Crops High-input non-traditional Natural Resource Management Livestock Socio-economics and rural	Algeria, Egypt, Ghana, Mauritania, Niger, Nigeria, Sierra Leone, Somalia, and Sudan.
Three	CCF < 2.0 and AgGDP >= 1.0%	Adaptive Screening and Testing	High-input non-traditional Natural Resource Management Livestock Socio-economics and rural	Libya, Morocco, Tunisia, Burkina Faso, Gambia, Guinea-Bissau, Liberia, Mali, Senegal, Togo, Gabon, Sao Tome, Lesotho, Malawi, Botswana, Swaziland, Zambia, Zimbabwe, Comoros, and Kenya.
Four	CCF < 2.0 and AgGDP < 1.0%	Screening and Testing	Natural Resource Management Livestock Socio-economics and rural	Benin, Chad, Burundi, Central Africa, Rwanda, Zaire, Angola, Madagascar, Mozambique, Ethiopia, and Tanzania.

Source: Developed from the analysis conducted by the author.

traditional, natural resource management, livestock, and socio-economics and rural engineering. Those countries are Libya, Morocco, Tunisia, Burkina Faso, Gambia, Guinea-Bissau, Liberia, Mali, Senegal, Togo, Gabon, Sao Tome & Principle, Botswana, Lesotho, Malawi, Swaziland, Zambia, Zimbabwe, Comoros, and Kenya.

Fourth Category:

Fourth category includes the RMCs that have CCF less than 2.0 points, and spend less than 1.0% of the annual AgGDP. In this category, there are 11 countries satisfy the above said characteristics. These countries lie in the in-efficient category for conducting some types and topics of agricultural research. Recommended research type is screening and testing for natural research management, livestock, and socio-economics and rural development. Those countries are Benin, Chad, Burundi, Central Africa Republic, Rwanda, Zaire, Angola, Madagascar, Mozambique, Ethiopia, and Tanzania.

However, the above categorization analysis of the RMCs is not a static classification. Data used in this analysis is average data for the period of 1981-85. Updated data will re-rank RMCs among the above four categories according to their research return factor RRF, research intensity ratio

RIR, and AgGDP. Further, diversity of research, range of disciplines, and length of technical equipment acquired is proposed as additional criteria to assess the research capacity and scope of the NARS.

Part Five: Strategy for Rural Poverty Reduction

I. Findings: Summary and Conclusion

A theoretical review of the main factors for agricultural development, suggested that there are three factors that could contribute to the future increase in food supply in Africa, which are i) expansion of land under cultivation, ii) irrigation intensive development, and iii) biological increase in yield. Further, recent studies debate that only through biological increase in yield the future food supply would significantly increase. The debate focuses on the world food production in general as an observation from previous experience. No specific review was made to the food production situation in the different continents or specifically in Africa. The graphical and time series analysis in this paper focused on the major explanatory variables by adding two more production factors (mechanization and fertilizers) to the above mentioned three variables. Preliminary results provide us with important observations concerning the most effective technology for agricultural growth in Africa. The preliminary time series analysis included four additional factors. These are land expansion, irrigation, mechanization and fertilizers in addition to the biological increase in yield as the major food production related factors.

Obtained results are somewhat pertinent to the theoretical argument, which is the theme of this paper. In Africa, expansion of land under cultivation as well as irrigation technology has little impact on simulating agricultural production. In other words, agricultural growth could be accelerated significantly without bringing more land under cultivation. Furthermore, all over Africa, there has been an increase of interest in boosting food production in a sustainable environmental framework, precisely because governments and researchers have realized that the land frontier for increased food production has been reached.

In order to obtain robust results, an econometric model is built in two forms for more depth statistical analysis of the above mentioned five factors of agricultural development. This paper concluded that high yielding varieties and fertilizer application are the major two factors that have steady impact on food supply increase.

One pertinent conclusion that could be drawn from the above graphical and econometric scenarios is that agricultural research in Africa must focus on adoption and multiplication of HYVs with improved extension and distribution / delivery systems. This would enable the dissemination of the technology and its attendant agronomic practices, such as the use of appropriate fertilizer. It must also be realized that fertilizer use requires production investment that the samllholder farmers, who dominate cereal production in Africa, would find difficult to make.

The result of the statistical analysis, which proves the relevance of HYVs and fertilizer, is further underscored, with different weights, by using filed data analysis (Carr, J.S. 1989). For a maize yield of 4,000 kg/ha, improved and hybrid (HYV) technology accounts for 20 percent and fertilizer application contributes a staggering 51 percent (table 3.1). Narrowing the gap between existing and achievable maize yield through technology transfer would increase the yield by about 70 percent. In addition, more yield increase could be achieved in combination with the appropriate agronomic practices such as the recommended plant density, timely planting, weeding and harvesting. Appropriate extension would add 10 percent and pest control 4 percent for the yield to reach 85 percent increase in each cultivated hectare. In the absence of HYV and fertilizer use, the best yield estimate would be 600 kg/ha, even with the recommended agronomic practices. It is important to note that this lower level of 600 kg/ha is the average dominant level of cereal productivity in most African countries.

The results underscore the position of this paper, that in the short term, the key to increased agricultural production and subsequently food-self sufficiency is the availability and affordability of HYVs of the major staples and fertilizers to the smallholder farmers. As long as farmers are not producing enough to feed themselves, poverty-reduction will just be a dream for the poor population in Africa. Government policies and commitments on poverty reduction must pay more than lip service to food self-sufficiency, with necessary rural infrastructure for practical extension and marketing of the surplus.

Needles to say that for poverty to be reduced there is serious need to build the capacity of the existing NARSs in African countries in a sustainable and long-term approach. It is recommended that in providing development assistance and finance for capacity building of the existing agricultural research institutions (NARS), countries be focused in their research on the proposed types and topics of research in table 4.1. Further, producing improved seed by itself is not a enough solution for shortage of food supply. Seed must be accessible to poor farmers and food production must be marketable. In this respect, seed distribution need to be strengthened through promotion of the private sector and rural roads need to be constructed for seed distribution to be possible and for marking to be particle. Without development of a sustainable seeds distribution system and marketing access, research support would be ineffective effort.

In general, using fertilizer to raise agricultural production per unit of area is an effective alternate for the expansion of land area. Fertilizer may also lead to land saving by reducing erosion, building up soil fertility and structure, and improving its water-holding capacity. Fertilizers should be viewed as a vertical expansion of economic productive land. Unfortunately, fertilizer is not being widely used by African farmers. Only 13 out of 38 African countries use more than 10 Kg N-P-K fertilizer per hectare of arable land, and only five countries used over 20 Kg per hectare. On the other hand, total fertilizer used in SSA was about 3.4 million tons by the mid-1990s. FAO estimated that a six-fold increase in fertilizer use to six million tons would be needed in Africa between 1990 and 2010 to raise agriculture production by 2.9% per year. Africa accounts for only 2.25% of the developing world's fertilizer consumption.

The slow expansion of fertilizer use by African farmers during the last two decades is attributed to a mixture of factors affecting supply and demand such as (i) price decreases for export crops (ii) reduction in fertilizer imports, due to foreign exchange problems and (iii) removal of government subsidies form fertilizer. It is important to state that the form in which the international development assistance provided to developing countries, is particular responsible for the poor economic performance of Africa. With the new reform policies and economic sector adjustment programs, it was made clear that no more international finance would be made to the public sector for agricultural development including manufacturing of fertilizers. Furthermore, line of credit finance is not reaching the poor in the rural areas. With the weak private sector in Africa, the hope to develop fertilizer manufacturing is minimal. Thus, donor community and international finance institutions need to develop new lending instruments as an appropriate form of finance that would develop the local production of fertilizer in African countries. Such lending instrument could be through international partnership for know-how and technology transfer of fertilizers manufacturing.

II. Present Situation and Outlook

There is strong evidence of the linkage between agricultural research and poverty reduction. Agricultural research helps to produce the technology and the knowledge necessary for sustainable agricultural development, which is essential for economic growth. Rural economic growth, in turn is the most effective instrument for poverty reduction in countries where the majority of the poor live in rural areas.

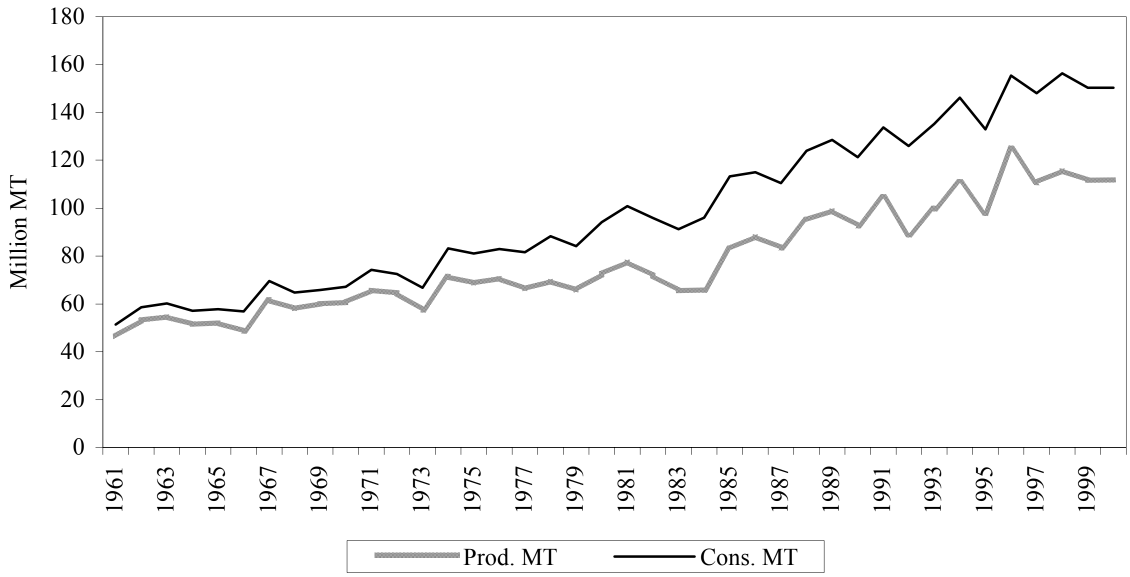
For effective poverty reduction effort, innovative thinking to re-orient the present design of agricultural development projects is required. With the increasing recognition of the importance of poverty reduction, we have to accept that the regular present development project as a lending instrument has minimal effect on poverty reduction. Development assistance data shows that the an annual US$5 billion for agricultural sector in Africa, unable to keep the annual agricultural growth rate (2.6%) at the rate of population growth (2.7%) so that the average food production today is below that of 1960s.

Statistical analysis and field results indicate the relevance of hybrid seeds and fertilizer. For maize yield, the use of improved and hybrid technology along with appropriate application of fertilizers accounts for 71 percent. Further yield increase could be achieved in combination with the appropriate agronomic practices. Appropriate extension and pest control would add 14 percent for maize yield to reach 85 percent increase in each cultivated hectare (table 3.1).

During the last two decades, African countries produced an annual average of 93 million metric tons of cereals from an annual average cultivated area of 8.42 million hectares. Average annual consumption of cereals was about 123.73 million metric tons leaving an increased gap of consumption of about an annual average of 30.73 million metric tons, which is closed by imports.

Using the same area of land that is currently used for cereal production - 8.42 million hectares - with the same extension and pest control level of technology, the consumption gap could be completely closed by a widespread usage of improved and hybrid seeds along with appropriate use of fertilizers. Closing the gap would require an increased in the cereal production less than 35 percent. The production consumption gap, which illustrated in Figure 5.1 would be closed by increasing the cereal yield from about 11 ton per hectare to 14.8 ton per hectare. This estimate is made under the following assumption i) fixed irrigation development; ii) static extension; iii) continuos annual population growth of 2.6 percent; and iv) static pest control technology. Although most of these assumptions are realistic, it is expected that irrigation development would continue and accelerate the narrowing the cereal production consumption gap.

Figure 5.1: Cereal Production and Consumption Gap in Africa (1961-2000)



It should be noticed that the required development effort toward rural poverty reduction would not be a result of one single piece of technology, but an interaction effects should be considered when a strategic planning is put in place. However, in the absence of HYV and fertilizer use, the best yield estimate would be 600 kg/ha, even with the recommended agronomic practices.

III. The Strategy

Building on the concluded results of this study, design of development project need to focus on i) capacity building for biotechnology; ii) private sector promotion for farm input distribution; iii) rural infrastructure for market linkage; and iv) rural credit for financing access to farm inputs. The following four-component development strategy for rural poverty reduction is proposed for decision-makers' consideration.

1) Capacity Building for Technology Transfer

The revolution in the biological sciences promises powerful new tools for generic improvement of food crop and livestock species. Most of the world's top 300 companies, spending on agricultural research and development surpasses US$ 24 billion, are private sector companies. This large investments in biotechnology research also has major implications for poverty reduction because their research finding priorities often miss the crops that are vital to the poor in the developing world.

Best usage of biotechnology require careful judgement of research capacity and experience in research priorities. Recognizing the importance of biotechnology as the keyword for agricultural growth and rural poverty reduction, human resources is the number one constraint that facing most developing countries today. The second constraint facing biological yield increase and appropriate application is the availability of fertilizers.

Biotechnology as the keyword for agricultural growth and rural poverty reduction is achievable through biological yield increase and appropriate application of fertilizers. The starting point for African countries is the human resource development and research skills building. The second step, is that finance and development assistance should be made to scientific research and capacity building of the existing agricultural research institutions (NARS), for biological yield increase through the development and adoption of improved seeds appropriate to the local agricultural characteristics including soil fertility, plant disease, and local agricultural practices. Size and type of development assistance will depend on the existing capacity of the NARS institutions. The proposed types and topics of research in table 4.1 could be used as a guide for aide allocation.

For capacity building of human resources, International Services for National Agricultural Research (ISNAR) developed and conducted a management training course to help practitioners on the frontline of biotechnology management develop their skills. The training course includes also management of information technology for agricultural research program which strengthen the link between industry, universities, and research institutions by means of information. Further, ISNAR developed Biotechnology Services (IBC), to prevent a growing information gap between industrialized countries and developing countries in biotechnology-related areas. IBC has internet-based information forum that provides interactive interface with biotechnology trainees.

Usage of high yielding varieties requires application of suitable fertilizers in order to maximize the yield of hybrid varieties. Without fertilizers, usage of the hybrid seeds will not significantly reduce poverty in Africa. However, the reform policies and sector adjustment programs discourage government finance for public sector manufacturing. On the other hand, the private sector is still weak and needs longer time to grow. It is proposed therefore, that donor community and international finance institutions develop new lending instruments to promote private sector for local production of fertilizer in African countries. Such lending instrument could be through international partnership for know-how and technology transfer of fertilizers manufacturing.

2) Private Sector Promotion

Production of improved seeds and or high yielding varieties would lose its effectiveness in increasing food supply in the absence of sufficient distribution system. In Africa countries, when improved seeds are available but not for the poor farmers or even not available on the right time for plantation. They are ineffective for simulating food supply. Promotion of the private sector to grow and take the initiative in farm inputs distribution, agro-business, and marketing of outputs needs to be further investigated. Innovative approaches must be proposed by marketing and business expertise. For the private sector to expand and grow in steady steps in African countries there is grave need to introduce “business decentralization” using “car-dealer” trading approach.

In application of such business technique, the private sector would contract a farmer at each village to provide secured storage facilities and act as sub-dealer for the distribution of the farm inputs. Also, agro-industry and food processing including storage techniques will all create markets to absorb food and horticulture production and simulated yield increase and thus farm income growth.

3) Rural Infrastructure

Rural road is indispensable instrument for poverty reduction in African countries. Market facilities promote rural production. Marketing is a function of roads, storage, processing facilities, and purchasing power. Although, purchasing power is week in poor countries, roads would provide producers with actual sizable local market, promote private sector, job creation and activate market economy and competition. Impact of biotechnology investment for higher crop yield would be minimal without rural rods.

Lesson learned from agricultural development in African countries proved that farmers in remote areas are losing when assisted by distribution of improved seeds and fertilizer under "safety net" program. These free farm input led to surplus of cereal production in the rural areas where traders could not smoothly reach. In absence of rural roads, prices decreased and producers would not able to recover their cost of production mainly because transportation cost is inefficient and represents barrier for commercial farming and growth.

Technology transfer for higher food supply would not be effective without active private sector and means of transportation. Needles to say that with poor or inadequate rural roads, high cost of transportation is deducted from anticipated possible profit that could have been made by the poor producers to cover their cost of production. It is saddening to cultivate for poor returns. Improved or hybrid seeds without an appropriate distribution system and market linkage, rural development would not be any more than poverty reduction dream for the donors and the poor.

4) Rural Micro-Finance

Concluding from the obtained results of this study, the most effective technology for agricultural growth and poverty reduction is the usage of high yielding varieties with appropriate fertilizers. These two production factors would generate another green revolution in Africa. Since the target group of the Financial Development Institutions is the poor and since more than 72 percent of the poor live in the rural areas, it seems that the only way out of rural poverty in Africa is by making technology accessible to the rural poor.

Improved seeds could be affordable to large group of the rural poor farmers but appropriate fertilizers will continue to be unaffordable to both government and poor farmers. Government due to shortage of foreign currency and increasing price of fertilizer would not be able to import enough fertilizers or even finance the private sector to import it at least for the coming twenty years. For the poor farmers, who might not be able to sell his/her produce due to the high transportation cost using inappropriate roads, affordability of fertilizer purchase is minimal.

Rural finance has become indispensable for accessible biological yield increase. Needles to say that prices of farm inputs including its cost of transportation to the farm gate due to rural poor roads is paid by the poorest of the society and not by the Government who is collecting taxes from rich to help the poor. This raises a serious concern of the need to enable the macroeconomic environment for rural development through the policy-based lending instrument.

Notes and References

1. The Green Revolution Technology requires using high yielding varieties with reliable water supply and fertilizer application agreeable with these varieties.
2. Poverty line is defined by less than one dollar a day per person or US$ 350 a year per person according to 1993 survey data.
3. The World Bank. (1998). “African Development Indicators”.
4. The World Bank. (1998). “African Development Indicators”
5. Estimated at 28 percent of the gross disbursement flows of ODA
6. Average annual gross disbursement for the period.
7. Average annual gross disbursement for the period.
8. The World Bank. (1998). “Agricultural Intensification in Sub-Saharan Africa”.
9. Maddison, A. (1996). “Monitoring the World Economy: 1820-1992. Paris: OECD”.
10. The World Bank. (1999). “Agricultural Intensification in Sub-Saharan Africa”.
11. EPA=East Asia and Pacific, MENA=Middle East and North Africa, LAC=Latin America and Caribbean
12. The World Bank (1998). “African Development Indicators”.
13. The World Bank. (1998). “African Development Indicators”.
14. International Service for National Agricultural Research (ISNAR). (1991). “Towards A New Agricultural Revolution: Research, Technology Transfer, and Application for Food Security in Africa”, (IFPRI/ISNAR).

Annex I

Annex 1: National Agricultural Research Expenditures, Personnel Estimates, and Capacity Compound Factor in Africa (Average 1981-85)

Country	Expenditure (Million US$)	Total Number of Researchers	AgGDP (Million US$)	Expenditures US$		Capacity Component Factor
				Per Researcher	% per AgGDP	
North Africa						
Algeria	21.3	305	3,429	69,833	0.62	2.3
Egypt	44.7	4,246	5,906	10,528	0.76	12.4
Libya	20.1	127	874	158,567	2.30	1.5
Morocco	25.2	217	1,913	116,129	1.32	0.8
Tunisia	14.7	121	1,174	121,487	1.25	1.4
Sub-Total	126.0	5,016	13,296	25,120	0.95	—
Western Africa						
Benin	2.3	47	351	48,936	0.66	1.8
Burkina Faso	17.4	120	416	145,000	4.18	0.4
Cameroon	15.4	176	1,607	87,500	0.96	1.9
Cape Verde	0.2	16	19	12,500	1.05	5.0
Chad	1.6	28	241	57,142	0.66	0.8
Gambia	2.8	62	33	45,161	8.48	1.0
Ghana	2.9	147	2,173	19,727	0.13	8.8
Guinea	8.8	177	763	49,717	1.15	3.1
Guinea-Bissau	0.8	8	57	100,000	1.40	0.6
Ivory-Coast	28.8	201	2,622	143,283	1.10	1.9
Liberia	5.2	33	358	157,575	1.45	1.1
Mali	13.8	275	533	50,181	2.59	1.4
Mauritania	0.6	12	186	50,000	0.32	2.2
Niger	1.9	57	522	33,333	0.36	2.5
Nigeria	80.7	1003	31,048	80,458	0.26	4.3
Senegal	14.7	174	398	84,482	3.69	0.8
Sierra Leone	1.4	46	419	30,434	0.33	3.8
Togo	5.9	58	240	101,724	2.56	0.8
Sub-Total	205.2	2,640	21,986	77,727	0.93	—
Central Africa						
Burundi	4.4	56	540	78,571	0.81	1.5
Cent. A.R.	2.1	22	350	95,455	0.60	1.4
Congo	2.6	73	145	35,616	1.80	2.1
Gabon	2.6	24	175	108,333	1.49	1.6
Rwanda	2.1	34	643	61,765	0.33	1.8
Sao T.&P.	0.2	3	9	66,667	2.22	1.4
Zaire	4.0	43	2,344	93,023	0.17	0.8
Sub-Total	18.0	255	4,206	70,588	0.43	—

Annex I: Continued

Country	Expenditure (Million US$)	Total Number of Researchers	AgGDP (Million US$)	Expenditures US$ Per Researcher	% per AgGDP	Capacity Component Factor
Southern Africa						
Angola	4.3	28	1,511	153,570	0.28	1.3
Botswana	5.8	56	90	103,570	6.44	0.9
Lesotho	6.0	18	59	333,333	10.17	0.1
Madagascar	6.6	82	921	80,488	0.72	1.1
Malawi	4.9	82	412	59,756	1.19	1.0
Mauritius	5.4	100	126	54,000	4.29	2.3
Mozambique	7.9	77	1,298	102,597	0.61	1.0
Swaziland	3.1	14	88	221,429	3.52	0.6
Zambia	4.0	110	396	36,364	1.01	1.7
Zimbabwe	16.6	166	595	100,000	2.79	0.7
Sub-Total	64.6	733	5,496	88,131	1.18	—
Eastern Africa						
Comoros	1.0	14	37	71,429	2.70	1.3
Ethiopia	11.8	136	1,911	86,765	0.62	0.5
Kenya	27.1	462	1,827	58,658	1.48	1.6
Seychelles	0.3	7	10	42,857	3.00	2.3
Somalia	0.4	31	513	12,903	0.07	5.2
Sudan	12.1	206	2,470	58,738	0.49	2.0
Tanzania	19.7	276	2,701	71,377	0.73	1.8
Uganda	12.5	185	1,319	67,568	0.95	2.2
Sub-Total	84.9	1,317	10,788	64,465	0.79	—
Sub-Saharan Africa	372.7	1,944	42,476	75,384	0.88	—
Total Africa	498.7	9,960	55,772	50,070	0.98	—

* Number of researchers is estimated as full-time equivalents.
Source: Collected and calculated from different sources: (1) Philip G. Pardey, Agricultural Research Policy, International Quantitative Perspectives, Cambridge University Press, 1989. (2) African Development Bank, Selected Statistics on Regional Member Countries, 1994.